Zhao et al. Lipids in Health and Disease (2024) 23:394
https://doi.org/10.1186/s12944-024-02375-8

Lipids in Health and Disease

RESEARCH Open Access

Temporal changes in lipid concentrations and the prevalence of dyslipidemia among individuals with diabetes, prediabetes, and normal blood glucose from 2011 to 2015

Mengjie Zhao[1†], Yurong Cheng[2†], Mengxuan Li[1], Wantong Zhang[1,4], Jinjin Ji[1,3] and Fang Lu[1,3,4*]

Abstract

Background Dyslipidemia plays a pivotal role in the development of diabetes mellitus (DM) and other metabolic disorders. This study aimed to investigate the trends in lipid concentrations among Chinese participants with different blood glucose statuses—ranging from DM and prediabetes mellitus (pre-DM) to normal blood glucose levels—between 2011 and 2015. Additionally, this study sought to provide a comprehensive description of the potential temporal changes in the prevalence of dyslipidemia among these populations in China during this period.

Methods The data for this study were derived from the China Health and Retirement Longitudinal Study (CHARLS), encompassing two time points in 2011 and 2015. The 2011 data sample included 11,408 participants aged 45 years and above, whereas the 2015 data sample included 12,224 participants within the same age range.

Results In this study, a comparative analysis of data from 2011 to 2015 revealed that individuals diagnosed with DM and pre-DM experienced significant decreases in total cholesterol (TC) and low-density lipoprotein cholesterol (LDL-C) and a significant increase in high-density lipoprotein cholesterol (HDL-C) ($P < 0.05$). For participants with pre-DM, the levels of residual cholesterol (RC) significantly increased, whereas the levels of the atherogenic index of plasma (AIP) significantly decreased ($P < 0.05$). Among participants with normal blood glucose, there was a significant decrease in the levels of TC and LDL-C and a significant increase in the levels of triglycerides (TGs), RCs, and the AIP ($P < 0.05$). Between 2011 and 2015, the concentrations of TC, TG, LDL-C, RC, and AIP, both unadjusted and adjusted, were significantly higher in individuals with DM than in those with pre-DM and normal blood glucose, with the opposite being true for HDL-C. In 2015, the prevalence of dyslipidemia among participants with DM, pre-DM, and normal blood glucose was 36.56% (95% CI: 34.49%, 38.66%), 15.78% (95% CI: 14.93%, 16.67%), and 11.23% (95% CI: 10.17%, 12.36%), respectively. The results of the present study revealed a significant decrease in the incidence of dyslipidemia in urban areas between 2011 and 2015 ($P < 0.05$).

[†]Mengjie Zhao and Yurong Cheng contributed equally to this work.

*Correspondence:
Fang Lu
deerfang@126.com

Full list of author information is available at the end of the article

Conclusion This study revealed that the prevalence of dyslipidemia is greater among DM patients, particularly those in the 55–64 years age group. Notably, over the four-year observation period, lipid profiles improved among DM patients and pre-DM patients. However, TG levels remained elevated, especially in the 45–54 years age group.

Keywords Diabetes, Prediabetes, Cholesterol, Dyslipidemia, Prevalence

Introduction

Diabetes mellitus (DM), a global health challenge, is characterized by high prevalence, low treatment rates, and high mortality, exerting a heavy burden on individual health and the global health system. According to statistical data from 2017, approximately 5 million people aged 20–99 worldwide died from DM, and the global expenditure on medical care for DM was estimated to be as high as 850 billion dollars that year [1]. The International Diabetes Federation's "Diabetes Atlas" (10th edition) indicates that in 2021, the number of individuals with DM aged 20–79 years worldwide was approximately 537 million, accounting for 10.5%, and this number is expected to increase to 783 million by 2045 [2]. In China, the burden of DM is particularly severe; data from 2021 show that the number of patients with DM in China has reached 141 million, ranking first in the world and becoming the country with the heaviest DM burden globally. Moreover, a large-scale epidemiological study of Chinese adults revealed that the prevalence of DM in adults over 18 years old was 11.6%, and the prevalence of prediabetes mellitus (pre-DM) was as high as 50.1% [3].

The health crisis caused by DM mainly stems from the extensive impact of its complications. Among these complications, vascular diseases are particularly common and deadly and can be divided into two major categories: damage to large blood vessels, such as coronary artery disease and stroke, and damage to microvessels, including kidney and retinal diseases. Research has shown that more than half of the deaths associated with DM are closely related to atherosclerotic cardiovascular disease (ASCVD) caused by large blood vessel diseases [4]. The high incidence and mortality of cardiovascular diseases (CVDs) are largely due to the widespread presence of metabolic abnormalities of the heart, among which lipid metabolism abnormalities are among the key factors. The results of three national representative cross-sectional surveys in 2002, 2010, and 2015 revealed that the levels of total cholesterol (TC), triglycerides (TGs), and low-density lipoprotein cholesterol (LDL-C) in Chinese adults have continued to rise [5]. From 2002 to 2015, the prevalence of hypercholesterolemia, hypercholesterolemia of low-density lipoprotein cholesterol (hyper-LDL-Cemia), hypertriglyceridemia, and hypocholesterolemia of high-density lipoprotein cholesterol (hypo-HDL-C-emia) increased to varying degrees.

Although many studies have discussed the prevalence of DM in China [6–8], the understanding of blood lipid levels in DM patients in China is still limited. Diabetic patients often have abnormalities in lipid metabolism, which further exacerbates the risk of CVD and cerebrovascular diseases and the mortality they cause. This study aimed to analyze the trends in lipid concentrations and the prevalence of dyslipidemia among Chinese adults with DM, pre-DM, and normal blood glucose levels from 2011 to 2015.

Methods

Study design and population

The data for this study were derived from two surveys conducted by the China Health and Retirement Longitudinal Study (CHARLS), implemented by the National School of Development at Peking University, in the years 2011 and 2015 [9]. CHARLS is a nationwide survey covering mainland China, encompassing 150 counties or districts across 28 provinces, as well as 450 villages or communities, with a focus on residents aged 45 and above. The survey provides extensive information, including demographics, socioeconomic status, and health conditions. Participants in CHARLS are updated with data every two years through face-to-face computer-assisted personal interviews (CAPIs), and the data collection process has been approved by the Biomedical Ethics Review Committee of Peking University. All the participants took part in the survey after signing an informed consent form.

This study focused on the participants who provided blood samples in 2011 and 2015, with 11,847 and 13,420 participants, respectively. After individuals under the age of 45 years and those with incomplete data on blood lipid and blood glucose levels were excluded, a total of 11,408 participants (in 2011) and 12,224 participants (in 2015) were included for analysis. A total of 7,315 participants overlapped in the sample at both time points. To maintain the representativeness of the cohort and compensate for sample attrition (e.g., due to relocation, health issues), new participants were included in each round of follow-up. Thus, even the nonoverlapping population (i.e., new participants) is representative. The screening process of the study is illustrated in Fig. 1.

Data collection

The data collection was carried out by team members who had undergone professional training, following established standard operating procedures, at the participants' residences as well as at local community or

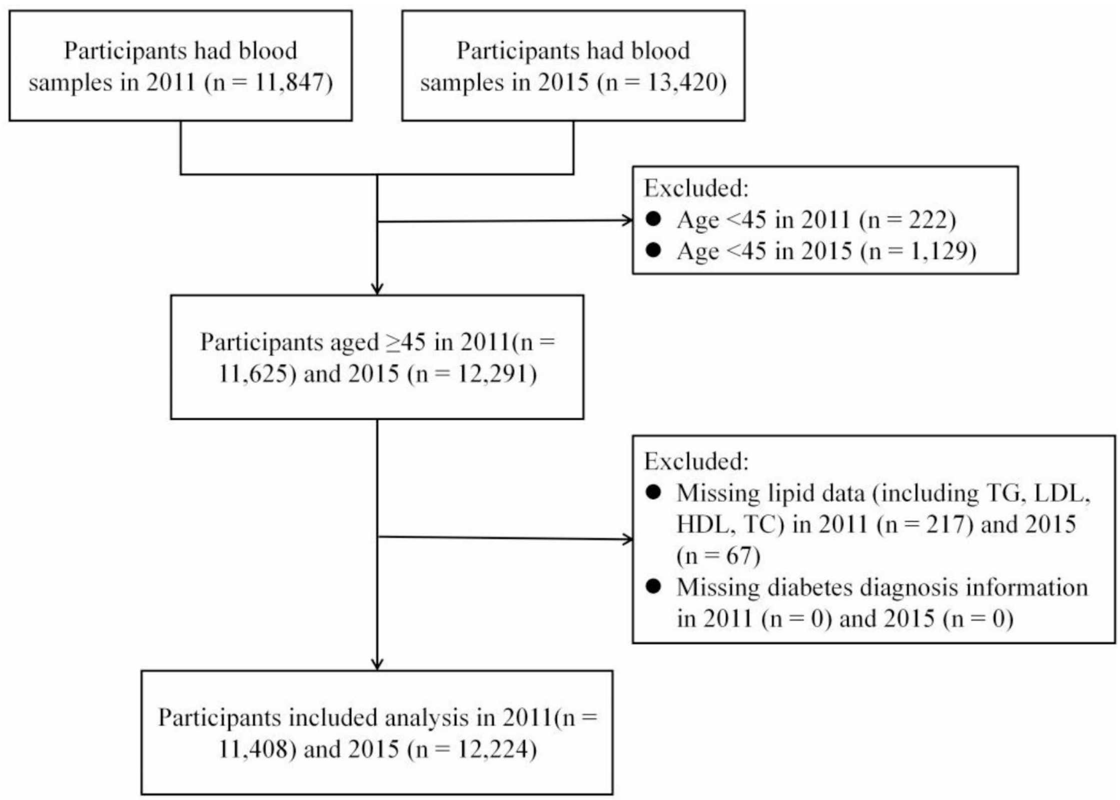

Fig. 1 Participant screening flowchart

township medical centers and county-level Centers for Disease Control and Prevention (CDC). The information gathered included participants' demographic characteristics (e.g., age, sex, marital status, educational background, and residential area), health and lifestyle status (e.g., smoking and drinking status, hypertension), and physical indicators (e.g., body mass index (BMI)). The participants' weight and height were measured via standardized equipment after their shoes and heavy clothing were removed. After completing the questionnaire survey and physical measurements, blood samples were collected by professional nurses at township hospitals or CDC offices after at least 8 h of fasting, with a collection volume of 8 milliliters of fasting blood. The levels of TC, TG, LDL-C, HDL-C, and fasting plasma glucose (FPG) in the blood samples were subsequently tested via enzymatic colorimetric methods. In addition, glycated hemoglobin A1c (HbA1c) levels were determined via boronate affinity high-performance liquid chromatography (HPLC).

Definitions

In this study, the diagnosis of DM was based on an FPG ≥ 126 mg/dL, an HbA1c ≥ 6.5%, a self-reported physician diagnosis, or the use of hypoglycemic medication. Pre-DM is characterized by fasting blood glucose levels between 100 and 125 mg/dL or HbA1c levels between 5.7 and 6.4%. The classification from the "Guidelines for the China Adult Dyslipidemia Prevention, Evaluation and Treatment" was used to define elevated TC (≥ 240 mg/dL), reduced HDL-C (< 40 mg/dL), elevated LDL-C (≥ 160 mg/dL), and elevated TG (≥ 200 mg/dL) [10]. To minimize the impact of lipid-lowering medication on blood lipid levels, dyslipidemia was defined as a TC/HDL-C ratio > 5.0 or self-reported dyslipidemia [11].

The diagnosis of hypertension was based on self-reported physician diagnosis and/or the use of any antihypertensive medication and/or an average systolic/diastolic blood pressure (SBP/DBP) ≥ 140/90 mmHg [12]. The calculation of remnant cholesterol (RC) is performed by subtracting HDL-C and LDL-C from TC [13]. The atherogenic index of plasma (AIP) is calculated by taking the natural logarithm of the ratio of triglycerides to HDL-C [14].

