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ORIGINAL ARTICLE

The differences of metabolic profiles, socioeconomic status and diabetic retinopathy in U.S. working-age and elderly adults with diabetes: results from NHANES 1999–2018

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Abstract

Aims Controlled metabolic factors and socioeconomic status (SES) was crucial for prevention of diabetic retinopathy (DR). The study aims to assess the metabolic factors control and SES among working-age adults (18–64 years) with diabetes compared to older adults (65 years and older).

Methods Totals of 6738 participants with self-reported diagnosed diabetes from National Health and Nutrition Examination Survey were included, of whom 3482 were working-age and 3256 were elderly. The prevalence of DR, metabolic factors control, and the impact of SES and diabetic duration on DR was estimated. Subgroup analysis among working-age adults was employed across different diabetic duration and SES level.

Results The prevalence of DR was 20.8% among working-age adults and 20.6% in elderly adults. Further, working-age adults possessed suboptimal control on glycemia (median HbA1c: 7.0% vs. 6.8%, $p < 0.001$) and lipids (Low-density lipoprotein < 100 mg/dL: 46.4% vs. 63.5%, $p < 0.001$), but better blood pressure control (< 130/80 mmHg: 53.5% vs. 37.5%, $p < 0.001$) compared to the elderly, judging based on age-specific control targets. Prolonged diabetic duration didn't improve glycemic and composite factors control. SES like education and income impacted metabolic factors control and adults with higher SES were more likely to control well. Diabetic duration was a significant risk factor (OR = 4.006, 95%CI= (2.752,5.832), $p < 0.001$) while higher income (OR = 0.590, 95%CI= (0.421,0.826), $p = 0.002$) and educational level (OR = 0.637, 95%CI= (0.457,0.889), $p = 0.008$) were protective against DR.

Conclusions Working-age adults with diabetes demonstrate suboptimal metabolic profile control, especially glycemia and lipids. Additional efforts are needed to improve metabolic factor control and reduce DR risk, particularly for those with longer diabetes duration, less education, and lower incomes.

Keywords Diabetic retinopathy · Metabolic factors · Socioeconomic status · Working-age adults · NHANES

Introduction

Diabetes has imposed a heavy burden on public health, with the prevalence increasing continuously. Diabetic retinopathy (DR) is the its major ocular microvascular complication, affecting approximately 30–40% of those diagnosed with diabetes [1]. In working-age adults, DR is the leading cause of blindness, resulting in irreversible visual loss and onerous economic burden. Therefore, prevention and timely treatment of DR in the patients are of great clinical significance.

Considerable literature has documented the critical importance of controlling traditional risk factors and promoting socioeconomic status (SES) for the prevention of DR, regarding disparity of health care accessibility,

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self-management and lifestyle choices [2, 3]. However, for working-age adults (18–64 years), suboptimal risk factor control and lower SES compared to older adults (≥ 65 years) had been observed to increase the chance of DR definitely [4]. While, the studies investigating the prevalence of DR, metabolic factor control and SES levels across the working-age and elderly adults with diabetes are still insufficient.

In this study, we mainly focus on 3 aspects of risk factors, including blood glucose, blood pressure, and lipids and 4 aspects of SES considering gender, ethnicity/race, educational level and family poverty-to-income ratio level in NHANES to assess the prevalence of DR, the difference of metabolic profiles and SES between the working-age and elderly adults, and the impact of SES on DR.

Methods

Data resource and study population

This study analyzed data from the National Health and Nutrition Examination Survey (NHANES), a continuous, cross-sectional survey of the non-institutionalized United States population conducted every two years. NHANES employs a complex, multistage probability sampling design and collects information through physical exams, laboratory tests, and health questionnaires.

The analysis encompassed 3482 working-age and 3256 elderly nonpregnant participants with self-reported diagnosed diabetes from the NHANES 1999–2018. Working-age participants were from the interview ($n = 3482$), examination ($n = 3385$), 24-hour diet recall ($n = 2859$), and fasting ($n = 1436$) samples. As a complementary analysis, a cohort of older adults 65 years and older was included. A total of 6678 participants from the interview sample, 6372 from the examination sample, 5349 from 24-hour diet recall sample and 2632 from fasting sample were analyzed (Fig. 1).

