

Neighborhood Vulnerability, Care Engagement, and Diabetic Retinopathy in an Underserved Urban Health System: A Retrospective Observational Study in Philadelphia

Savitri A. Nandula

Temple University

Allison R. Casola

Temple University

Ajay D. Rao

Temple University

John Turella

Temple University

Harris Quach

Temple University

Henderer Jeffrey

Temple University

Yi Zhang

Temple University

Melissa Ulas

Melissa.Ulas@temple.edu

Temple University

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Abstract

This study evaluated the association between social determinants of health (SDOH) and diabetic retinopathy (DR) among adults with type 2 diabetes mellitus (T2DM) receiving care at Temple University Health System in Philadelphia. Data was collected from 932 adults using electronic health records between 2019 and 2024. DR status was determined based on retinal imaging. SDOH were evaluated both at an individual level (interpreter use, insurance type, employment status) and community level (Social Vulnerability Index (SVI)). After adjusting for other factors, the links between SDOH, clinical factors, and DR were examined by using multivariate logistic regression. Those with DR (14% of participants) were more likely to use insulin (36% vs 19%, $p < 0.001$), have higher systolic blood pressure (138 vs 131 mmHg, $p < 0.001$), miss more clinic appointments (4.57 vs 3.36, $p = 0.002$), and have worse glycemic control (HbA1c 7.74% vs 7.46%, $p = 0.04$). Also, they were found to have higher glucose levels (195.98 vs 152.06 mg/dL, $p < 0.001$), a lower estimated glomerular filtration rate (68.34 vs 77.30 mL/min/1.73m², $p = 0.048$), higher triglycerides (158.39 vs 137.78 mg/dL, $p = 0.027$), and higher microalbumin-to-creatinine ratios (133.76 vs 47.73, $p = 0.006$). After adjusting for Multivariable logistics regression analysis only missing clinic appointments (aOR 1.12, 95% CI 1.03–1.22, $p = 0.007$) and higher systolic blood pressure (aOR 1.02, 95% CI 1.01–1.04, $p = 0.001$) were found as significant independent predictors. Focusing on clinical risk factors and hindrances to care may improve healthcare engagement and help decrease vision loss and other disparities in diabetes related complications.

Introduction

In Urban settings, diabetes management and its complications are still challenging despite the availability of healthcare services [1]. Although social determinants of health (SDOH) have been associated with diabetic retinopathy (DR), the mechanisms underlying this relationship remain poorly understood [2]. This study examined whether healthcare utilization patterns including missed appointments, completed visits, and hospital or emergency department (ED) use reveal an association between SDOH and DR in an urban population.

People with Type 2 diabetes mellitus (T2DM) have a high risk for DR, which is a significant public health concern on account of being one of the leading causes of preventable microvascular complications and blindness [3–5]. Reduced retinal capillary blood flow, retinal and vitreous hemorrhage, reduced visual acuity, and, ultimately, blindness, are characteristics of DR [6].

DR generally begins with non-proliferative diabetic retinopathy (NPDR), characterized by mild to moderate retinal changes. Without proper management, NPDR can advance to proliferative diabetic retinopathy (PDR), marked by the growth of abnormal blood vessels. Vision-threatening diabetic retinopathy (VTDR) encompasses severe NPDR, PDR, and diabetic macular edema, which affects the central retina and may also involve the fovea, potentially leading to significant vision loss. The International Clinical Diabetic Retinopathy (ICDR) classifies DR into mild, moderate, and severe NPDR, followed by PDR [6, 7].

While regular screening and early treatment can significantly reduce the risk of vision loss from diabetic retinopathy [8], the downside of the disease remains starkly inequitable across populations. Even in urban areas, patients may face many hurdles in controlling diabetes and its complications due to social determinants of health: neighborhood disadvantages, fragmented medical systems, limited access to specialty care, and socioeconomic barriers [9, 10].

Known risk factors for DR include high blood glucose, high blood pressure, kidney disease, and having diabetes for a longer time [11–13]. However, these do not fully explain why some groups are more affected by DR than others. Participation in diabetes care, attendance at eye screenings, and management of risk factors can be influenced by social factors such as unstable insurance coverage, language barriers, employment status, transportation issues, and neighborhood conditions [2, 14]. For urban health systems, it is important to understand these issues as barriers often come from difficulties navigating complex healthcare systems rather than a lack of resources [15].