Statistical analysis

Data following a normal distribution are reported as the mean ± standard deviation (SD), whereas nonnormally distributed data are described as the median and interquartile range (IQR). Count data are presented as frequencies and percentages (n %). Between-group comparisons were performed via the Wilcoxon rank sum test, t test, or chi-square test. Cross-sectional data analysis methods were used for the 2011 and 2015 data. To correct for measurement errors in blood lipid concentrations and control for potential confounding factors, this study utilized analysis of covariance (ANCOVA), including variables such as age, sex, residential area, marital status, education level, smoking status, drinking status, hypertension, and BMI. Model parameter estimation was conducted via the least squares method, and F tests were applied to evaluate the statistical significance of the models. Furthermore, prevalence rates for 2011 and 2015 were calculated, and subgroup analyses were performed for the total population and different blood glucose status groups on the basis of age groups (45–54, 55–64, 65–74, and 75+), sex, marital status, education level, residential area (rural or urban), and region (Southwest, South, East, Central, Northwest, North, and Northeast). After adjusting for the aforementioned variables in a multivariable manner, logistic regression analysis was used to compare the incidence of dyslipidemia between 2011 and 2015. The standard for statistical significance was set at a P value of less than 0.05. All the statistical analyses in this study were completed via SPSS and R software.

Results

Baseline characteristics

In 2011 and 2015, 11,408 and 12,224 participants, respectively, were included in the study. Compared with those in 2011, the proportions of those with diabetes, prediabetes, and normal blood glucose living in towns, using lipid-lowering and antihypertensive medications increased, and they had a significantly greater level of education in 2015, whereas the number of people with hypertension and alcohol consumption decreased significantly ($P<0.05$). Additionally, there was a decrease in the proportion of married individuals with DM and a decline in the proportion of smokers among those with pre-DM ($P<0.05$). In 2015, participants with normal blood glucose levels were younger and had a higher BMI than in 2011 ($P<0.05$). Table 1 presents the demographic details of the sample. A baseline characterization of the analysis for the overlapping 2011 and 2015 populations was added, as detailed in Table S1.

During the period from 2011 to 2015, significant changes occurred in the blood lipid levels of patients with DM and pre-DM. Specifically, there was a significant reduction in TC and LDL-C levels, whereas HDL-C levels significantly increased ($P<0.05$) (Table 2). For individuals with pre-DM, RC levels significantly increased, whereas AIP levels significantly decreased ($P<0.05$). Concurrently, participants with normal blood glucose levels presented significant increases in TG, RC, and AIP levels and significant decreases in TC, LDL-C, and HDL-C levels ($P<0.05$). Figure 2 visually presents these trends in lipid concentration changes. After adjusting for age, sex, place of residence, marital status, education level, smoking and drinking status, history of hypertension, and BMI, the significance was maintained for all other blood lipid indicators, except for the HDL-C levels in individuals with normal blood glucose levels, which were no longer significant ($P>0.05$).

Table 2 also reveals another important finding: compared with participants with pre-DM and those with normal blood glucose levels, individuals with diagnosed DM have a more unfavorable blood lipid profile. Between 2011 and 2015, both unadjusted and adjusted levels of TC, TG, LDL-C, RC, and AIP were generally higher in individuals with diagnosed DM than in the other two groups, whereas HDL-C was the opposite. After excluding participants using lipid-lowering medications, the results remained consistent with those in Table 2 (Table S2). Further exclusion of participants using both lipid-lowering and glucose-lowering medications still resulted in significant improvements in TC, TG, LDL-C, and HDL-C concentrations (Table S3).

Prevalence of dyslipidemia in 2011 and 2015

Tables 3, 4 and 5 detail the prevalence of dyslipidemia among subjects with different blood glucose statuses in 2011 and 2015, as well as the impact of socioeconomic factors such as marital status, education, and place of residence on the prevalence rates. The 2011 data revealed that the prevalence rates of dyslipidemia in populations with DM, pre-DM, and normal blood glucose were 51.31% (95% CI: 48.21-54.40%), 30.16% (95% CI: 28.99-31.35%), and 17.64% (95% CI: 16.54-18.79%), respectively. The prevalence of dyslipidemia among urban residents was significantly greater than that among rural residents, and the prevalence among individuals with higher education levels was also significantly greater than that among individuals with lower education levels. Notably, there was no difference in prevalence rates across various age groups (Fig. 3). A significantly higher prevalence rate was observed only among married individuals than among unmarried individuals in the pre-DM population, and the prevalence rate among females was higher than that among males (Fig. 4). Additionally, regardless of blood glucose status, the prevalence rate in the northern region was significantly higher than that in the southern region (Fig. 5A–D). Tables S4–S6 provide specific data on age, sex, and regional group prevalence rates for 2011.

By 2015, the prevalence of dyslipidemia had decreased to 36.56% (95% CI: 34.49-38.66%) in individuals with DM, 15.78% (95% CI: 14.93-16.67%) in those with pre-DM, and 11.23% (95% CI: 10.17-12.36%) in those with normal blood glucose. Compared with 2011, there was a reversal in the prevalence rates, with rural residents now having higher rates than urban residents do. Among those with DM, the prevalence of dyslipidemia was consistently

Table 1 Demographic characteristics of the population by blood glucose status in 2011 and 2015

Variables	Diabetes		*P*	Prediabetes		*P*	Normal		*P*
	2011	2015		2011	2015		2011	2015	
N	1,031	2,098		5,899	6,823		4,478	3,303	
Age, years, Median (IQR)	60.00 (54.00, 67.00)	61.00 (54.51, 67.00)	0.083	59.00 (53.00, 66.00)	59.00 (52.00, 66.00)	0.144	57.00 (50.00, 65.00)	56.00 (50.00, 64.00)	< 0.001
Age, years, n (%)			0.147			0.089			< 0.001
45–54	275 (26.67)	525 (25.02)		1,869 (31.68)	2,116 (31.01)		1,701 (37.99)	1,416 (42.87)	< 0.001
55–65	441 (42.77)	855 (40.75)		2,321 (39.35)	2,697 (39.53)		1,620 (36.18)	1,152 (34.88)	
65–74	230 (22.31)	547 (26.07)		1,210 (20.51)	1,494 (21.90)		797 (17.80)	561 (16.98)	
≥ 75	85 (8.24)	171 (8.15)		499 (8.46)	516 (7.56)		360 (8.04)	174 (5.27)	
Sex, n (%)			0.629			0.213			0.017
Male	428 (41.51)	890 (42.42)		2,831 (47.99)	3,199 (46.89)		2,121 (47.36)	1,655 (50.11)	
Hypertension, n (%)			0.004			< 0.001			< 0.001
Yes	581 (56.35)	1,068 (50.91)		2,300 (38.99)	2,095 (30.70)		1,387 (30.97)	813 (24.61)	
Antihypertensive drugs, n (%)			0.041			< 0.001			< 0.001
Yes	499 (48.4)	1097 (52.29)		1591 (26.97)	2167 (31.76)		930 (20.77)	836 (25.31)	
Lipid-lowering drugs, n (%)			0.039			< 0.001			< 0.001
Yes	182 (17.65)	436 (20.78)		299 (5.07)	455 (6.67)		146 (3.26)	161 (4.87)	
Hypoglycemic drugs, n (%)			< 0.001			< 0.001			-
Yes	466 (45.20)	801 (38.18)		21 (0.36)	0 (0)		0 (0)	0 (0)	
Smoking status, n (%)			0.862			< 0.001			0.323
Yes	355 (34.43)	729 (34.75)		2,339 (39.65)	2,504 (36.7)		1,789 (39.95)	1,283 (38.84)	
Drinking status, n (%)			0.032			< 0.001			< 0.001
Yes	761 (73.81)	1,471 (70.11)		4,530 (76.79)	4,863 (71.27)		3,436 (76.73)	2,280 (69.03)	
Residence, n (%)			< 0.001			< 0.001			< 0.001
Rural	801 (77.69)	347 (16.54)		4,976 (84.35)	768 (11.26)		3,815 (85.19)	313 (9.48)	
Urban	230 (22.31)	1,751 (83.46)		923 (15.65)	6,055 (88.74)		663 (14.81)	2,990 (90.52)	
Education level, n (%)			0.002			< 0.001			< 0.001
No formal education	472 (45.78)	962 (45.85)		2,827 (47.92)	3,206 (46.99)		2,094 (46.76)	1,423 (43.08)	
Primary school	216 (20.95)	438 (20.88)		1,270 (21.53)	1,458 (21.37)		998 (22.29)	684 (20.71)	
Middle or high school	277 (26.87)	485 (23.12)		1,577 (26.73)	1,726 (25.3)		1,236 (27.60)	995 (30.12)	
College or above	66 (6.40)	213 (10.15)		225 (3.81)	433 (6.35)		150 (3.35)	201 (6.09)	
Marital status, n (%)			0.008			0.095			0.243
Married	910 (88.26)	1,778 (84.75)		5,119 (86.78)	5,851 (85.75)		3,961 (88.45)	2,893 (87.59)	
Other	121 (11.74)	320 (15.25)		780 (13.22)	972 (14.25)		517 (11.55)	410 (12.41)	
BMI, kg/m^2, Median (IQR)	25.13 (22.62, 27.74)	25.24 (22.87, 27.74)	0.430	23.47 (21.02, 26.10)	23.54 (21.22, 26.12)	0.091	22.54 (20.44, 25.08)	22.86 (20.69, 25.21)	0.003
BMI, kg/m^2, n (%)			0.767			0.365			0.001
< 18.5	32 (3.10)	69 (3.29)		397 (6.73)	415 (6.08)		402 (8.98)	229 (6.93)	
18.5–25	472 (45.78)	922 (43.95)		3,489 (59.15)	4,008 (58.74)		2,929 (65.41)	2,185 (66.15)	
25–30	414 (40.16)	880 (41.94)		1,699 (28.80)	2,027 (29.71)		981 (21.91)	790 (23.92)	
≥ 30	113 (10.96)	227 (10.82)		314 (5.32)	373 (5.47)		166 (3.71)	99 (3.00)	

high among those aged 55–64 years (Fig. 3). Among individuals with different levels of education, there were still significant differences in the prevalence of dyslipidemia among patients with pre-DM (Table 4). For DM, the prevalence rate among married individuals was significantly greater than that among unmarried individuals, whereas sex had no significant effect on the prevalence rate (Fig. 4). The prevalence rate in the northern region continued to be higher than that in the southern region (Fig. 5E–H), a phenomenon that persisted in the 2015 data. Tables S4–S6 provide detailed data on age, sex, and regional group prevalence rates for 2015.