Diabetes, diabetic retinopathy and risk factors control definition

The definition of diabetes was based on self-reported diagnosis by a professional physician. In contrast to self-reported diabetes, newly diagnosed diabetic patients identified by glycated hemoglobin A1c (HbA1c) and fasting blood glucose were missing on the diabetic duration data, which are pivotal risk indicators of DR. DR was defined as having self-reported retinopathy based on Diabetes Interview Questionnaires as mentioned on former publications [4–7]. The participants diagnosed with diabetes were asked "Has a doctor ever told you that diabetes has affected your eyes or that you had retinopathy (ret-in-op-ath-ee)?". Only those respondents answering "Yes" was considered as having DR.

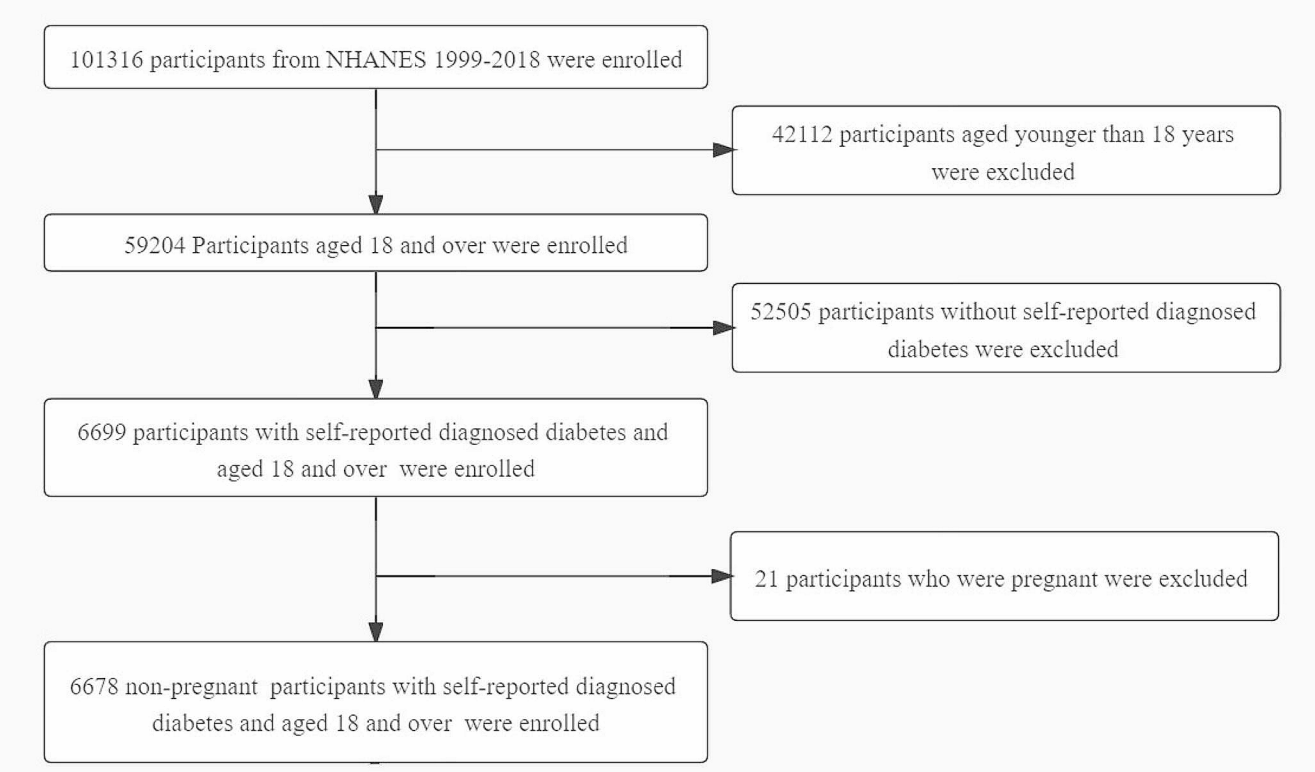

Fig. 1 A comprehensive flow chart of the study design

HbA1c was measured via high-performance liquid chromatography methods. Glycemic control was defined as HbA1c level less than 7% (8.5 mmol/L) or 8% (10.2 mmol/L). Participants' blood pressure was measured by a professional physician using a mercury sphygmomanometer after sitting still for 5 min. Elevated mean blood pressure ($\geq$ 140/90 mmHg or $\geq$ 130/80 mmHg) indicated poorer control. Non-high-density lipoprotein (non-HDL) cholesterol, calculated as total measured cholesterol minus HDL cholesterol, assessed lipid control. And non-HDL level < 130 mg/dL is considered as well-controlled plasma lipids [8]. Low-density lipoprotein (LDL) cholesterol was estimated among those fasting respondents to assess lipid control and LDL < 100 mg/dL is regarded as satisfactory.