Philadelphia has a high burden of diabetes, exceeding state and national averages [16, 17], with increased prevalence among young adults and persistent inequities. Temple University Health System (TUHS) serves a diverse urban patient population, making it an important setting to examine the relationship between SDOH and DR. We evaluated whether individual and community-level SDOH were associated with DR among adults with T2DM receiving care within TUHS between 2019 and 2024.

Methods

Study design and population

The design of this study is retrospective observational. Participants included in the study were adults aged ≥ 18 years old with an established diagnosis of T2DM and at least 2 documented retinal imaging examinations during the 5-year study period from 2019 to 2024 [12]. Eligible participants were also required to have a Philadelphia residential ZIP code as well as HbA1c values measured at both initial and follow-up visits.

Participants who had indeterminate retinal imaging evaluations, Type 1 DM, gestational diabetes, or simply missed their initial or follow-up retinal imaging were excluded due to the possibility of confounding variables. In addition, macular degeneration and retinal vein occlusion due to non-diabetic retinal diseases also led to the exclusion of participants to avoid confounding diagnoses [6].

Data source and variables

The data utilized were de-identified electronic medical records of patients in accordance with HIPAA regulations [18]; the Institutional Review Board (IRB #32580) approval was obtained from Temple University. The data was collected from records included demographic characteristics (age, sex, race, ethnicity, primary language, and employment status), clinical measures (i.e., BMI, blood pressure, HbA1c,

creatinine levels), retinal imaging findings, and healthcare utilization indicators (missed appointments, completed visits, and hospitalizations).

The primary outcome was a positive EyeArt reading for more than mild diabetic retinopathy. EyeArt is an FDA-approved AI-assisted screening system that allows classification as either positive or negative for referable diabetic retinopathy from retinal photos; however, it does not determine the stage of diabetic retinopathy [19]. DR is defined as a binary variable indicating either the presence or absence of DR in either eye based on retinal examination findings (International Clinical Diabetic Retinopathy (ICDR) grading) obtained from electronic medical records between 2019 and 2024 [5,11]. The first retinal examination during the study period was used as the initial assessment, and the most recent retinal examination served as the follow-up evaluation over the five-year period.

SDOH were assessed at the individual and community levels of exposure. Employment status, interpreter use, and insurance type variables [2,20] were evaluated at the individual level. The SVI based on ZIP code was evaluated at the community level. To obtain a ZIP-code-level SVI, the U.S. Department of Housing and Urban Development and United States Postal Service (HUD/USPS) ZIP code census-tract crosswalk files [21] were used to identify census tracts of each ZIP code. Then, SVIs for each of these census tracts were obtained from the CDC [22]. These tract-level SVIs were combined using population weights to get ZIP-code-level SVIs [23]. In this study, ZIP-code-level SVIs have been categorized into tertiles: low (<0.33), medium ($0.33-0.66$), and high (>0.66), with lower values representing lower social vulnerability and higher values indicating greater social vulnerability. While an SVI is a percentile-based index that lacks fixed risk cutoffs, said cutoffs are based on prior research [8,9,15].

The study also examined whether healthcare utilization patterns including missed appointments, completed visits, and hospital or emergency department (ED) use mediated the relationship between social determinants of health and diabetic retinopathy. For clinical measures such as HbA1c, lipid levels, kidney function tests (i.e., urine albumin-to-creatinine ratio) and blood pressure measurements, continuous variables were evaluated [10,15]. The first clinical measures during the study period were used as the initial, and the most recent results served as the follow-up metrics over the five-year period. Race, ethnicity, and sex were evaluated as potential effect modifiers to determine whether the associations varied across population subgroups. Additionally, age, smoking status, alcohol use, and comorbid conditions were considered potential confounding factors of this study. Comorbid conditions including hypertension, chronic kidney disease, cardiovascular disease, stroke, depression, and obesity were coded as binary variables indicating either the presence or absence of each condition [9,14].

Statistical Analysis

Data was analyzed using R under version 4.4.2 [24]. Descriptive statistics included demographics, clinical measures, and SDOH characteristics were stratified by DR status. Normality was assessed using the Shapiro–Wilk test, visual inspection of histograms, and Q–Q plots. Categorical variables were compared using appropriate tests such as the chi-square test or the Fisher's exact test [25]. Continuous variables were compared using independent-sample t-tests or Mann-Whitney U-tests based on its

distributional normality [26,27]. Missing data was handled by multiple imputations by chained equations (MICE) [28].