Temporal changes in the incidence of dyslipidemia from 2011 to 2015

During the period from 2011 to 2015, a longitudinal analysis was conducted on the prevalence of dyslipidemia among subjects with different blood glucose statuses, including the overall prevalence and specific prevalence rates stratified by age, sex, place of residence,

Table 2 Unadjusted and least squares-adjusted mean concentrations (standard errors) of lipid profiles in participants with different blood glucose statuses in 2011 and 2015

Variables	Diabetes		*P*	Prediabetes		*P*	Normal		*P*
	2011	2015		2011	2015		2011	2015	
N	1,031	2,098		5,899	6,823		4,478	3,303	
Unadjusted									
TC (mg/dl)	200.02 (1.29)	191.05 (0.93)	< 0.001	196.59 (0.50)	186.78 (0.44)	< 0.001	186.74 (0.52)	175.46 (0.55)	< 0.001
TG (mg/dl)	174.97 (4.10)	177.63 (2.43)	0.556	144.62 (1.38)	142.07 (1.05)	0.140	107.98 (0.88)	123.56 (1.27)	< 0.001
LDL-C (mg/dl)	118.61 (1.19)	105.56 (0.69)	< 0.001	117.48 (0.48)	104.70 (0.34)	< 0.001	113.92 (0.47)	96.39 (0.46)	< 0.001
HDL-C (mg/dl)	45.70 (0.49)	48.34 (0.24)	< 0.001	50.34 (0.20)	51.73 (0.14)	< 0.001	52.97 (0.22)	52.07 (0.21)	0.004
RC (mg/dl)	35.70 (1.07)	37.15 (0.53)	0.176	28.77 (0.36)	30.34 (0.22)	< 0.001	19.85 (0.22)	27.00 (0.26)	< 0.001
AIP	0.520 (0.012)	0.506 (0.007)	0.270	0.400 (0.005)	0.385 (0.003)	0.008	0.275 (0.004)	0.327 (0.005)	< 0.001
Adjusted									
TC (mg/dl)	200.04 (1.83)	190.80 (1.05)	< 0.001	196.79 (0.72)	186.84 (0.70)	< 0.001	185.35 (0.70)	176.95 (1.12)	< 0.001
TG (mg/dl)	175.31 (5.19)	178.24 (2.98)	0.623	144.23 (1.85)	142.83 (1.79)	0.585	108.83 (1.32)	126.65 (2.12)	< 0.001
LDL-C (mg/dl)	119.78 (1.49)	105.27 (0.86)	< 0.001	117.94 (0.63)	104.73 (0.61)	< 0.001	113.17 (0.60)	97.56 (0.97)	< 0.001
HDL-C (mg/dl)	44.26 (0.55)	48.21 (0.32)	< 0.001	49.73 (0.26)	51.38 (0.25)	< 0.001	52.33 (0.27)	51.76 (0.43)	0.261
RC (mg/dl)	36.00 (1.24)	37.33 (0.71)	0.355	29.12 (0.43)	30.73 (0.41)	0.007	19.85 (0.30)	27.64 (0.49)	< 0.001
AIP	0.539 (0.014)	0.509 (0.008)	0.060	0.407 (0.006)	0.390 (0.006)	0.041	0.281 (0.005)	0.341 (0.009)	0.041

Age, sex, residence, marital status, education, smoking status, drinking status, hypertension, and BMI were adjusted for

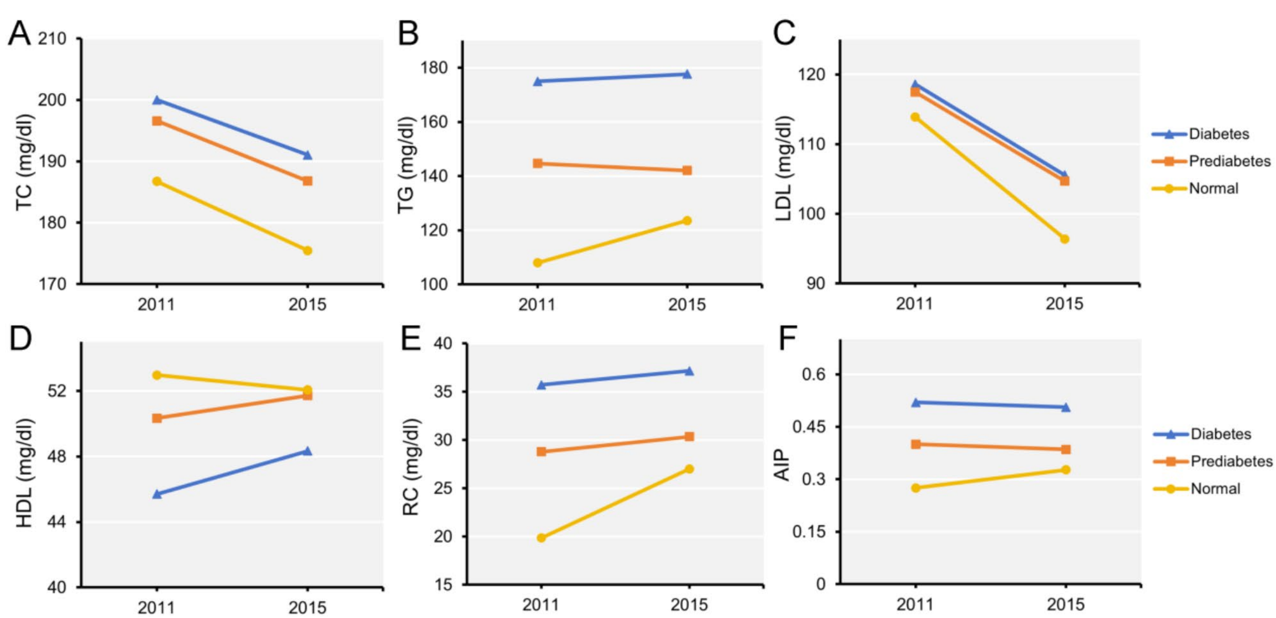

Fig. 2 Trends in lipid concentration changes between 2011 and 2015

education level, and marital status. According to the data in Tables 6, 7 and 8, except for the stable prevalence rate among rural residents with normal blood glucose, the overall prevalence of dyslipidemia and the prevalence rates in each subgroup for other blood glucose statuses showed a significant downward trend. Further analysis revealed that, except for the nonsignificant trend of LDL-C reduction among individuals with a university degree or above in the DM population, LDL-C levels in all other blood glucose status subjects significantly decreased. Notably, TG levels tended to increase in the female subgroup, whereas changes in TG levels in the other DM subgroups were not significant (Table 6).

Discussion

This study, on the basis of data from the CHARLS survey, assessed the prevalence of dyslipidemia and its temporal trends among different blood glucose status groups in adults aged 45 years and above. Several key points emerged from the analysis. First, individuals diagnosed with DM in 2011 presented the most unfavorable blood lipid profile, with the adjusted mean concentration of HDL-C being the lowest among the three groups,

Table 3 Overall and stratified prevalence of dyslipidemia in DM patients by marital status, education level, and place of residence in 2011 and 2015

	n (%)	$AIP \geq AIP_{median}$ %(95% CI)	$RC \geq RC_{median}$ %(95% CI)	LDL-C ≥ 160%(95% CI)	HDL-C < 40%(95% CI)	TC ≥ 240%(95% CI)	TG ≥ 200%(95% CI)	Dyslipidemia %(95% CI)
2011								
Total	1,031	66.63 (63.66, 69.51)	56.16 (53.07, 59.22)	13.39 (11.37, 15.62)	39.57 (36.58, 42.64)	15.13 (13.03, 17.50)	27.26 (24.58, 30.11)	51.31 (48.21, 54.40)
Marital Status								
Married	910 (88.26)	67.36 (64.21, 70.40)	56.59 (53.30, 59.84)	12.97 (10.85, 15.32)	41.21 (37.99, 44.49)	14.95 (12.69, 17.43)	28.46 (25.55, 31.51)	51.98 (48.68, 55.27)
Other	121 (11.74)	61.16 (51.87, 69.88)	52.89 (43.61, 62.03)	16.53 (10.40, 24.37)	27.27 (19.57, 36.12)	16.53 (10.40, 24.37)	18.18 (11.76, 26.22)	46.28 (37.17, 55.57)
P value		0.005	0.441	0.280	0.003	0.648	0.017	0.239
Education level								
No formal education	472 (45.78)	61.23 (56.67, 65.65)	52.97 (48.35, 57.54)	15.89 (12.71, 19.51)	31.57 (27.40, 35.97)	15.68 (12.52, 19.28)	24.58 (20.76, 28.72)	46.61 (42.04, 51.23)
Primary school	216 (20.95)	73.15 (66.71, 78.93)	65.28 (58.52, 71.61)	13.89 (9.57, 19.23)	43.98 (37.25, 50.88)	17.59 (12.76, 23.34)	28.70 (22.77, 35.23)	56.02 (49.12, 62.75)
Middle or high school	277 (26.87)	69.68 (63.89, 75.03)	55.23 (49.17, 61.19)	9.75 (6.52, 13.86)	46.93 (40.93, 52.99)	13.00 (9.27, 17.54)	29.96 (24.63, 35.73)	53.07 (47.01, 59.07)
College or above	66 (6.40)	71.21 (58.75, 81.70)	53.03 (40.34, 65.44)	9.09 (3.41, 18.74)	51.52 (38.88, 64.01)	12.12 (5.38, 22.49)	30.30 (19.59, 42.85)	62.12 (49.34, 73.78)
P value		0.007	0.022	0.078	< 0.001	0.461	0.352	0.023
Residence								
Rural	801 (77.69)	63.80 (60.36, 67.13)	54.68 (51.16, 58.17)	12.98 (10.73, 15.51)	36.70 (33.36, 40.15)	14.61 (12.23, 17.24)	27.09 (24.04, 30.31)	49.06 (45.55, 52.59)
Urban	230 (22.31)	76.52 (70.50, 81.84)	61.30 (54.68, 67.63)	14.78 (10.46, 20.04)	49.57 (42.93, 56.21)	16.96 (12.34, 22.44)	27.83 (22.14, 34.10)	59.13 (52.48, 65.55)
P value		< 0.001	0.074	0.480	< 0.001	0.381	0.825	0.007
2015								
Total	2,098	69.40 (67.38, 71.37)	70.54 (68.54, 72.49)	4.86 (3.98, 5.87)	22.78 (21.00, 24.64)	9.72 (8.49, 11.07)	29.22 (27.28, 31.22)	36.56 (34.49, 38.66)
Marital Status								
Married	1,778 (84.75)	70.02 (67.83, 72.15)	70.81 (68.64, 72.92)	4.89 (3.94, 6.00)	23.85 (21.88, 25.90)	9.79 (8.44, 11.26)	30.37 (28.24, 32.57)	37.51 (35.26, 39.81)
Other	320 (15.25)	65.94 (60.46, 71.12)	69.06 (63.68, 74.09)	4.69 (2.65, 7.61)	16.88 (12.94, 21.44)	9.38 (6.41, 13.11)	22.81 (18.33, 27.81)	31.25 (26.21, 36.64)
P value		0.144	0.528	0.875	0.006	0.819	0.006	0.032
Education level								
No formal education	962 (45.85)	66.11 (63.02, 69.10)	69.85 (66.85, 72.74)	5.09 (3.79, 6.68)	18.30 (15.90, 20.89)	9.98 (8.16, 12.05)	28.90 (26.05, 31.88)	35.24 (32.22, 38.35)
Primary school	438 (20.88)	72.15 (67.69, 76.30)	71.46 (66.98, 75.65)	5.48 (3.54, 8.04)	24.89 (20.90, 29.21)	10.27 (7.59, 13.51)	28.77 (24.57, 33.25)	38.13 (33.56, 42.86)
Middle or high school	485 (23.12)	71.55 (67.30, 75.52)	71.13 (66.88, 75.13)	4.74 (3.03, 7.03)	27.42 (23.50, 31.63)	10.72 (8.11, 13.82)	33.20 (29.02, 37.58)	35.88 (31.60, 40.32)
College or above	213 (10.15)	73.71 (67.26, 79.49)	70.42 (63.80, 76.46)	2.82 (1.04, 6.03)	28.17 (22.24, 34.72)	5.16 (2.61, 9.05)	22.54 (17.11, 28.74)	40.85 (34.18, 47.77)
P value		0.025	0.923	0.491	< 0.001	0.121	0.038	0.396
Residence								
Rural	347 (16.54)	73.49 (68.51, 78.06)	71.18 (66.11, 75.89)	4.61 (2.66, 7.38)	25.65 (21.13, 30.58)	8.07 (5.43, 11.45)	28.53 (23.84, 33.60)	42.07 (36.82, 47.46)
Urban	1,751 (83.46)	68.59 (66.36, 70.76)	70.42 (68.22, 72.55)	4.91 (3.95, 6.03)	22.22 (20.29, 24.24)	10.05 (8.68, 11.56)	29.35 (27.23, 31.55)	35.47 (33.22, 37.76)
P value		0.071	0.775	0.812	0.164	0.255	0.758	0.020