Demographic and body measures variables

Demographic variables included age, gender (male/female), race/ethnicity (Mexican American, Other Hispanic, non-Hispanic White, non-Hispanic Black, other), educational level (less than high school, high school or equivalent, college and more), family economic status (family income-to-poverty ratio, $\leq$ 130%, 130–350%, > 350%), health insurance status (uninsured, any health insurance) and marital status (married, unmarried, other status) based on self-reported questionnaires. Diabetes duration was calculated from self-reported age at diagnosis and current age and divided the cohort into three groups: 0–10 years, 11–19 years and $\geq$ 20 years.

Body mass index (BMI) is calculated by dividing weight in kilograms by height in meters squared and classified as normal (BMI 18.5–25), overweight (BMI 25-29.99), obesity class I (BMI 30-34.99), obesity class II (BMI 35-39.99), and obesity class III (BMI over 40).

Diabetic nephropathy (DN) was defined either a urine albumin to creatinine ratio of 30 mg/g or higher, or estimated glomerular filtration rate less than 60 mL/min/1.73 m^2 from mobile examination center. Cardiovascular diseases (CVD) were defined by existence of any self-reported congestive heart failure, coronary heart disease, heart attack, or stroke [9].

Statistical analysis

Totals of 10 cycles from NHANES 1999–2018 were used. After examining the distribution of demographic and clinical characteristics of the participants from both groups, the prevalence of DR and rate of achieving risk factor control goals were estimated using student's *t* test in weighted linear regression model for continuous variables or weighted Rao-Scott χ^2 test for categorical variables, overall and by subgroup stratification. In subgroup analysis, participants were stratified by SES including sex, race or ethnicity, family economic status and educational level, and diabetic duration to appraise prevalence of DR and controlling rate of traditional risk factors. In addition, difference between working-age adults and elderly adults in risk factors controlling was compared. To identify the relationship of SES, diabetic duration and DR, univariable and multivariable logistic regression was employed, adjusting for potential confounders or not. Proper weight was used. If missing data level for primary analyses was no more than 10%, complete case analysis was applied. Statistical analysis was performed using Statistical Analysis Software procedures (SAS version 9.4) to account for complex sampling design. And a two-sided p value < 0.05 was considered statistically significant.

Results

Descriptive statistics

3482 working-age patients were included in the study, of whom 1736 (51.2%) were male. The median age was 52.2 years (IQR: 44.7 to 58.4 years). The demographic and clinical characteristics of the working-age and elderly group was compared in Table 1. Of note, shorter duration of diabetes (6.0 vs. 10.7 years, $p < 0.001$), more high educational level individuals (college and more: 51.9% vs. 42.6%, $p < 0.001$), more low-income individuals ($\leq$ 1.30: 28.0% vs. 24.5%, $p < 0.001$), more uninsured individuals (15.6% vs. 1.7%, $p < 0.001$), more unmarried individuals (12.9% vs. 3.4%, $p < 0.001$) and less normal BMI (11.1% vs. 15.3%, $p < 0.001$) were found in working-age patients. While in the elderly, a higher prevalence of DN and CVD was noted (DN: 44.5% vs. 70.1%, $p < 0.001$; CVD: 33.2% vs. 38.9%, $p < 0.001$).

Prevalence of diabetic retinopathy

We calculated, compared the prevalence of DR and conducted subgroup analysis in different age groups (Table 2). The prevalence of DR was 20.8% in the working-age and 20.6% in the elderly group. In diabetic duration subgroups analysis, significant higher risk of DR was detected in those working-age participants with shorter diabetic duration ($\leq$ 10 years: working-age vs. elderly group: 14.5% vs. 11.2%, $p = 0.049$). No other statistically significant differences in DR prevalence existed between age groups. However, the prevalence of DR increased significantly in both age groups as the duration of diabetes extended (working-age adults: increasing from 14.5 to 41.9%, $p < 0.001$; elderly adults: increasing from 11.2 to 34.2%, $p < 0.001$).