Multivariable logistic regression was used to estimate odds ratios (ORs) and 95% confidence intervals (CIs) for the association between SDOH and DR using pooled estimates [29,30]. Model 1 included SDOH exposures only. Model 2 adjusted for confounders like age, smoking status, alcohol use, and selected comorbidities along with the exposure variables. Model 3 adjusted Model 2 for mediators including healthcare utilization factors and clinical biomarkers. A random-intercept model was fitted to assess clustering by community vulnerability. Interaction terms were evaluated to explore effect modification by sex, race, and ethnicity [14].

Sensitivity analyses included categorizations of SVIs into quartiles and a composite SDOH score. Formal mediation analyses were used to explore whether glycemic control, blood pressure, and/or healthcare utilization might indirectly impact the relationship between SDOH and DR. Model fit was assessed with the Hosmer–Lemeshow test, while discrimination was assessed using the area under the ROC curve (AUC) [31]. Multicollinearity was evaluated using variance inflation factors (VIF). Statistical significance was defined using two-sided p-values less than 0.05.

Results

A total of 932 adults with T2DM met study criteria, 131 of whom (14%) had DR based on either initial assessment or follow-up retinal examination during the study period. Table 1 summarizes the descriptive statistics of demographic, social, clinical, and healthcare utilization characteristics of the cohort by DR status.

Table 1. Participant demographic, social, clinical, and healthcare utilization characteristics by diabetic retinopathy status (N = 932)

Characteristics	Total	DR (No)	DR (Yes)	P-value
	n (%) / M ± SD	n (%) / M ± SD	n (%) / M ± SD	
Sex				0.72
Female	515 (55)	445 (86)	70 (14)	
Male	417 (45)	356 (85)	61 (15)	
Race				0.49
Asian	54 (6)	46 (6)	8 (6)	
African American	533 (57)	450 (56)	83 (63)	
White	121 (13)	106 (13)	15 (11)	
Other	202 (22)	178 (22)	24 (18)	
Unknown	22 (2)	21 (3)	1 (0.8)	
Ethnicity				0.68
Hispanic	198 (21)	174 (22)	24 (18)	
Non-Hispanic	707 (76)	604 (75)	103 (79)	
Others	27 (3)	23 (3)	4 (3)	
Patient Language				0.60
English	818 (88)	697 (87)	121 (92)	
Non-English	113 (12)	103 (11)	10 (8)	
Interpreter Used				0.58
No	853 (92)	731 (86)	122 (14)	
Yes	79 (9)	70 (89)	9 (11)	
Employment Status				0.57
Employed	299 (32)	257 (86)	42 (14)	
Unemployed	203 (22)	181 (89)	22 (11)	
Retired	55 (6)	46 (84)	9 (16)	
Disability	38 (4)	31 (82)	7 (18)	
Others	107 (12)	90 (15)	17 (18)	

Type of Insurance				0.82
Commercial	294 (32)	255 (87)	39 (13)	
Medicaid	217 (23)	187 (86)	30 (14)	
Medicare	380 (41)	324 (85)	56 (15)	
Other	8 (0.9)	6 (75)	2 (25)	
Uninsured	33 (4)	29 (88)	4 (12)	
Social Vulnerability Index				0.56
High	313 (34)	265 (85)	48 (15)	
Medium	283 (30)	242 (86)	41 (15)	
Low	336 (36)	294 (88)	42 (13)	
Smoking Status				0.34
Every Day	114 (12)	101 (89)	13 (11)	
Some Days	39 (4)	34 (88)	5 (13)	
Light Smoker	7 (0.8)	6 (86)	1 (14)	
Former	297 (32)	251 (85)	46 (16)	
Never	452 (49)	391 (87)	61 (14)	
Never Assessed	4 (0.4)	2 (50)	2 (50)	
Alcohol Use				0.97
Yes	303 (33)	260 (86)	43 (14)	
No	365 (40)	316 (87)	49 (13)	
Not Currently	163 (18)	139 (85)	24 (15)	
Never	63 (7)	55 (87)	8 (13)	
Not Asked	6 (0.6)	5 (83)	1 (17)	
Hypertension				0.62
Yes	743 (80)	165 (87)	107 (14)	
No	189 (20)	636 (86)	24 (13)	
Chronic Kidney Disease				0.07
Yes	178 (19)	145 (82)	33 (19)	
No	754 (81)	656 (87)	98 (13)	