The median AIP is calculated on the basis of the total data from all participants rather than on separate calculations for each subgroup or each survey. The median AIP was 0.351. The median RC is calculated on the basis of the total data from all participants rather than on separate calculations for each subgroup or each survey. The median RC is 23.55 mg/dl

Table 4 Overall and stratified prevalence of dyslipidemia in the prediabetic population by marital status, education level, and place of residence in 2011 and 2015

	n (%)	AIP ≥ AIP_{median} %(95% CI)	RC ≥ RC_{median} %(95% CI)	LDL-C ≥ 160%(95% CI)	HDL-C < 40%(95% CI)	TC ≥ 240%(95% CI)	TG ≥ 200%(95% CI)	Dyslipidemia %(95% CI)
2011								
Total	5,899	52.50 (51.22, 53.78)	46.08 (44.80, 47.36)	11.66 (10.85, 12.51)	27.11 (25.98, 28.26)	13.15 (12.30, 14.04)	18.14 (17.16, 19.15)	30.16 (28.99, 31.35)
Marital Status								
Married	5,119 (86.78)	52.88 (51.50, 54.26)	46.49 (45.12, 47.87)	11.49 (10.63, 12.39)	27.49 (26.27, 28.73)	12.99 (12.08, 13.94)	18.81 (17.75, 19.91)	30.65 (29.39, 31.93)
Other	780 (13.22)	50.00 (46.43, 53.57)	43.33 (39.82, 46.89)	12.82 (10.55, 15.37)	24.62 (21.63, 27.80)	14.23 (11.85, 16.88)	13.72 (11.38, 16.33)	26.92 (23.84, 30.18)
P value		< 0.001	0.099	0.280	0.093	0.340	< 0.001	0.035
Education level								
No formal education	2,827 (47.92)	51.29 (49.43, 53.15)	45.24 (43.40, 47.10)	12.35 (11.15, 13.61)	24.55 (22.97, 26.18)	14.15 (12.88, 15.49)	17.62 (16.23, 19.07)	28.19 (26.54, 29.89)
Primary school	1,270 (21.53)	51.10 (48.31, 53.89)	45.35 (42.59, 48.14)	11.57 (9.87, 13.46)	26.06 (23.67, 28.57)	12.05 (10.31, 13.97)	17.17 (15.13, 19.35)	27.80 (25.35, 30.35)
Middle or high school	1,577 (26.73)	55.42 (52.93, 57.89)	47.37 (44.88, 49.87)	10.46 (9.00, 12.08)	31.39 (29.10, 33.74)	12.49 (10.90, 14.23)	18.90 (16.99, 20.92)	33.80 (31.46, 36.19)
College or above	225 (3.81)	55.11 (48.36, 61.73)	51.56 (44.82, 58.25)	12.00 (8.06, 16.98)	35.11 (28.89, 41.73)	11.56 (7.69, 16.47)	24.89 (19.38, 31.07)	42.67 (36.12, 49.41)
P value		0.034	0.184	0.319	< 0.001	0.178	0.031	< 0.001
Residence								
Rural	4,976 (84.35)	51.33 (49.93, 52.72)	44.84 (43.45, 46.23)	11.39 (10.52, 12.31)	26.21 (24.99, 27.45)	13.20 (12.27, 14.18)	17.89 (16.83, 18.98)	28.64 (27.38, 29.92)
Urban	923 (15.65)	58.83 (55.58, 62.03)	52.76 (49.48, 56.02)	13.11 (11.00, 15.46)	31.96 (28.96, 35.08)	12.89 (10.80, 15.23)	19.50 (16.99, 22.21)	38.35 (35.20, 41.58)
P value		< 0.001	< 0.001	0.136	< 0.001	0.798	0.242	< 0.001
2015								
Total	6,823	51.36 (50.16, 52.55)	60.13 (58.96, 61.30)	3.58 (3.15, 4.04)	13.48 (12.68, 14.32)	6.96 (6.37, 7.59)	17.32 (16.43, 18.24)	15.78 (14.93, 16.67)
Marital Status								
Married	5,851 (85.75)	52.08 (50.79, 53.36)	60.59 (59.32, 61.84)	3.38 (2.94, 3.88)	13.45 (12.59, 14.35)	6.87 (6.24, 7.55)	18.07 (17.09, 19.08)	15.79 (14.87, 16.75)
Other	972 (14.25)	47.02 (43.84, 50.21)	57.41 (54.23, 60.54)	4.73 (3.49, 6.26)	13.68 (11.58, 16.01)	7.51 (5.93, 9.35)	12.86 (10.82, 15.13)	15.74 (13.51, 18.18)
P value		0.003	0.061	0.036	0.844	0.468	< 0.001	0.968
Education level								
No formal education	3,206 (46.99)	47.91 (46.17, 49.66)	59.83 (58.10, 61.53)	3.49 (2.89, 4.19)	11.67 (10.57, 12.83)	6.99 (6.13, 7.92)	16.34 (15.08, 17.67)	13.72 (12.55, 14.96)
Primary school	1,458 (21.37)	51.78 (49.18, 54.38)	59.05 (56.48, 61.59)	4.18 (3.22, 5.34)	14.88 (13.09, 16.82)	7.68 (6.37, 9.17)	18.59 (16.62, 20.68)	17.01 (15.11, 19.04)
Middle or high school	1,726 (25.30)	54.63 (52.25, 57.00)	60.20 (57.84, 62.52)	3.07 (2.31, 4.00)	14.14 (12.53, 15.87)	5.91 (4.84, 7.13)	18.31 (16.51, 20.22)	17.38 (15.62, 19.25)
College or above	433 (6.35)	62.36 (57.60, 66.94)	65.82 (61.14, 70.28)	4.16 (2.48, 6.49)	19.63 (15.99, 23.69)	8.55 (6.09, 11.59)	16.40 (13.03, 20.23)	20.55 (16.84, 24.67)
P value		< 0.001	0.083	0.344	< 0.001	0.122	0.158	< 0.001
Residence								
Rural	768 (11.26)	61.59 (58.04, 65.04)	67.19 (63.74, 70.50)	4.04 (2.76, 5.68)	14.97 (12.52, 17.70)	8.72 (6.82, 10.95)	18.36 (15.68, 21.28)	20.31 (17.52, 23.33)
Urban	6,055 (88.74)	50.06 (48.79, 51.33)	59.24 (57.99, 60.48)	3.52 (3.07, 4.01)	13.29 (12.45, 14.18)	6.74 (6.12, 7.40)	17.19 (16.25, 18.17)	15.21 (14.31, 16.14)
P value		< 0.001	< 0.001	0.466	0.199	0.042	0.421	< 0.001

The median AIP is calculated on the basis of the total data from all participants rather than on separate calculations for each subgroup or each survey. The median AIP was 0.351. The median RC is calculated on the basis of the total data from all participants rather than on separate calculations for each subgroup or each survey. The median RC is 23.55 mg/dl

Table 5 Overall and stratified prevalence of dyslipidemia in the population with normal blood glucose by marital status, education level, and place of residence in 2011 and 2015

	n (%)	AIP ≥ AIP_{median} %(95% CI)	RC ≥ RC_{median} %(95% CI)	LDL-C ≥ 160%(95% CI)	HDL-C < 40%(95% CI)	TC ≥ 240%(95% CI)	TG ≥ 200%(95% CI)	Dyslipidemia %(95% CI)
2011								
Total	4,478	37.00 (35.59, 38.44)	31.69 (30.33, 33.07)	7.82 (7.05, 8.64)	18.65 (17.52, 19.82)	7.41 (6.66, 8.22)	6.99 (6.26, 7.78)	17.64 (16.54, 18.79)
Marital Status								
Married	3,961 (88.45)	37.39 (35.88, 38.92)	32.19 (30.73, 33.67)	7.37 (6.58, 8.23)	18.63 (17.43, 19.88)	6.84 (6.07, 7.67)	7.20 (6.41, 8.04)	17.72 (16.55, 18.95)
Other	517 (11.55)	34.04 (29.96, 38.31)	27.85 (24.03, 31.93)	11.22 (8.63, 14.26)	18.76 (15.49, 22.40)	11.80 (9.15, 14.90)	5.42 (3.63, 7.73)	17.02 (13.88, 20.54)
P value		< 0.001	0.046	0.002	0.943	< 0.001	0.136	0.694
Education level								
No formal education	2,094 (46.76)	35.29 (33.24, 37.38)	31.42 (29.44, 33.46)	8.36 (7.21, 9.63)	16.91 (15.32, 18.58)	8.26 (7.12, 9.52)	6.73 (5.70, 7.89)	15.28 (13.77, 16.90)
Primary school	998 (22.29)	35.17 (32.21, 38.22)	33.37 (30.44, 36.39)	7.92 (6.32, 9.77)	19.44 (17.03, 22.03)	8.12 (6.50, 9.99)	5.71 (4.35, 7.34)	19.54 (17.12, 22.14)
Middle or high school	1,236 (27.60)	40.70 (37.94, 43.49)	31.23 (28.65, 33.90)	6.39 (5.09, 7.90)	20.39 (18.17, 22.74)	5.34 (4.15, 6.74)	8.01 (6.56, 9.67)	18.93 (16.78, 21.23)
College or above	150 (3.35)	42.67 (34.64, 50.99)	28.00 (20.98, 35.91)	11.33 (6.74, 17.52)	23.33 (16.82, 30.93)	8.00 (4.20, 13.56)	10.67 (6.22, 16.74)	27.33 (20.38, 35.20)
P value		0.004	0.488	0.074	0.026	0.013	0.050	< 0.001
Residence								
Rural	3,815 (85.19)	36.15 (34.62, 37.69)	31.53 (30.06, 33.03)	7.79 (6.95, 8.68)	18.03 (16.83, 19.29)	7.58 (6.76, 8.46)	6.76 (5.99, 7.61)	16.70 (15.53, 17.92)
Urban	663 (14.81)	41.93 (38.14, 45.79)	32.58 (29.02, 36.29)	7.99 (6.05, 10.33)	22.17 (19.06, 25.53)	6.49 (4.73, 8.64)	8.30 (6.31, 10.66)	23.08 (19.92, 26.48)
P value		0.004	0.593	0.853	0.012	0.323	0.153	< 0.001
2015								
Total	3,303	42.54 (40.84, 44.24)	49.86 (48.14, 51.58)	1.76 (1.34, 2.26)	13.14 (12.01, 14.34)	3.57 (2.97, 4.26)	11.84 (10.76, 12.99)	11.23 (10.17, 12.36)
Marital Status								
Married	2,893 (87.59)	43.24 (41.43, 45.07)	50.74 (48.90, 52.58)	1.83 (1.38, 2.39)	13.27 (12.06, 14.56)	3.63 (2.98, 0.0438)	12.34 (11.16, 13.59)	11.58 (10.44, 12.80)
Other	410 (12.41)	37.56 (32.86, 42.45)	43.66 (38.80, 48.61)	1.22 (0.40, 2.82)	12.20 (9.19, 15.76)	3.17 (1.70, 0.0536)	8.29 (5.81, 11.40)	8.78 (6.23, 11.95)
P value		0.029	0.007	0.377	0.545	0.64	0.018	0.093
Education level								
No formal education	1,423 (43.08)	40.34 (37.78, 42.94)	51.23 (48.60, 53.86)	1.83 (1.20, 2.67)	11.45 (9.85, 13.22)	3.72 (2.80, 0.0484)	10.82 (9.26, 12.55)	9.84 (8.34, 11.50)
Primary school	684 (20.71)	42.84 (39.09, 46.64)	47.95 (44.15, 51.77)	1.90 (1.02, 3.23)	15.50 (12.87, 18.43)	3.07 (1.91, 0.0465)	11.84 (9.52, 14.50)	12.13 (9.78, 14.82)
Middle or high school	995 (30.12)	44.62 (41.50, 47.77)	49.65 (46.50, 52.80)	1.11 (0.55, 1.97)	13.37 (11.31, 15.64)	3.42 (2.38, 0.0474)	12.86 (10.85, 15.11)	11.56 (9.64, 13.71)
College or above	201 (6.09)	46.77 (39.71, 53.92)	47.76 (40.69, 54.90)	3.98 (1.73, 7.69)	15.92 (11.15, 21.73)	4.98 (2.41, 0.0896)	13.93 (9.46, 19.50)	16.42 (11.58, 22.28)
P value		0.108	0.487	0.047	0.041	0.612	0.354	0.031
Residence								
Rural	313 (9.48)	48.88 (43.22, 54.57)	53.35 (47.66, 58.99)	2.88 (1.32, 5.39)	14.70 (10.96, 19.11)	4.79 (2.71, 0.0778)	13.74 (10.12, 18.06)	16.29 (12.38, 20.86)
Urban	2,990 (90.52)	41.87 (40.10, 43.67)	49.50 (47.69, 51.31)	1.64 (1.21, 2.16)	12.98 (11.79, 14.23)	3.44 (2.82, 0.0416)	11.64 (10.51, 12.84)	10.70 (9.62, 11.87)
P value		0.017	0.194	0.113	0.391	0.222	0.274	0.003