Table 1 Characteristics of U.S. working-age and elderly adults with diagnosed diabetes, NHANES 1999–2018[a]

Characteristic	No.	18–64 years ($N=3482$)	≥65 years ($N=3196$)	P value[b]
Age, years	6678	52.2 (44.7,58.4)	72.2 (67.6,77.7)	<0.001*
Gender	6678			0.093
Male	3384	1736 (51.2)	1648 (48.3)	
Female	3294	1746 (48.8)	1548 (51.7)	
Race or ethnicity	6678			<0.001*
Mexican American	1342	812 (11.0)	530 (5.6)	
Other Hispanic	581	346 (7.0)	235 (4.0)	
Non-Hispanic White	2364	959 (55.1)	1405 (70.0)	
Non-Hispanic Black	1789	1020 (17.9)	769 (12.9)	
Others	602	345 (9.0)	257 (7.5)	
Diabetic duration, years	6603	6.0 (2.1,12.5)	10.7 (4.7,19.8)	<0.001*
Duration categories	6603			<0.001*
<10 years	3314	2056 (62.0)	1258 (41.2)	
11–19 years	1855	928 (24.6)	927 (30.1)	
≥20 years	1434	484 (13.4)	950 (28.7)	
Educational level	6662			<0.001*
Less than high school	2592	1200 (23.7)	1392 (31.0)	
High school or equivalent	1493	770 (24.4)	723 (26.4)	
College and more	2577	1508 (51.9)	1069 (42.6)	
Poverty-to-income ratio	5940			<0.001*
≤1.30	2193	1193 (28.0)	1000 (24.5)	
1.30–3.50	2422	1159 (35.6)	1263 (48.6)	
>3.50	1325	785 (36.4)	540 (26.9)	
Health insurance status	6651			<0.001*
Uninsured	804	715 (15.6)	89 (1.7)	
Any insurance	5847	2754 (84.4)	3093 (98.3)	
Marital status	6607			<0.001*
Married	3620	1927 (59.1)	1693 (57.3)	
Unmarried	579	452 (12.9)	127 (3.4)	
Other status	2408	1055 (28.0)	1353 (39.3)	
BMI categories	6119			<0.001*
Normal weight (18.5–24.9)	876	384 (11.1)	492 (15.3)	
Overweight (25.0-29.9)	1852	872 (23.4)	980 (33.2)	
Class I obesity (30.0-34.9)	1631	867 (26.6)	764 (27.6)	
Class II obesity (35.0-39.9)	936	553 (18.0)	383 (15.5)	
Class III obesity (≥40)	824	611 (20.9)	213 (8.5)	
Diabetic complications and comorbidity				
DN	6286			<0.001*
With DN	2812	1136 (44.5)	2210 (70.1)	
Without DN	3474	1676 (55.5)	1264 (29.9)	
CVD	6651			<0.001*
With CVD	1863	641 (33.2)	1222 (38.9)	
Without CVD	4788	2816 (66.7)	1972 (61.1)	

[a] Data were shown as unweighted number (weighted %) or median (interquartile range, IQR). BMI indicates body mass index. For interview weights, 6678 patients were included into analysis, and the number of missing data are as follows: Poverty-to-income ratio 738, insurance status 27, marital status 71, educational level status 16, diabetic duration status 75, CVD 27. For mobile examination center weights, 6372 patients were included into analysis, and the number of missing data are as follows: BMI 253 and DN 86

[b] P value was calculated by Rao-Scott Chi-square test or student's t test in weighted linear regression. Statistical significance was defined as $P<0.05$

Furthermore, inverse trend was observed among different educational level. The prevalence of DR in both groups decreased significantly as the educational level improved ($p<0.05$). Similarly, individuals with higher family poverty-to-income ratio level had lower risk of DR in working-age group, which was not observed to be significant in the elderly, even though the same trend remained. The gender difference in prevalence within the two age groups was not statistically significant.