Hyperlipidemia				0.99
Yes	763 (82)	656 (86)	24 (14)	
No	169 (18)	145 (86)	107 (14)	
Obesity				0.44
Yes	544 (58)	472 (86)	72 (13)	
No	388 (42)	329 (85)	59 (15)	
Heart Disease				0.046*
Yes	237 (25)	194 (24)	43 (33)	
No	695 (75)	607 (87)	88 (13)	
Stroke				0.74
Yes	82 (9)	69 (84)	13 (16)	
No	850 (91)	732 (86)	118 (14)	
Depression				0.55
Yes	240 (26)	203 (85)	37 (15)	
No	692 (74)	598 (87)	94 (14)	
Initial Medications				<0.001*
Insulin used	196 (21)	149 (19)	47 (36)	
Insulin not used	736 (79)	652 (81)	84 (64)	
Non-Insulin used	744 (80)	640 (80)	104 (79)	0.90
Non-Insulin not used	188 (20)	161 (20)	27 (21)	
Latest Medications				<0.001*
Insulin used	195 (21)	148 (18)	47 (36)	
Insulin not used	737 (79)	653 (82)	84 (64)	
Non-Insulin used	777 (83)	665 (83)	112 (85)	0.60
Non-Insulin not used	155 (17)	136 (17)	19 (15)	
Age (years)	57.48 (10.89)	57.47 (10.83)	57.6 (11.25)	0.88
Total hospital visits	20.87 (14.78)	20.55 (14.8)	22.79 (14.59)	0.06
Total emergency visits	4.4 (5.75)	4.46 (6.03)	4.08 (4.01)	0.63
Total no-show counts	3.53 (3.16)	3.36 (2.97)	4.57 (3.85)	0.002*

HbA1C baseline (%)	7.83 (2.07)	7.79 (2.06)	8.07 (2.13)	0.09
HbA1C latest (%)	7.50 (1.74)	7.46 (1.72)	7.74 (1.85)	0.04*
Latest Creatinine (mg/dl)	1.44 (6.67)	1.11 (1.1)	1.49 (7.22)	0.22
Latest eGFR (mL/min/1.73m²)	75.85 (24.98)	77.3 (23.77)	68.34 (29.65)	0.048*
Latest LDL (mg/dl)	91.92 (34.78)	86.67 (30.28)	92.9 (35.52)	0.208
Latest HDL (mg/dl)	47.21 (13.08)	47.02 (13.29)	47.24 (13.05)	0.88
Latest Triglyceride (mg/dl)	155.29 (116.1)	137.78 (78.71)	158.39 (121.33)	0.027*
Microalbumin/Creatinine (mg/mmol)	61.4 (197.67)	47.73 (156.06)	133.76 (335.41)	0.006*
Latest Glucose (mg/dl)	158.32 (92.05)	152.06 (88.63)	195.98 (103.11)	<0.001*
BMI (kg/m²)	32.95 (7.27)	33.06 (7.97)	32.93 (7.14)	0.869
Diastolic BP (mmHg)	78.91 (10.17)	79.52 (9.13)	78.81 (10.33)	0.38
Systolic BP (mmHg)	132.27 (17.96)	131.3 (17.42)	138.11 (20.05)	<0.001*

Note: Values are presented as n (%) for categorical variables and mean (SD) for continuous variables. P-values for categorical variables were calculated using chi-square tests or Fisher's exact tests, as appropriate. P-values for continuous variables were calculated using independent-sample t-tests for normally distributed variables and Mann-Whitney U tests for non-normally distributed variables. All tests were two-sided. *p < 0.05. Abbreviations: DR, diabetic retinopathy; BMI, body mass index; BP, blood pressure; HbA1c, glycated hemoglobin; eGFR, estimated glomerular filtration rate; HDL, high-density lipoprotein; LDL, low-density lipoprotein.

Participant Characteristics

The following statistics were recorded in relation to demographics: average age is 57.5 years (SD 10.9), 55% of participants were female, 57% of participants identified as Black, and 21% of participants identified as Hispanic. Additionally, variables concerning language and employment status were also considered: while 88% of participants spoke English, 9% of participants had limited English and relied on interpreter services. 32% of participants were employed, 22% of participants were unemployed, and 41% of all participants had Medicare coverage. Community social vulnerability for low (36%), medium (30%), and high (34%) SVIs were recorded respectively, showing evenly distributed SVI categories among participants.

Hypertension (80%), hyperlipidemia (82%), obesity (58%), depression (26%), and heart disease (25%) were common. Participants with DR were more likely than those without DR to have heart disease (33%

vs 24%, $p=0.046$), to use insulin (36% vs 19%, $p<0.001$), and to have more missed clinic appointments (4.57 vs 3.36, $p=0.002$).