The median AIP is calculated on the basis of the total data from all participants rather than on separate calculations for each subgroup or each survey. The median AIP was 0.351. The median RC is calculated on the basis of the total data from all participants rather than on separate calculations for each subgroup or each survey. The median RC is 23.55 mg/dl

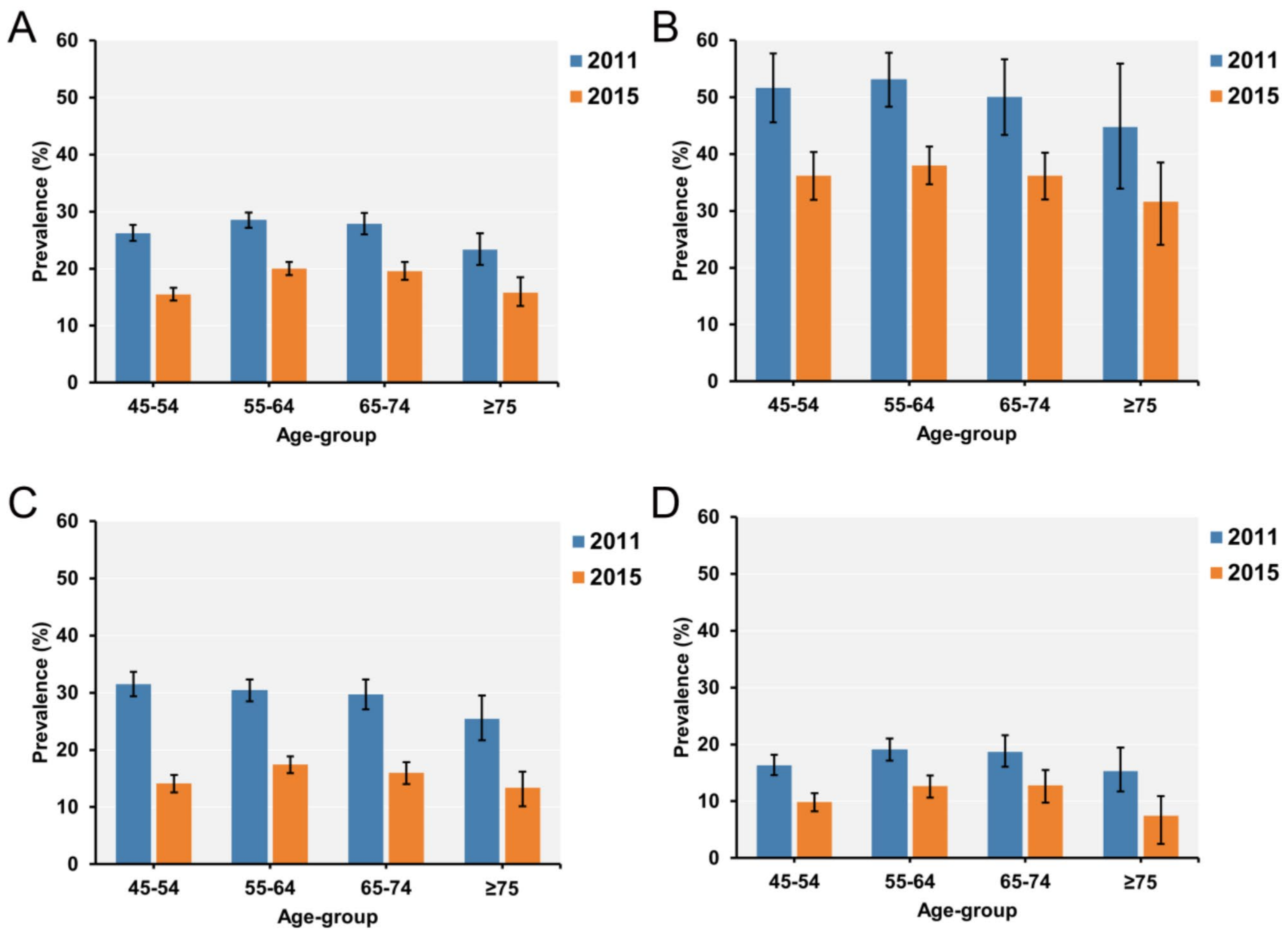

Fig. 3 Prevalence rates across different age groups for populations with varying blood glucose statuses in 2011 and 2015. Figures **A**, **B**, **C**, and **D** display the prevalence rates of dyslipidemia among the general population, those with DM, those with pre-DM, and individuals with normal blood glucose levels, respectively

whereas the adjusted mean concentrations of TC, TG, LDL-C, RC, and AIP were the highest. Second, between 2011 and 2015, the blood lipid parameters of the three groups of participants improved in terms of the mean concentrations, both unadjusted and after multivariable adjustment. Third, the trend of improvement in blood lipid parameters remained significant even after individuals using lipid-lowering and blood sugar-lowering medications were excluded (Table S3). Last, it is noteworthy that the significant decrease in AIP and RC levels was limited to participants with pre-DM and those with normal blood glucose.

The direct link between lipid components and the risk of CVD has been widely confirmed, although discussions on the relative advantages of different lipid indicators in risk prediction are still inconclusive [15, 16]. The results of this study revealed that in the DM patient population, there were significant improvements in the average concentrations of TC, LDL-C, and HDL-C, whereas TG, AIP, and RC showed slight increasing trends. For individuals with pre-DM, the levels of TC, LDL-C, HDL-C, and AIP improved significantly, but the level of RC increased significantly. Among participants with normal blood glucose levels, the average concentrations of TC, LDL-C, and HDL-C also significantly improved, yet the levels of AIP and RC increased. Previous studies have indicated that the incidence and mortality of DM and CVD among Chinese adults remain relatively high [17–19]. This may suggest the importance of TG, AIP, and RC in predicting the risk of DM and CVD. Several recent studies also support this view, providing further evidence for the significance of these lipid indicators in risk prediction [20–23].

TG, as a lipid component in the blood, plays a key role in the body's energy storage and supply. Epidemiological studies, genome-wide analyses, and Mendelian randomization studies have confirmed a causal link between TG levels and an increased risk of CVD and death [24–26]. Therefore, monitoring TG levels is crucial for assessing CVD risk and taking preventive measures. In the field of DM, elevated TG levels have been found to be associated with an increased risk of DM [27, 28]. A cross-sectional study from Northwest China revealed that high

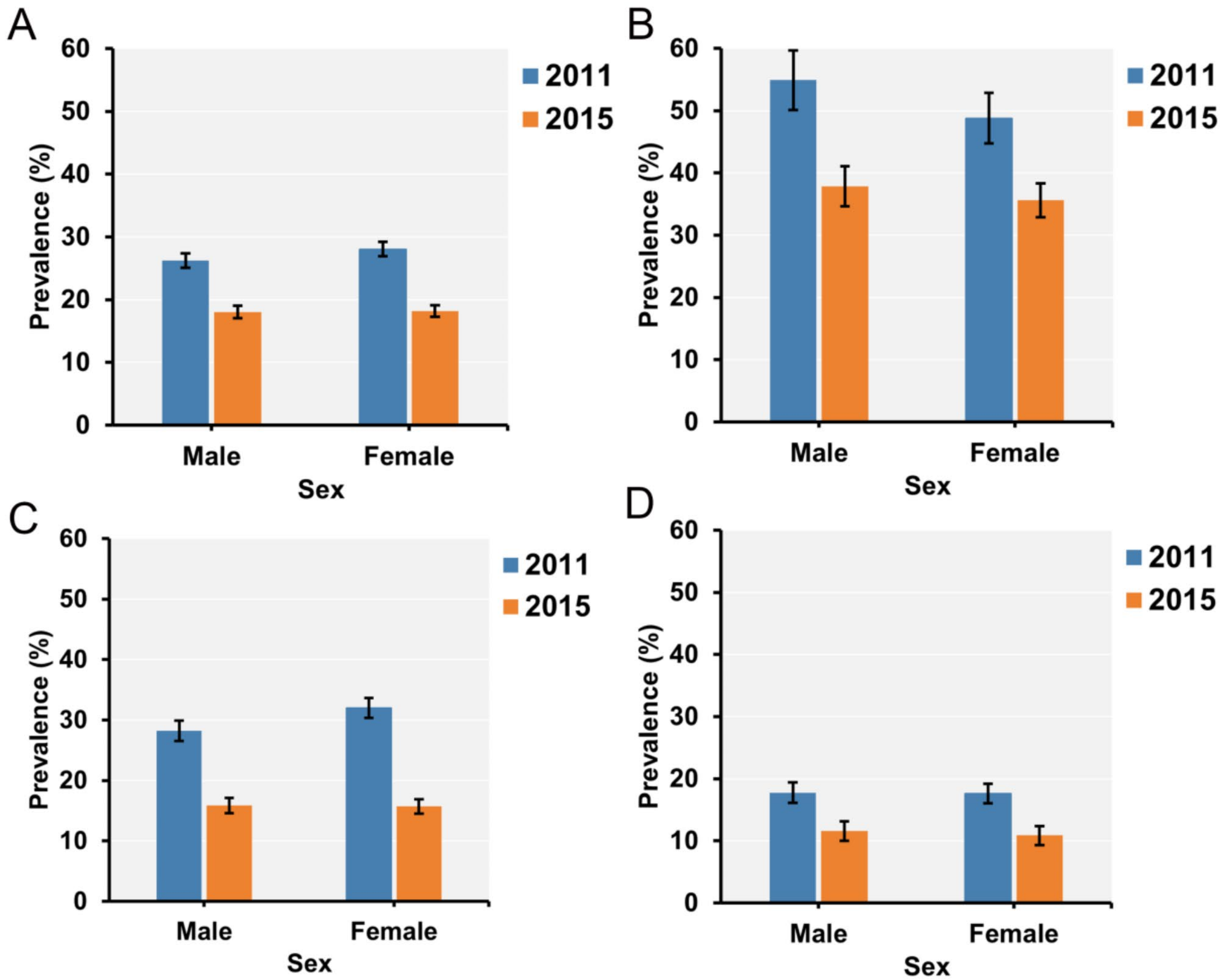

Fig. 4 Prevalence rates by sex for populations with different blood glucose statuses in 2011 and 2015. Panels **A**, **B**, **C**, and **D**, respectively illustrate the prevalence rates of dyslipidemia between different sexes within the general population, those with DM, those with pre-DM, and individuals with normal blood glucose levels