Risk factor control in different age groups

We estimated the control rate of traditional risk factors including HbA1c, blood pressure, non-HDL and LDL in different age groups. For glycemic control, the median HbA1c

Table 2 The prevalence of DR among U.S. working-age adults and elderly adults with diagnosed diabetes, NHANES 1999–2018[a]

		18–64 years	*P* value[b]	≥ 65 years	*P* value[b]	*P* value[b]
Overall	/	767 (20.8)		728 (20.6)		0.920
			< 0.001*		< 0.001*	
Duration	0–10 years	323 (14.5)		155 (11.2)		0.049*
	11–19 years	249 (25.3)		217 (21.1)		0.145
	≥ 20 years	194 (41.9)		350 (34.2)		0.075
			0.825		0.112	
Gender	Male	407 (21.0)		363 (19.1)		0.351
	Female	360 (20.5)		365 (22.0)		0.465
			0.701		< 0.001*	
Ethnicity/race	Mexican American	183 (19.9)		130 (23.6)		0.132
	Other Hispanic	76 (21.3)		64 (24.8)		0.397
	Non-Hispanic White	202 (20.0)		275 (19.3)		0.769
	Non-Hispanic Black	221 (22.0)		196 (24.9)		0.192
	Others	85 (23.6)		63 (20.8)		0.520
			0.013*		< 0.001*	
Educational level	Less than high school	287 (23.8)		358 (25.5)		0.444
	High school or equivalent	177 (23.2)		159 (23.2)		0.996
	College and more	301 (18.2)		211 (15.6)		0.215
			0.001*		0.080	
Family income-to-poverty ratio	≤ 1.30	320 (26.6)		231 (23.4)		0.128
	1.30–3.50	238 (20.6)		282 (20.4)		0.925
	> 3.50	138 (17.2)		113 (17.3)		0.953

[a] Data were shown as unweighted number (weighted %)

[b] *P* value was calculated by Rao-Scott Chi-square test. Statistical significance was defined as $P < 0.05$

for the working-age was 7.0% compared to 6.7% for older adults ($p < 0.001$). The rate of HbA1c control was significantly worse in working-age populations than in older adults, either by lenient (69.2% vs. 83.7%, $p < 0.001$) or rigorous standards (50.1% vs. 60.2%, $p < 0.001$). To the contrary, the rate for achieving BP targets was higher in working-age group regardless of the criteria applied (< 140/90 mmHg: 77.6% vs. 60.4%, $p < 0.001$; <130/80 mmHg: 53.5% vs. 37.5%, $p < 0.001$). For lipids control, higher rates of LDL and non-HDL control were observed in young adults. Only less than 20% of working-age patients achieved 3 risk factor control (HbA1c < 7% + BP < 140/90 mm Hg + non-HDL < 130 mg/dL), whereas the rate was 23.8% in elderly group. The control rate of HbA1c, BP, and LDL levels were detailed in Table 3.

Risk factor control in working-age subgroup

Further subgroup analyses were conducted by gender, ethnicity/race, diabetic duration, educational level and family poverty-to-income ratio in working-age population considering the severe outcomes caused by DR among the group. In gender subgroup, males had lower controlling rate of glycemic and blood pressure but higher rate of lipid control (LDL and non-HDL) than females ($p < 0.05$). Overall combined risk factor control was similar, around 19% in both genders (Table S1).

Of the different ethnic groups, Mexican-Americans had the worst glycemic control (HbA1c < 7%: 40.0% and HbA1c < 8%: 59.3%, $p < 0.001$). But Non-Hispanic Black population had the poorest blood pressure control (< 140/90 mmHg: 65.3% and < 130/80 mmHg: 41.9%). The worst control of lipids was observed in the Hispanic group (non-HDL < 130 mg/dL: 30.2% and LDL < 100 mg/dL: 27.8%). For composite risk factor control, the lowest control rate was in the Mexican-American and Hispanic populations. The details were shown as Table S2.

Glycemic control significantly worsened with the prolongation of diabetes (HbA1c < 7% decreased from 56.9 to 41.3% and HbA1c < 8% decreased from 73.2 to 67.6%). Although diastolic blood pressure improved, the overall blood pressure control rate did not improve significantly. While the control rate of lipids increased with the prolongation of diabetic duration (non-HDL < 130 mg/dL increased from 37.7 to 54.8% and LDL < 100 mg/dL increased 42.2–56.6%). However, prolonged diabetic duration did not promote improvement in composite risk factors (Table S3).