In comparison to participants without DR, those with DR had higher follow-up HbA1c values (7.74% vs 7.46%, $p=0.04$), higher glucose levels (195.98 vs 152.06 mg/dL, $p<0.001$), a lower estimated glomerular filtration rate (68.34 vs 77.30 mL/min/1.73m², $p=0.048$), higher triglycerides (158.39 vs 137.78 mg/dL, $p=0.027$), higher microalbumin-to-creatinine ratios (133.76 vs 47.73, $p=0.006$), and a higher systolic blood pressure (138.11 vs 131.30 mmHg, $p<0.001$). Age, race, ethnicity, insurance type, interpreter use, and SVI category did not differ significantly between groups (**Figure 1**).

Multivariate Analysis

Table 2 presents regression results. In unadjusted analyses (Model 1), disability status was associated with higher odds of DR compared with unemployment (OR 2.22, 95% CI 1.03-4.80, $p=0.04$). Insurance type, interpreter use, and SVI category were not significantly associated with DR.

In the primary adjusted model (Model 2), employment status was no longer statistically significant despite disability status remaining associated with higher odds of DR (aOR 2.06, 95% CI 0.93-4.57, $p=0.07$) as well as heart disease approached statistical significance (aOR 1.52, 95% CI 0.97-2.39, $p=0.06$). No significant associations were observed for insurance type, interpreter use, age, smoking, alcohol use, hypertension, chronic kidney disease, depression, obesity, or SVI category.

Table 2. Unadjusted and adjusted logistic regression models evaluating associations with diabetic retinopathy (N = 932)

Predictor	Model 1		Model 2		Model 3	
	OR (95% CI)	p-value	aOR (95% CI)	p-value	aOR (95% CI)	p-value
Interpreter Used						
No	Ref		Ref		Ref	
Yes	0.74(0.36-1.55)	0.42	0.71 (0.33–1.50)	0.36	0.82 (0.37–1.79)	0.61
Insurance Type						
Uninsured	Ref		Ref		Ref	
Private	1.06 (0.35-3.26)	0.91	1.11 (0.36–3.45)	0.86	1.27 (0.39–4.15)	0.69
Public	1.13(0.38-3.36)	0.82	1.14 (0.37–3.48)	0.82	1.09 (0.34–3.51)	0.88
Employment Status						
Unemployed	Ref		Ref		Ref	
Employed	1.30 (0.77-2.21)	0.33	1.37 (0.79–2.38)	0.26	1.50 (0.85–2.64)	0.15
Retired	1.59 (0.72-3.51)	0.25	1.48 (0.62–3.53)	0.38	1.64 (0.66–4.06)	0.28
Disability	2.22 (1.03-4.80)	0.04*	2.06 (0.93–4.57)	0.07	2.12 (0.93–4.83)	0.07
SVI Category						
Low			Ref		Ref	
Medium	1.18 (0.74-1.89)	0.48	1.19 (0.74–1.91)	0.46	1.13 (0.70–1.84)	0.62
High	1.28 (0.82-2.01)	0.28	1.28 (0.81–2.02)	0.29	1.17 (0.73–1.88)	0.52

Age (years)	0.99 (0.97– 1.01)	0.50	0.99 (0.97– 1.01)	0.43
Comorbidities				
No	Ref		Ref	
Hypertension	1.06 (0.74– 1.91)	0.47	0.83 (0.45– 1.50)	0.54
CKD	1.41 (0.87– 2.28)	0.16	1.32 (0.79– 2.22)	0.29
Obesity	0.81 (0.55– 1.19)	0.29	0.81 (0.54– 1.21)	0.30
Heart Disease	1.52 (0.97– 2.39)	0.06	1.39 (0.84– 2.29)	0.20
Depression	1.13 (0.72– 1.78)	0.59	0.96 (0.59– 1.56)	0.87
Smoking status				
No	Ref		Ref	
Everyday	0.75 (0.38– 1.48)	0.41	0.76 (0.38– 1.51)	0.43
Some Days	0.88 (0.35– 2.22)	0.79	0.80 (0.31– 2.08)	0.65
Former	1.03 (0.66– 1.59)	0.91	1.01 (0.64– 1.60)	0.97
Alcohol use				
No	Ref		Ref	
Not Currently	1.06 (0.62– 1.82)	0.85	1.03 (0.59– 1.80)	0.90
Yes	1.31 (0.72– 1.78)	0.59	1.11 (0.70– 1.76)	0.67