TG levels increase the risk of diabetic microvascular complications, especially in the elderly population [29]. This study revealed that the prevalence of dyslipidemia in the northern Chinese population is greater than that in the southern population, particularly among those with pre-DM, where the prevalence of hypertriglyceridemia in the northern population is significantly greater than that in the southern population, a phenomenon that persisted from 2011 to 2015. In contrast, no significant regional differences were observed between the DM and normal blood glucose populations. Previous studies have confirmed that an increase in BMI is usually associated with increased concentrations of TC, LDL-C, and TG, as well as a decrease in HDL-C concentration [30]. However, this study revealed that the increase in BMI was significant only in the population with normal blood glucose, and the increase in TG concentration was also limited to this group. These findings suggest that under normal blood glucose conditions, weight gain or obesity may be more likely to lead to an increase in TG levels. Additionally, as BMI increases in the normal population, improvements in TC and LDL-C are observed. This may be related to lipid metabolic adjustments associated with weight gain in the normal population. Additionally, this study revealed a significant shift from rural to urban residents between 2011 and 2015. This transformation may have been caused by several factors: first, a majority of overlapping participants migrated from rural to urban areas between 2011 and 2015 (Table S1); second, the new survey participants in 2015 indeed originated more from urban areas, which could also be a reason for the change in the urban−rural distribution (Table S1); furthermore, with the acceleration of urbanization, some areas that were originally marked as rural may have been reclassified as urban areas by 2015. There was a significant difference in dyslipidemia between urban and rural

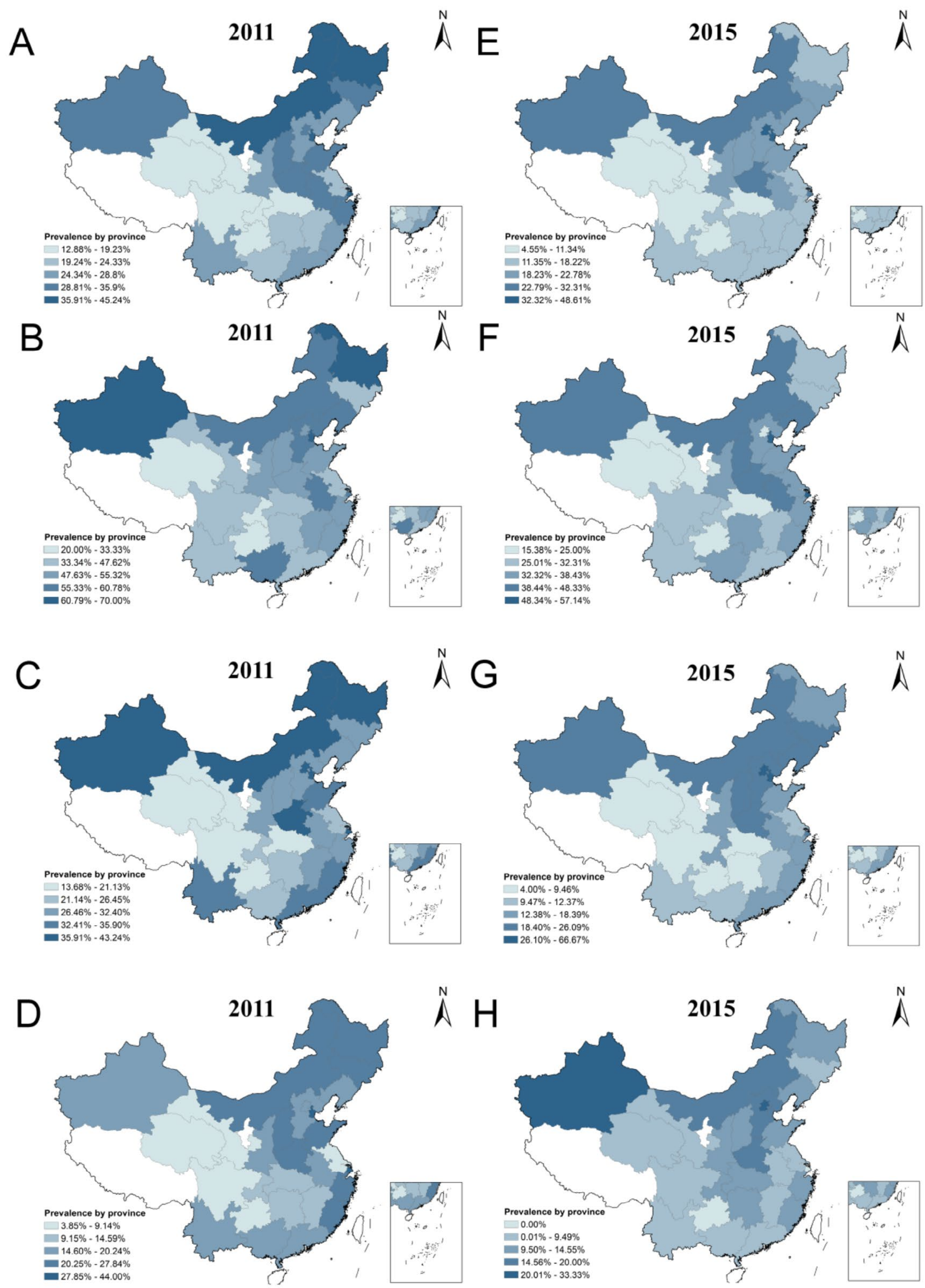

Fig. 5 Regional prevalence rates of dyslipidemia among populations with different blood glucose statuses in 2011 and 2015. Panels **A**, **B**, **C**, and **D** present the prevalence rates of dyslipidemia in the total population, individuals with DM, individuals with pre-DM, and individuals with normal blood glucose levels across various regions in 2011. Figures **E**, **F**, **G**, and **H** present the prevalence rates of dyslipidemia in the total population, individuals with DM, individuals with pre-DM, and individuals with normal blood glucose levels across various regions in 2015. Individuals residing in Hainan, Ningxia, Taiwan and Tibet were not included in the survey

Table 6 Temporal changes in the overall prevalence, age-specific prevalence, sex, place of residence, education level and marital status-specific prevalence of lipid abnormalities in patients with DM from 2011–2015

2015 vs. 2011	TG ≥ 200 mg/dl		HDL-C < 40 mg/dl		LDL-C ≥ 160 mg/dl		TC ≥ 240 mg/dl		Dyslipidemia	
	OR (95% CI)	*P* value	OR (95% CI)	*P* value	OR (95% CI)	*P* value	OR (95% CI)	*P* value	OR (95% CI)	*P* value
Total	1.16 (0.94, 1.44)	0.177	0.38 (0.31, 0.47)	< 0.001	0.31 (0.22, 0.45)	< 0.001	0.56 (0.42, 0.75)	< 0.001	0.54 (0.45, 0.66)	< 0.001
Age										
< 60	1.04 (0.75, 1.43)	0.825	0.38 (0.28, 0.53)	< 0.001	0.32 (0.19, 0.54)	< 0.001	0.54 (0.35, 0.83)	0.005	0.50 (0.36, 0.68)	< 0.001
≥ 60	1.26 (0.94, 1.71)	0.125	0.38 (0.29, 0.51)	< 0.001	0.31 (0.19, 0.51)	< 0.001	0.58 (0.39, 0.87)	0.008	0.57 (0.44, 0.74)	< 0.001
Sex										
Male	0.88 (0.63, 1.23)	0.445	0.46 (0.33, 0.62)	< 0.001	0.31 (0.16, 0.59)	< 0.001	0.38 (0.22, 0.64)	< 0.001	0.43 (0.31, 0.59)	< 0.001
Female	1.40 (1.05, 1.87)	0.022	0.33 (0.24, 0.45)	< 0.001	0.31 (0.21, 0.48)	< 0.001	0.66 (0.47, 0.94)	0.022	0.64 (0.49, 0.83)	0.001
Residence										
Urban	1.12 (0.81, 1.55)	0.484	0.28 (0.21, 0.38)	< 0.001	0.28 (0.17, 0.43)	< 0.001	0.53 (0.36, 0.80)	0.002	0.39 (0.29, 0.53)	< 0.001
Rural	1.14 (0.81, 1.60)	0.453	0.50 (0.35, 0.70)	< 0.001	0.48 (0.26, 0.88)	0.018	0.63 (0.38, 1.04)	0.070	0.70 (0.51, 0.95)	0.024
Education level										
No formal education	1.22 (0.79, 1.89)	0.362	0.48 (0.31, 0.74)	0.001	0.20 (0.10, 0.38)	< 0.001	0.35 (0.20, 0.63)	< 0.001	0.59 (0.40, 0.88)	0.009
Primary school	1.04 (0.64, 1.71)	0.869	0.35 (0.21, 0.57)	< 0.001	0.45 (0.21, 0.95)	0.036	0.76 (0.41, 1.41)	0.392	0.50 (0.32, 0.79)	0.003
Middle or high school	1.31 (0.89, 1.91)	0.168	0.34 (0.23, 0.50)	< 0.001	0.46 (0.23, 0.91)	0.026	0.80 (0.47, 1.35)	0.393	0.50 (0.35, 0.73)	< 0.001
College or above	0.61 (0.32, 1.17)	0.139	0.34 (0.18, 0.64)	0.001	0.31 (0.09, 1.06)	0.062	0.41 (0.15, 1.14)	0.087	0.43 (0.24, 0.78)	0.005
Marital status										
Other	1.09 (0.59, 2.02)	0.793	0.59 (0.33, 1.07)	0.081	0.11 (0.04, 0.29)	< 0.001	0.40 (0.19, 0.84)	0.016	0.47 (0.28, 0.81)	0.006
Married	1.17 (0.92, 1.48)	0.193	0.35 (0.28, 0.45)	< 0.001	0.38 (0.26, 0.57)	< 0.001	0.62 (0.45, 0.86)	0.004	0.57 (0.45, 0.70)	< 0.001

Age, sex, residence, marital status, education, smoking status, drinking status, hypertension, and BMI were adjusted for

populations in the subgroup analyses, and this difference may partly reflect changes in lipids due to urban/rural lifestyle changes.

Notably, even after individuals using lipid-lowering and blood sugar-lowering medications were excluded, participants with DM and pre-DM still generally presented high BMIs and hypertriglyceridemia, whereas TC, HDL-C, and LDL-C levels tended to improve. Individuals with DM often present with low levels of HDL-C, high levels of small dense LDL-C particles, and elevated TG levels [31], which may be associated with insulin resistance in the diabetic state, affecting the storage and release of lipids in adipocytes [31]. Furthermore, high TG levels are associated with an increased risk of insulin resistance, as they can lead to the accumulation of fat in key metabolic tissues. This accumulation not only triggers insulin resistance but also affects the secretion of adipokines, further disrupting insulin signaling and glucose uptake [32]. Additionally, these findings suggest the potential existence of other strong long-term trends that could counteract the potentially harmful effects of obesity on lipid concentrations. An increasing number of studies have shown that triglycerides combined with other indicators as a composite index (such as the triglyceride glucose index (TyG)) are independent predictors of DM incidence [33–35]. A 5-year longitudinal study involving 25,248 Chinese participants revealed that the TyG index has the potential to serve as a reliable marker for predicting the transition from pre-DM to normal blood glucose levels in Chinese populations [36]. These findings further emphasize the importance of TG levels as biomarkers for assessing the risk of DM.