In educational subgroup analysis (Table S4), higher education was associated with significantly improved glycemic and lipid control but not BP control. The overall risk factor control rate gradually improved as the education level

Table 3 The control rate of metabolic risk factors among U.S. working-age and elderly adults with diagnosed diabetes, NHANES 1999–2018[a]

	18–64 years	≥ 65 years	*P* value[b]
Glucose control			
HbA1c, %	7.0 (6.1,8.4)	6.7 (6.1,7.5)	< 0.001*
HbA1c < 7%	1506 (50.1)	1647 (60.2)	< 0.001*
HbA1c < 8%	2148 (69.2)	2281 (83.7)	< 0.001*
Blood pressure control			
Systolic blood pressure, mmHg	124.2 (114.5,136.1)	135.1 (123.0,148.8)	< 0.001*
Diastolic blood pressure, mmHg	73.2 (65.7,79.6)	63.9 (56.3,71.6)	< 0.001*
< 140/90 mmHg	2392 (77.6)	1667 (60.4)	< 0.001*
< 130/80 mmHg	1630 (53.5)	1030 (37.5)	< 0.001*
Lipids control			
Non-HDL, mg/dL	138.8 (111.4,171.1)	119.1 (95.9,150.8)	< 0.001*
Non-HDL < 130 mg/dL	1302 (41.4)	1591 (58.9)	< 0.001*
Lipids control			
LDL, mg/dL	102.4 (80.6,130.1)	86.6 (67.4,113.0)	< 0.001*
LDL < 100 mg/dL	581 (46.4)	686 (63.5)	< 0.001*
All three risk factors control			
HbA1c < 7%, Blood pressure < 140/90mmHg and non-HDL < 130 mg/dL	544 (19.6)	577 (23.8)	0.012
HbA1c < 7%, Blood pressure < 140/90mmHg and LDL < 100 mg/dL	222 (19.9)	248 (25.2)	0.040

[a] Data were shown as unweighted number (weighted %) or median (interquartile range, IQR). HbA1c indicates Hemoglobin A1C; non-HDL indicates non-high-density lipoprotein; LDL indicates low-density lipoprotein

[b] *P* value was calculated by Rao-Scott Chi-square test or student's test in weighted linear regression. Statistical significance was defined as $P < 0.05$

elevated, regardless of the significance (Less than high school vs. High school or equivalent vs. College and more: 15.3% vs. 20.3% vs. 21.2%, $p = 0.043$).

Finally, we assessed risk factor control among working-age patients with different family income levels (Table S5). With the increase in family income level, the control rates of glycemia and lipids were significantly higher than those individuals with lower income. There was no dramatic change in blood pressure control. Similar with the education level subgroup, a significantly higher composite risk factor control rate was observed in the higher income group (≤ 1.30 vs. 1.30–3.50 vs. >3.50: 12.4% vs. 16.6% vs. 28.5%, $p < 0.001$).

The role of socioeconomic status and diabetic duration on DR

To investigate the impact of SES and diabetic duration on DR, weighted univariable and multivariable logistic regression was employed among two age groups and the total participants enrolled in our study. In univariate logistic regression (Table S6), the results demonstrated that being Non-Hispanic Black and having a long-time diagnosis of diabetes are risk factors for DR, whereas a high level of income and education decreases the risk of developing DR in both groups. After adjusting for age, gender, race/ethnicity, diabetic duration, educational level, family poverty-to-income ratio, HbA1c control, blood pressure control, non-HDL control, DN and CVD, long diabetic duration was still an independent risk factor for both groups. And higher family poverty-to-income ratio was observed as a protective factor for DR among working-age adults (OR = 0.590, 95%CI= (0.421,0.826), $p = 0.002$), while receiving more education has been observed to have a beneficial effect among older adults (OR = 0.637, 95%CI= (0.457,0.889), $p = 0.008$). However, no significant association was revealed between gender, ethnicity/race and DR (Table 4).

Discussion

This large, nationally representative study described overall and SES-stratified DR prevalence and metabolic risk factor control rates among working-age and elderly U.S. adults with diagnosed diabetes. Among working-age adults, glycemic and lipid control remained suboptimal compared to elderly. In subgroup analysis, females had poorer lipid control. Longer duration did not improve risk factors, except lipids and those with less education and income had worse metabolic factors control. Additionally, our study revealed that high socioeconomic levels, such as high education or income, were significantly associated with a lower chance of DR development.