Baseline HbA1c (%)	1.03 (0.50– 2.12)	0.93
Latest HbA1c (%)	1.07 (0.52– 2.12)	0.85
Total visits (counts)	1.00 (0.99– 1.02)	0.67
Missed appointments (counts)	1.12 (1.03– 1.22)	0.007*
Systolic BP (mmHg)	1.02 (1.01– 1.04)	0.001*
Diastolic BP (mmHg)	0.99 (0.96– 1.01)	0.24

Note: Model 1 is unadjusted. Model 2 adjusts for age, comorbidities, smoking status, and alcohol use. Model 3 additionally adjusts for clinical and healthcare utilization variables, including HbA1c, total visits, missed appointments, and blood pressure. Abbreviations: OR odds ratio; aOR, adjusted odds ratio; CI, confidence interval; SVI, Social Vulnerability Index; BP, blood pressure; CKD, chronic kidney disease. * $p < 0.05$.

In the fully adjusted model (Model 3), retired status (aOR 1.64, 95% CI 0.66-4.06, $p=0.284$) mildly attenuated the odds of DR but it did not reach statistical significance. Missed appointments (aOR 1.12, 95% CI 1.03-1.22, $p=0.007$) and systolic blood pressure (aOR 1.02, 95% CI 1.01-1.04, $p=0.001$) were associated with higher odds of DR, whereas HbA1c, total visits, diastolic blood pressure, and the primary SDOH measures were not (**Figure 2**). As can be seen from Figure 2, the fully adjusted model revealed that only missed appointments and systolic blood pressure were the independent predictors of diabetic retinopathy, whereas the main social determinants of health were not associated with DR independently.

A random-intercept model showed minimal clustering by community vulnerability, so pooled logistic regression results were retained for interpretation. No statistically significant interactions were observed by sex, race, or ethnicity. In mediation analyses based on Model 2, missed appointments showed the strongest evidence of a possible indirect pathway between social vulnerability and DR, accounting for approximately 17% of the effect (ACME 0.0046, $p=0.056$), whereas glycemic measures, blood pressure, and total visits showed limited mediation. Sensitivity analyses using SVI quartiles and a composite SDOH score did not materially change the findings. For Model 3, model calibration was acceptable based on the Hosmer–Lemeshow goodness-of-fit test ($p=0.52$). Model discrimination was modest (AUC=0.69), and multicollinearity was low (maximum VIF=1.7).

Discussion

Our study included electronic health record data of 932 adults with T2DM. The results of the confounder adjusted regression model demonstrated that individual-level SDOH factors (insurance type, interpreter use, employment status) and community-level measures (ZIP-level Social Vulnerability Index) were not associated with DR. In contrast, the mediator adjusted regression model showed that SDOH may influence DR through indirect pathways like healthcare access, utilization and clinical factors such as systolic blood pressure. This pattern is consistent with the conceptual framework of this study which shows social conditions affecting outcomes through downstream mediators rather than direct biological effects [2, 9]. Also, the study population is already engaged in healthcare, which could be a reason for the indirect effect [10].

A key finding of this study is the significant association between missed clinic appointments and the odds of DR among participants. This supports the ADA guidelines, which recommend annual retinal screening in adults with T2DM to prevent complications [32]. Walker et al. (2014) showed that community-level factors play a major role in the utilization of healthcare resources. Building on this framework, our study suggests that missed clinic visits could be due to underlying structural and social factors like lack of awareness, employment status, and transportation barriers that reduce preventive care and increase risk of complications [14, 15].

Elevated systolic blood pressure was significantly associated with DR, consistent with established biological mechanisms linking hypertension to retinal damage [4, 33]. Hypertension contributes to endothelial dysfunction, retinal ischemia, and vascular damage, accelerating DR progression in T2DM [5, 6]. This aligns with prior studies mentioning hypertension as a major risk factor for DR and ADA guidelines emphasizing BP control in strategies to prevent DR [6, 32]. The latest HbA1c was significant in bivariate analysis; however, it was not significant in multivariate analysis regardless of the adjustments made. This could be due to using HbA1C as a single measurement rather than as a cumulative measure [11, 34].

Strengths of this study are having a large, diverse urban cohort to improve statistical power, improving accuracy by using objective retinal imaging, and the use of a multi-level SDOH framework [16, 17, 23]. The validity of the study is further strengthened using robust statistical methods like multivariate modeling and multiple imputations [28, 30].

Limitations involve a retrospective design that does not establish causality. In addition to the absence of crucial variables such as diabetes duration and medication adherence, we also see limitations in capturing fine-scale neighborhood variation, DR progression over the years, and coinciding laboratory values with eye exam. Furthermore, using ZIP-level SVIs and single health system setting limits the generalization [23].