Interestingly, the diabetic population had a greater RC status than did those with pre-DM and normal blood glucose, but no significant changes in RC were observed between 2011 and 2015. Concurrently, the RC levels in the pre-DM and normal blood glucose populations have shown an increasing trend, which may be related to the annual conversion rate of approximately 5–10% from pre-DM to DM [37]. RC, which is the cholesterol remaining in the blood after HDL-C, LDL-C, and TG are accounted for, is typically associated with an increased risk of CVD. RC is considered an important independent predictor of incident DM in the general population [38]. Additionally, the AIP levels were greater in the diabetic population than in the nondiabetic population, but no significant changes were observed from 2011 to 2015. A significant reduction in AIP levels was noted in the pre-DM population, whereas a significant increase was observed in the population with normal blood glucose. The AIP,

Table 7 Temporal changes in the overall prevalence, age-specific prevalence, sex, place of residence, education level and marital status-specific prevalence of lipid abnormalities in patients with pre-DM from 2011–2015

2015 vs. 2011	TG ≥ 200 mg/dl		HDL-C < 40 mg/dl		LDL-C ≥ 160 mg/dl		TC ≥ 240 mg/dl		Dyslipidemia	
	OR (95% CI)	*P* value	OR (95% CI)	*P* value	OR (95% CI)	*P* value	OR (95% CI)	*P* value	OR (95% CI)	*P* value
Total	0.96 (0.84, 1.10)	0.604	0.38 (0.33, 0.43)	< 0.001	0.27 (0.22, 0.33)	< 0.001	0.54 (0.46, 0.65)	< 0.001	0.39 (0.34, 0.44)	< 0.001
Age										
< 60	1.07 (0.89, 1.28)	0.485	0.33 (0.27, 0.39)	< 0.001	0.32 (0.24, 0.43)	< 0.001	0.59 (0.46, 0.75)	< 0.001	0.36 (0.30, 0.43)	< 0.001
≥ 60	0.86 (0.70, 1.05)	0.136	0.44 (0.36, 0.53)	< 0.001	0.23 (0.17, 0.30)	< 0.001	0.50 (0.39, 0.64)	< 0.001	0.42 (0.35, 0.50)	< 0.001
Sex										
Male	0.99 (0.81, 1.22)	0.948	0.45 (0.37, 0.53)	< 0.001	0.24 (0.17, 0.34)	< 0.001	0.47 (0.35, 0.62)	< 0.001	0.42 (0.35, 0.50)	< 0.001
Female	0.96 (0.80, 1.15)	0.651	0.30 (0.25, 0.37)	< 0.001	0.29 (0.22, 0.37)	< 0.001	0.59 (0.47, 0.73)	< 0.001	0.37 (0.31, 0.44)	< 0.001
Residence										
Urban	1.00 (0.83, 1.20)	0.963	0.37 (0.32, 0.44)	< 0.001	0.24 (0.19, 0.31)	< 0.001	0.51 (0.40, 0.64)	< 0.001	0.36 (0.31, 0.43)	< 0.001
Rural	0.91 (0.72, 1.15)	0.431	0.38 (0.30,0.49)	< 0.001	0.27 (0.18, 0.41)	< 0.001	0.57 (0.42, 0.78)	< 0.001	0.46 (0.37, 0.58)	< 0.001
Education level										
No formal education	0.86 (0.66, 1.12)	0.256	0.35 (0.27, 0.45)	< 0.001	0.21 (0.14, 0.30)	< 0.001	0.47 (0.34, 0.65)	< 0.001	0.33 (0.26, 0.43)	< 0.001
Primary school	1.16 (0.84, 1.60)	0.378	0.49 (0.36, 0.67)	< 0.001	0.30 (0.19, 0.47)	< 0.001	0.62 (0.42, 0.93)	0.020	0.54 (0.40, 0.72)	< 0.001
Middle or high school	1.08 (0.86, 1.37)	0.496	0.32 (0.26, 0.40)	< 0.001	0.27 (0.19, 0.40)	< 0.001	0.49 (0.36, 0.66)	< 0.001	0.38 (0.31, 0.47)	< 0.001
College or above	0.61 (0.40, 0.93)	0.022	0.48 (0.33, 0.72)	< 0.001	0.30 (0.16, 0.59)	< 0.001	0.67 (0.38, 1.19)	0.172	0.38 (0.26, 0.55)	< 0.001
Marital status										
Other	0.82 (0.56, 1.18)	0.281	0.37 (0.26, 0.53)	< 0.001	0.34 (0.21, 0.53)	< 0.001	0.54 (0.36, 0.82)	0.003	0.39 (0.28, 0.53)	< 0.001
Married	0.99 (0.86, 1.14)	0.879	0.37 (0.32, 0.43)	< 0.001	0.26 (0.21, 0.32)	< 0.001	0.54 (0.45, 0.66)	< 0.001	0.39 (0.34, 0.45)	< 0.001

Age, sex, residence, marital status, education, smoking status, drinking status, hypertension, and BMI were adjusted for

an indicator of the potential for cholesterol deposition in the arterial wall, is closely related to the risk of CVD. Research has shown that in patients with normal glucose regulation (NGR), the AIP is significantly correlated with the severity of coronary artery disease, whereas this relationship is not evident in those with pre-DM or DM [39]. These findings suggest that the AIP may play a different role in the progression from pre-DM to DM, and further research is needed to clarify its specific role in different glycemic states.

Strengths and limitations

The study has several strengths. First, on the basis of the national representativeness and longitudinal nature of the CHARLS study, accurate estimates of blood lipid concentrations and the prevalence of their abnormalities in the Chinese elderly population were made. Second, by implementing strict quality control measures, high standards for data collection and the reliability of the study results were ensured. Third, through comparative analysis across time points, potential trends in the prevalence of dyslipidemia across different blood glucose statuses were comprehensively described. However, this study also has several limitations. First, owing to the age restriction of survey participants to those over 45 years old, the overall prevalence of dyslipidemia in China may not be fully representative. Second, the duration of DM was not clearly recorded, and a prolonged state of hyperglycemia may increase the risk of dyslipidemia [31]. Additionally, owing to database limitations, specific information on the use of lipid-lowering medications by participants could not be obtained, which limits the assessment of the potential impact of specific cholesterol-lowering drugs on the study results. Furthermore, a cross-sectional data analysis approach was employed, allowing for rapid assessment of health conditions and trends at a specific point in time. However, this method may not fully capture the dynamic processes of individuals over time. Treating the data as independent cross-sections could overlook potential time series effects, which may impact the interpretation of certain results. Future research should consider the use of more sophisticated statistical models, such as mixed-effects models or longitudinal data analysis methods, to more comprehensively account for the effects of time and individual changes.

Table 8 Temporal changes in the overall prevalence, age-specific prevalence, sex prevalence, residential prevalence, and prevalence by education level and marital status of dyslipidemia in the population with normal blood glucose from 2011–2015

2015 vs. 2011	TG ≥ 200 mg/dl		HDL-C < 40 mg/dl		LDL-C ≥ 160 mg/dl		TC ≥ 240 mg/dl		Dyslipidemia	
	OR (95% CI)	*P* value	OR (95% CI)	*P* value	OR (95% CI)	*P* value	OR (95% CI)	*P* value	OR (95% CI)	*P* value
Total	1.79 (1.41, 2.27)	< 0.001	0.59 (0.49, 0.71)	< 0.001	0.23 (0.16, 0.33)	< 0.001	0.57 (0.42, 0.78)	< 0.001	0.56 (0.46, 0.68)	< 0.001
Age										
< 60	1.99 (1.47, 2.68)	< 0.001	0.62 (0.48, 0.79)	< 0.001	0.19 (0.12, 0.31)	< 0.001	0.57 (0.38, 0.86)	0.007	0.53 (0.41, 0.69)	< 0.001
≥ 60	1.44 (0.97, 2.12)	0.068	0.54 (0.41, 0.72)	< 0.001	0.29 (0.18, 0.49)	< 0.001	0.57 (0.36, 0.91)	0.018	0.60 (0.45, 0.80)	< 0.001
Sex										
Male	1.72 (1.20, 2.48)	0.004	0.58 (0.45, 0.75)	< 0.001	0.27 (0.16, 0.47)	< 0.001	0.72 (0.43, 1.19)	0.200	0.52 (0.39, 0.69)	< 0.001
Female	1.81 (1.32, 2.49)	< 0.001	0.57 (0.43, 0.76)	< 0.001	0.20 (0.12, 0.32)	< 0.001	0.49 (0.33, 0.72)	< 0.001	0.59 (0.45, 0.76)	< 0.001
Residence										
Urban	1.66 (1.21, 2.26)	0.002	0.53 (0.42, 0.67)	< 0.001	0.21 (0.14, 0.32)	< 0.001	0.58 (0.39, 0.85)	0.006	0.47 (0.37, 0.59)	< 0.001
Rural	1.98 (1.32, 2.97)	0.001	0.74 (0.52, 1.07)	0.112	0.27 (0.13, 0.57)	0.001	0.56 (0.31, 1.03)	0.061	0.81 (0.57, 1.17)	0.263
Education level										
No formal education	1.55 (0.93, 2.58)	0.094	0.47 (0.32, 0.69)	< 0.001	0.23 (0.12, 0.45)	< 0.001	0.49 (0.27, 0.86)	0.014	0.53 (0.35, 0.79)	0.002
Primary school	2.17 (1.11, 4.24)	0.023	0.90 (0.56, 1.44)	0.655	0.20 (0.09, 0.44)	< 0.001	0.40 (0.19, 0.86)	0.019	0.58 (0.36, 0.94)	0.026
Middle or high school	1.96 (1.36, 2.84)	< 0.001	0.52 (0.39, 0.70)	< 0.001	0.19 (0.09, 0.39)	< 0.001	0.80 (0.47, 1.35)	0.402	0.54 (0.40, 0.73)	< 0.001
College or above	1.57 (0.79, 3.11)	0.199	0.70 (0.39, 1.25)	0.229	0.29 (0.11, 0.77)	0.013	0.52 (0.20, 1.34)	0.173	0.54 (0.31, 0.95)	0.032
Marital status										
Other	1.95 (0.90, 4.21)	0.090	0.63 (0.36, 1.10)	0.105	0.10 (0.03, 0.30)	< 0.001	0.27 (0.12, 0.61)	0.001	0.53 (0.29, 0.96)	0.036
Married	1.79 (1.39, 2.29)	< 0.001	0.58 (0.48, 0.71)	< 0.001	0.26 (0.18, 0.38)	< 0.001	0.65 (0.47, 0.92)	0.013	0.56 (0.46, 0.69)	< 0.001

Age, sex, residence, marital status, education, smoking status, drinking status, hypertension, and BMI were adjusted for

Conclusion

In summary, between 2011 and 2015, individuals in the middle-aged and elderly population diagnosed with DM and pre-DM showed a significant improvement in the average concentrations of TC, HDL-C, and LDL-C. This improvement may be partly attributed to the increased use of lipid-lowering medications, particularly in the DM population. However, despite improvements in blood lipid indicators, a considerable proportion of individuals with DM and pre-DM still have elevated levels of TG, AIP, and RC. Therefore, further progress is needed in the comprehensive management of dyslipidemia in DM patients to reduce their incidence of cardiovascular diseases and the risk of death.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12944-024-02375-8.

Supplementary Material 1

Acknowledgements

None.

Author contributions

MZ and YC; data collection, methodology, software, statistical analysis, writing—original draft preparation; ML and WZ: visualization, writing—review and editing: JJ and FL; conceptualization, writing—review and editing.

Funding

The Hospital Capability Enhancement Project of Xiyuan Hospital, CACMS (NO. XYZX0404-10), funded this research.

Data availability

The datasets generated and/or analysed during the current study are available in the China Health and Retirement Longitudinal Study repository, which can be accessed online at http://charls.pku.edu.cn. You can register as a CHARLS user to access all published data by following the necessary procedure.