From our observation, the overall prevalence was approximately 21% and that in working-age adults was slightly higher than elderly group without significant difference

Table 4 The association between socioeconomic status, diabetic duration and DR in U.S. adults with diagnosed diabetes, NHANES 1999-2018[a]

	All adults	*P* value	18–64 years	*P* value	≥ 65 years	*P* value
Gender						
Male (ref)	1	/	1	/	1	/
Female	0.938 (0.762,1.155)	0.545	0.850 (0.643,1.123)	0.252	1.100 (0.819,1.477)	0.525
Ethnicity/race						
Mexican American	0.821 (0.612,1.102)	0.188	0.765 (0.539,1.085)	0.132	1.040 (0.675,1.604)	0.857
Other Hispanic	1.093 (0.753,1.588)	0.638	1.021 (0.638,1.631)	0.932	1.315 (0.787,2.196)	0.293
Non-Hispanic White (ref)	1	/	1	/	1	/
Non-Hispanic Black	1.069 (0.851,1.341)	0.565	0.992 (0.732,1.343)	0.957	1.223 (0.889,1.681)	0.214
Others	1.235 (0.872,1.748)	0.233	1.248 (0.779,1.997)	0.354	1.160 (0.710,1.894)	0.552
Educational level						
Less than high school (ref)	1	/	1	/	1	/
High school or equivalent	1.041 (0.787,1.376)	0.778	1.035 (0.698,1.533)	0.863	1.029 (0.682,1.551)	0.891
College and more	0.761 (0.578,0.997)	0.045*	0.858 (0.591,1.244)	0.416	0.637 (0.457,0.889)	0.008*
Family poverty-to-income ratio						
0-1.30 (ref)	1	/	1	/	1	/
1.30–3.50	0.873 (0.686,1.109)	0.263	0.797 (0.588,1.079)	0.141	1.046 (0.738,1.481)	0.800
≥ 3.50	0.682 (0.508,0.917)	0.012*	0.590 (0.421,0.826)	0.002*	0.882 (0.547,1.422)	0.604
Diabetic duration						
0–10 years (ref)	1	/	1	/	1	/
11–19 years	1.953 (1.572,2.426)	< 0.001*	1.886 (1.410,2.523)	< 0.001*	2.037 (1.366,3.038)	< 0.001*
≥ 20 years	3.566 (2.765,4.601)	< 0.001*	4.006 (2.752,5.832)	< 0.001*	3.128 (2.195,4.459)	< 0.001*

[a] Data was shown as OR (95% CI). Ref: reference; OR: odds ratio; CI: confidence interval; model was adjusted for age, gender, race/ethnicity, diabetic duration, educational level, family poverty-to-income ratio, HbA1c control, blood pressure control, non-HDL control, DN and CVD

* Statistical significance was defined as $P < 0.05$

detected. Although it was lower than reported prevalence from NHANES 2005–2008 [10], this value was close to the global prevalence (22.7%) [11]. Consistent with our study, a representative study including 63,582 patients with type 2 diabetes from Taiwan also indicated that more increasing trends were observed among younger patients (aged < 60 years) [12]. Working-age adults are in the golden period of their careers and busy schedules leave them no enough time and financial resources to seek for healthcare until function impairments affect their work, which may explain the high prevalence in working-age people, especially in those with low SES as revealed in former publications [13–15]. Besides, no gender difference was observed from our research, which was not similar with prior studies [7]. Gender differences in DR occurrence are not significant, while some reports have found a higher susceptibility in men [16]. But other studies have suggested the opposite conclusion [17]. Among racial subgroups, we didn't find any higher prevalence of DR in working-age adults, which was supported by a cohort from San Francisco General Hospital [18]. Long duration was a well-recognized independent risk factor for DR, and our result corroborated the conclusion [19]. In our results, patients with lower income and educational level (lower SES) were more likely to suffer from DR, and literature sustained our conclusions that low SES was associated with an increased risk of diabetes and its complications [20]. Lower SES might influence metabolic implications about insulin resistance and impair the ability of β-cells to secrete insulin and alter the gut microbiota through living environment and dietary habits, further increasing the risk of diabetes [21, 22].

As revealed by the current research, significantly better metabolic factors control regarding HbA1c and lipids was observed among elderly population, similar with the lower prevalence of DR. Recently, a new subtype of diabetes, age-related diabetes mellitus has been reported in the older patients, who showed only modest metabolic derangements but no clinically diabetic manifestation [23]. Meanwhile, blood glucose in these patients fluctuates more gently, and the vascular stimulation by high glucose is less severe, leading to fewer microvascular and macrovascular complications [24]. However, higher prevalence of type 1 diabetes among younger adults has been universally indicated. Autoimmune destruction of β cells, resulting in insufficient insulin secretion played the crucial role in imbalanced energy metabolism, thus, even receiving insulin therapy, their metabolic control remains unsatisfactory [25]. According to our data, dramatic differences between SES on risk factors control were observed among working-age adults. Male were more likely to have poorer HbA1c and blood pressure but better lipids control, aligning with some studies on higher impaired fasting glucose and overall diabetes prevalence in men [26]. Other study enrolling 64 patients (32 men and 32 women) treated with insulin therapy also revealed the same