Conclusion

The study highlights the importance of strengthening care continuity, improving hypertension management, and addressing barriers to routine follow-up visits to reduce disparities in diabetic eye disease. The association between missed appointments and DR, independent of measured SDOH, suggests that care engagement may capture additional patient-level factors not fully reflected by common social vulnerability measures. These factors may include health literacy, self-management skills, trust in the healthcare system, and the ability to navigate care, all of which may overlap with but are not entirely explained by SDOH. To gain a deeper understanding of the relationship between social vulnerability and clinical outcomes, future research should consider broader structural and longitudinal determinants.

Declarations

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Author Contributions:

All authors contributed to study conception and design, interpretation of findings, and critical revision of the manuscript. All authors reviewed and approved the final manuscript. Savitri A. Nandula contributed to study design, performing the study, manuscript drafting, statistical analyses, and drafting manuscript. Melissa Ulas served as principal investigator, contributed to study conception and design, authored and edited the manuscript, and provided overall supervision. Ajay D. Rao mentored the study team and reviewed and edited the draft manuscript. Harris Quach contributed to the study methodology and statistical analysis and revised the manuscript. Yi Zhang contributed to the study design and editing introduction section. Jeffrey Henderer contributed to revising the introduction, discussion, and conclusion sections. John Turella contributed to data collection in honest data broker role.

Ethics approval and consent to participate: This study was conducted in accordance with the principles of the Declaration of Helsinki and was approved by the Temple University Institutional Review Board (IRB #32580) on 8/7/2025. The analysis used de-identified electronic health record data collected in accordance with institutional and ethical requirements.

Consent to Participate: This study was reviewed and approved under an Exempt determination by the Institutional Review Board. A HIPAA waiver of authorization was obtained; therefore, individual informed consent was not required for participation in this retrospective observational study.

Availability of data and materials: The data analyzed in this study were derived from electronic health records and are not publicly available because they contain protected health information. Data may be made available from the corresponding author on reasonable request and subject to institutional, ethical, and legal approvals.

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Figures

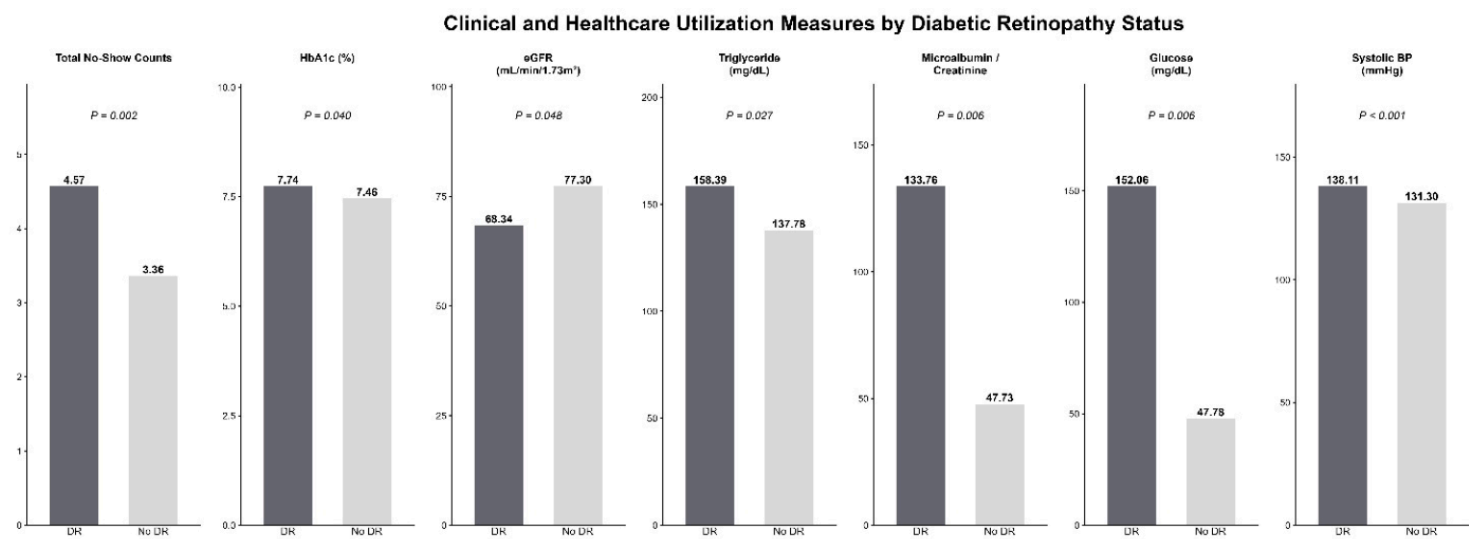


Figure 1

Selected clinical and healthcare utilization characteristics that differed significantly by diabetic retinopathy status in bivariate analyses