Declarations

Ethics approval and consent to participate
The CHARLS study was approved by the Institutional Review Board of Peking University. All participants provided written informed consent before participating in the CHARLS study.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Author details
[1]Xiyuan Hospital, China Academy of Chinese Medicine Sciences, Beijing 100091, China
[2]Beijing University of Chinese Medicine, Beijing 100029, China
[3]NMPA Key Laboratory for Clinical Research and Evaluation of Traditional Chinese Medicine, Beijing 100091, China
[4]National Clinical Research Center for Chinese Medicine Cardiology, Beijing 100091, China

Received: 18 August 2024 / Accepted: 13 November 2024
Published online: 28 November 2024

References
1. Cho NH, Shaw JE, Karuranga S, Huang Y, da Rocha Fernandes JD, Ohlrogge AW, Malanda B, et al. IDF Diabetes Atlas: global estimates of diabetes prevalence for 2017 and projections for 2045. Diabetes Res Clin Pract. 2018;138:271–81.
2. Sun H, Saeedi P, Karuranga S, Pinkepank M, Ogurtsova K, Duncan BB, Stein C, Basit A, Chan JCN, Mbanya JC, Pavkov ME, Ramachandaran A, Wild SH, James S, Herman WH, Zhang P, Bommer C, Kuo S, Boyko EJ, Magliano DJ. IDF Diabetes Atlas: Global, regional and country-level diabetes prevalence estimates for 2021 and projections for 2045. Diabetes Res Clin Pract. 2022;183:109119.
3. Xu Y, Wang L, He J, Bi Y, Li M, Wang T, Wang L, Jiang Y, Dai M, Lu J, Xu M, Li Y, Hu N, Li J, Mi S, Chen CS, Li G, Mu Y, Zhao J, Kong L, Chen J, Lai S, Wang W, Zhao W, Ning G. 2010 China Noncommunicable Disease Surveillance Group. Prevalence and control of diabetes in Chinese adults. JAMA. 2013;310(9):948–59.
4. Cosentino F, Grant PJ, Aboyans V, Bailey CJ, Ceriello A, Delgado V, Federici M, Filippatos G, Grobbee DE, Hansen TB, Huikuri HV, Johansson I, Jüni P, Lettino M, Marx N, Mellbin LG, Östgren CJ, Rocca B, Roffi M, Sattar N, Seferović PM, Sousa-Uva M, Valensi P, Wheeler DC, ESC Scientific Document Group. 2019 ESC guidelines on diabetes, prediabetes, and cardiovascular diseases developed in collaboration with the EASD. Eur Heart J. 2020;41(2):255–323.
5. Song PK, Man QQ, Li H, Pang SJ, Jia SS, Li YQ, He L, Zhao WH, Zhang J. Trends in Lipids Level and dyslipidemia among Chinese adults, 2002–2015. Biomed Environ Sci. 2019;32(8):559–70.
6. Liu M, Wang J, He Y, Jiang B, Wu L, Wang Y, Di Z, Zeng J. Awareness, treatment and control of type 2 diabetes among Chinese elderly and its changing trend for past decade. BMC Public Health. 2016;16:278.
7. Xu Y, Wang L, He J, Bi Y, Li M, Wang T, Wang L, Jiang Y, Dai M, Lu J, Xu M, Li Y, Hu N, Li J, Mi S, Chen CS, Li G, Mu Y, Zhao J, Kong L, Chen J, Lai S, Wang W, Zhao W, Ning G. Prevalence and control of diabetes in Chinese adults. JAMA. 2013;310(9):948–59.
8. Hu D, Fu P, Xie J, Chen CS, Yu D, Whelton PK, He J, Gu D. Increasing prevalence and low awareness, treatment and control of diabetes mellitus among Chinese adults: the InterASIA study. Diabetes Res Clin Pract. 2008;81(2):250–7.
9. Zhao Y, Hu Y, Smith JP, Strauss J, Yang G. Cohort profile: the China Health and Retirement Longitudinal Study (CHARLS). Int J Epidemiol. 2014;43(1):61–8.
10. Joint Committee for Developing Chinese guidelines on Prevention and Treatment of Dyslipidemia in Adults. Chinese guidelines on prevention and treatment of dyslipidemia in adults. Zhonghua Xin xue guan bing za zhi. 2007;35(5):390–419.
11. Allison MA, Budoff MJ, Wong ND, Blumenthal RS, Schreiner PJ, Criqui MH. Prevalence of and risk factors for subclinical cardiovascular disease in selected US hispanic ethnic groups: the multiethnic study of atherosclerosis. Am J Epidemiol. 2008;167(8):962–9.
12. Williams B, Mancia G, Spiering W, Agabiti Rosei E, Azizi M, Burnier M, et al. 2018 ESC/ESH guidelines for the management of arterial hypertension. Eur Heart J. 2018;39(33):3021–104.
13. Varbo A, Benn M, Tybjaerg-Hansen A, Jorgensen AB, Frikke-Schmidt R, Nordestgaard BG. Remnant cholesterol as a causal risk factor for ischemic heart disease. J Am Coll Cardiol. 2013;61(4):427–36.
14. Fernández-Macías JC, Ochoa-Martínez AC, Varela-Silva JA, Pérez-Maldonado IN. Atherogenic index of plasma: Novel Predictive Biomarker for Cardiovascular illnesses. Arch Med Res. 2019;50(5):285–94.
15. Di AE, Sarwar N, Perry P, Kaptoge S, Ray KK, Thompson A, Wood AM, Lewington S, Sattar N, Packard CJ, et al. Major lipids, apolipoproteins, and risk of vascular disease. JAMA. 2009;302:1993–2000.
16. Sniderman AD, Williams K, Contois JH, Monroe HM, McQueen MJ, De GJ, Furberg CD. A meta-analysis of low-density lipoprotein cholesterol, non-high-density lipoprotein cholesterol, and apolipoprotein B as markers of cardiovascular risk. Circ Cardiovasc Qual Outcomes. 2011;4:337–45.
17. Wang L, Peng W, Zhao Z, Zhang M, Shi Z, Song Z, Zhang X, Li C, Huang Z, Sun X, Wang L, Zhou M, Wu J, Wang Y. Prevalence and treatment of diabetes in China, 2013–2018. JAMA. 2021;326(24):2498–506.
18. Liu M, Liu SW, Wang LJ, Bai YM, Zeng XY, Guo HB, Liu YN, Jiang YY, Dong WL, He GX, Zhou MG, Yu SC. Burden of diabetes, hyperglycaemia in China from to 2016: findings from the 1990 to 2016, global burden of disease study. Diabetes Metab. 2019;45(3):286–93.
19. Liu S, Li Y, Zeng X, Wang H, Yin P, Wang L, Liu Y, Liu J, Qi J, Ran S, Yang S, Zhou M. Burden of Cardiovascular diseases in China, 1990–2016: findings from the 2016 global burden of Disease Study. JAMA Cardiol. 2019;4(4):342–52.
20. Qin M, Chen B. Association of atherogenic index of plasma with cardiovascular disease mortality and all-cause mortality in the general US adult population: results from NHANES 2005–2018. Cardiovasc Diabetol. 2024;23(1):255.
21. Sun Y, Li F, Zhou Y, Liu A, Lin X, Zou Z, Lv X, Zhou J, Li Z, Wu X, Dou S, Zhang M, Zhu J, Chen Y, Xiao X, Hu Y, Li H, Li Y. Nonlinear association between atherogenic index of plasma and type 2 diabetes mellitus in overweight and obesity patients: evidence from Chinese medical examination data. Cardiovasc Diabetol. 2024;23(1):226.
22. Huh JH, Han KD, Cho YK, Roh E, Kang JG, Lee SJ, Ihm SH. Remnant cholesterol and the risk of cardiovascular disease in type 2 diabetes: a nationwide longitudinal cohort study. Cardiovasc Diabetol. 2022;21(1):228.
23. Guo R, Wei L, Cao Y, Zhao W. Normal triglyceride concentration and the risk of diabetes mellitus type 2 in the general population of China. Front Endocrinol (Lausanne). 2024;15:1330650.
24. Nordestgaard BG, Benn M, Schnohr P, Tybjaerg-Hansen A. Nonfasting triglycerides and risk of myocardial infarction, ischemic heart disease, and death. JAMA. 2007;298(3):299–308.
25. Do R, Willer CJ, Schmidt EM, Sengupta S, Gao C, Peloso GM, Gustafsson S, Kanoni S, Ganna A, Chen J, Buchkovich ML, Mora S, Beckmann JS, Bragg-Gresham JL, Chang HY, Demirkan A, Den Hertog HM, Donnelly LA, Ehret GB, Esko T, Feitosa MF, Ferreira T, Fischer K, Fontanillas P, et al. Common variants associated with plasma triglycerides and risk for coronary artery disease. Nat Genet. 2013;45(11):1345–52.
26. Thomsen M, Varbo A, Tybjærg-Hansen A, Nordestgaard BG. Low nonfasting triglycerides and reduced all-cause mortality: a mendelian randomization study. Clin Chem. 2014;60(5):737–46.
27. Zhao J, Zhang Y, Wei F, Song J, Cao Z, Chen C, et al. Triglyceride is an independent predictor of type 2 diabetes among middle-aged and older adults. J Transl Med. 2019;17(1):403.
28. Peng J, Zhao F, Yang X, Pan X, Xin J, Wu M, et al. Association between dyslipidemia and risk of type 2 diabetes mellitus in middle-aged and older Chinese adults. BMJ Open. 2021;11(5):e042821.
29. Li J, Shi L, Zhao G, Sun F, Nie Z, Ge Z, Gao B, Yang Y. High triglyceride levels increase the risk of diabetic microvascular complications. Lipids Health Dis. 2023;22(1):109.
30. Zhu J, Zhang Y, Wu Y, Xiang Y, Tong X, Yu Y, Qiu Y, Cui S, Zhao Q, Wang N, Jiang Y, Zhao G. Obesity and Dyslipidemia in Chinese adults: a cross-sectional study in Shanghai, China. Nutrients. 2022;14(11):2321.
31. Bahiru E, Hsiao R, Phillipson D, Watson KE. Mechanisms and treatment of Dyslipidemia in Diabetes. Curr Cardiol Rep. 2021;23(4):26.
32. Vesković M, Šutulović N, Hrnčić D, Stanojlović O, Macut D, Mladenović D. The interconnection between hepatic insulin resistance and metabolic

dysfunction-associated steatotic liver disease. Curr Issues Mol Biol. 2023;45(11):9084–102.
33. Song B, Zhao X, Yao T, Lu W, Zhang H, Liu T, et al. Triglyceride glucose-body mass index and risk of incident type 2 diabetes mellitus. Front Endocrinol. 2022;13:907973.
34. Zou S, Yang C, Shen R, Wei X, Gong J, Pan Y, et al. Association between the triglyceride-glucose index and the incidence of diabetes. Front Endocrinol. 2021;12:784616.
35. Kim JA, Kim J, Roh E, Hong SH, Lee YB, Baik SH, et al. Triglyceride and glucose index and the risk of gestational diabetes mellitus. Diabetes Res Clin Pract. 2021;171:108533.
36. Chen X, Liu D, He W, Hu H, Wang W. Predictive performance of triglyceride glucose index (TyG index) to identify glucose status conversion. J Transl Med. 2023;21(1):624.
37. Chinese Society of Endocrinology, Chinese Diabetes Society, Chinese Endocrinologist Association. Intervention for adults with pre-diabetes: a Chinese expert consensus. Chin J Diabetes. 2023;15(06):484–94.
38. Xie G, Zhong Y, Yang S, Zou Y. Remnant cholesterol is an independent predictor of New-Onset diabetes. Diabetes Metab Syndr Obes. 2021;14:4735–45.
39. Wu X, Qiu W, Yang H, Chen YJ, Liu J, Zhao G. Associations of the triglyceride-glucose index and atherogenic index of plasma with the severity of new-onset coronary artery disease. Cardiovasc Diabetol. 2024;23(1):76.

Publisher's note