result [27]. But results from the ESC-EORP EUROASPIRE surveys suggested that females with diabetes had higher HbA1c than males [28]. Additionally, ethnicity/race differences were noted as well. Mexican-Americans had the worst glycemic, Non-Hispanic Black population had the poorest blood pressure control. The worst control of lipids was observed in the Hispanic group. The worst combined risk control was detected in Mexican-American and Hispanic groups. Prior work found self-monitoring most difficult for Hispanics, dietary management hardest for non-Hispanic whites, and physical activity most challenging for African-Americans, with poorest metabolic control in Hispanics [29]. Although risk factor control varies among races, increased attention remains important for racial minorities.

Despite the fact that the duration of diabetes has become a well-established risk factor for complications, few studies have investigated the control of risk factors across different duration. In our study, only lipids control improved with prolonged diabetic duration. Faisal S. Malik et al. reported that younger adults with type 1 diabetes and five-to-nine-year duration exhibited a temporal trend of worse glycemic control [30]. Patients with various duration may tend to use multiple medications to control metabolic factors, which may explain the differences in blood glucose control between different duration [31].

Our analysis pointed out that lower-SES including low-education and low-income individuals inclined to control metabolic factors worse, leading to higher chance of DR. Consistent with our conclusion, a two-sample mendelian randomization study also indicated 4.2 years of schooling educational attainment was associated with a 47% reduction in odds of type 2 diabetes [32]. Similarly, low education level was identified as a significant risk factor for cardiovascular disease with a population attributable fraction of 12.5% [33]. Diagnosed patients with low education have poorer glycemic and HbA1c control [34]. Furthermore, low-income group had poorer glycemia and lipids control but similar blood pressure compliance rates. The higher accessibility and affordability of BP-lowering medications and blood pressure measurements plays a key role compared with blood glucose and lipid measurements, which often require specialized laboratory testing. Cost-effectiveness studies in low- and middle-income countries also cautioned that more funds should be allocated to blood pressure and lipids management rather than glycemic control and diabetes screening [35].

Our study suggested that higher education and income were independent protective factors for DR, while long diabetic duration was a risk factor. This aligns with research linking SES to several diseases, such as cardiovascular disease [36], hypertension and renal disease [37], diabetes and DR [38]. Socioeconomic status has an influence on the development and progression of disease by affecting personal lifestyle habits, nutritional conditions, social interactions, accessibility and ability to pay for medical care. Generally, individuals with lower SES are usually engaged in heavy work and have higher level of physical activity, which is considered as positive for prevent DR. However, unhealthy dietary patterns contributed to poor glycemic control through multiple underlying mechanisms, facilitating DR occurrence and development [39]. In addition, our prior study also suggested that patients with low SES were inclined to possess worse lifestyle including more current smoker, more heavy drinking, lower healthy eating index, higher prevalence of depression and sleeping disorder (the data is unpublished). Therefore, it's of great necessity to promote healthy lifestyles among working-age adults with diabetes to prevent DR timely.

Our study initially estimated the prevalence of DR and metabolic risk factor control among working-age participants with diabetes by SES. Limitations include potential recall bias from self-reported diabetes and the cross-sectional design. Further cohort study is needed to confirm our results. Nevertheless, this study included a large representative population from NHANES selected by a complex, multistage sampling. And the use of objective statistical methods and adjustment of various interactions enabled us to eliminate bias.

In conclusion, working-age diabetic adults had high DR prevalence with suboptimal blood glucose and lipid control versus the elderly. Those with lower income and education had worse control, which was independent risk factor for DR. Further efforts are needed to advocate for strict risk factor control, self-management and patient education, especially in low-SES populations.

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Data availability The data and codes generated during the study were available from the corresponding author on reasonable request. The original data was publicly available from NHANES website, https://www.cdc.gov/nchs/nhanes/index.htm.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Consent to participate All participants provided informed written consent and tenets of the Declaration of Helsinki was followed.

Ethical standards The study received ethics approval from the National Center for Health Statistics. Shanghai General Hospital Ethics Committee waived any additional ethics approval because NHANES data was publicly available.

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