Adjusted Predictors of Diabetic Retinopathy (Model 3)

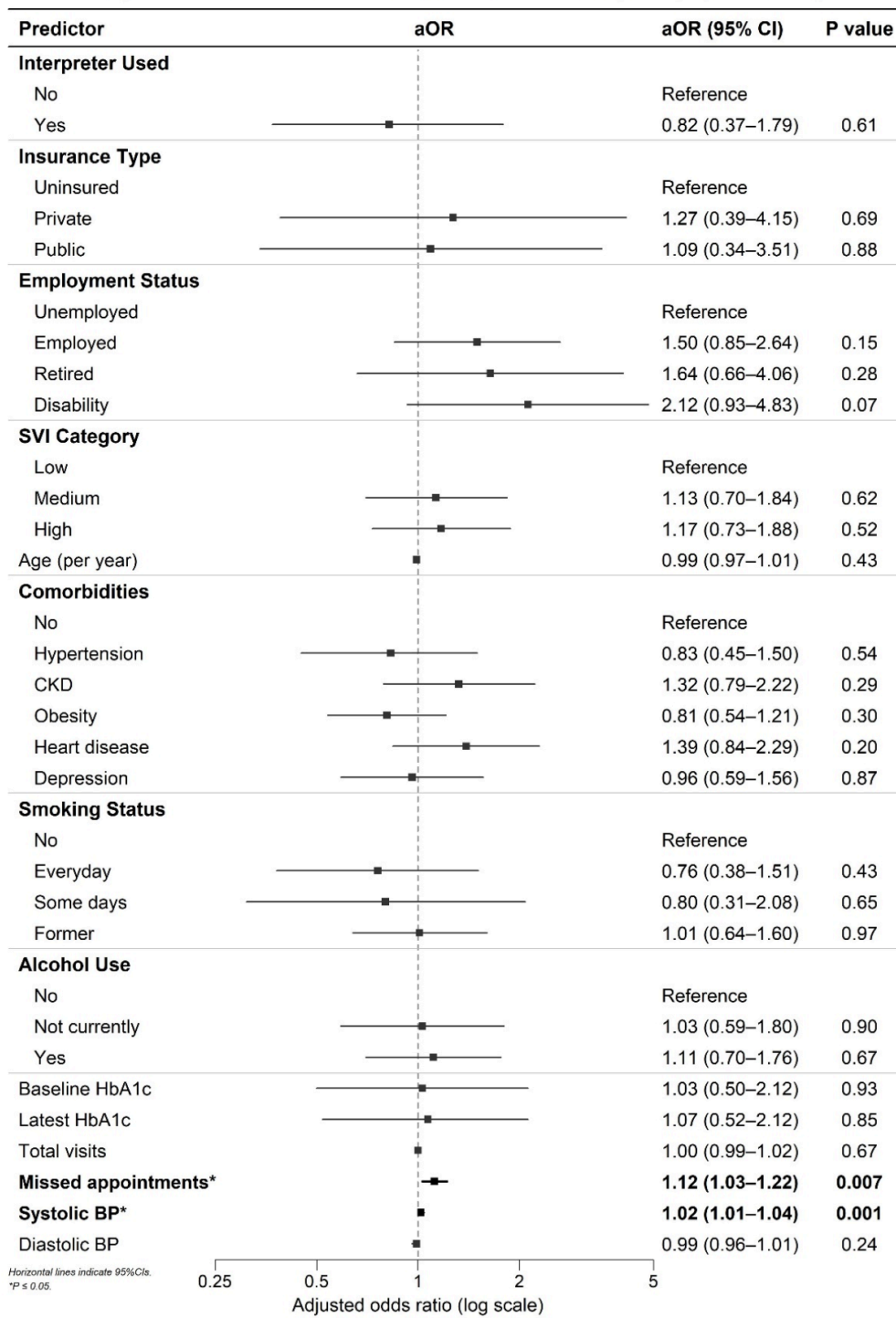


Figure 2

Forest plot of adjusted odds ratios and 95% confidence intervals from the fully adjusted logistic regression model for diabetic retinopathy; statistically significant predictors are highlighted in bold