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Original article

Correlates of prediabetes and type II diabetes in US South Asians: findings from the Mediators of Atherosclerosis in South Asians Living in America (MASALA) study

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ABSTRACT

Purpose: In this study, we aim to elucidate the role of sociodemographic, lifestyle, and cultural factors in prediabetes and diabetes in South Asian immigrants to the United States, a population at high risk of type II diabetes.

Methods: We performed a cross-sectional analysis of a community-based cohort of 899 South Asians without known cardiovascular disease from the Mediators of Atherosclerosis in South Asians Living in America study. Glycemic status was determined by fasting glucose, 2-hour postchallenge glucose, and use of diabetes medication. We used multinomial logistic regression models to estimate the independent associations of sociodemographic, lifestyle, and cultural factors with prediabetes and diabetes, adjusting for confounders identified using directed acyclic graphs.

Results: Approximately 33% of participants had prediabetes and 25% had diabetes. In multivariate analyses, an independent correlate of prediabetes was low exercise. Additional covariates associated with diabetes included lower family income, less education, high chronic psychological burden score, and greater time spent watching television; and fasting monthly or annually was inversely associated with diabetes prevalence.

Conclusions: We found several modifiable risk factors associated with prediabetes and diabetes that may help guide diabetes prevention interventions for South Asian immigrants to the United States.

Introduction

The prevalence of type II diabetes in individuals of South Asian origin is rising [1]. In India alone, there are more than 65 million people with diabetes, making it the country with the second highest number of cases worldwide [2]. South Asians have a higher diabetes prevalence compared to most other racial/ethnic groups [3], as well as more cardiovascular disease (CVD) complications with diabetes [4,5], and a higher mortality rate mainly due to higher rates of CVD [6]. Understanding the drivers of increased diabetes risk in South Asians is important for improving prevention and treatment options for this high-risk population.

South Asians' increased cardiometabolic risk is multifactorial reflecting a mixture of genetic, environmental, and lifestyle factors [7]. Greater visceral adiposity, insulin resistance (IR) and impaired β-cell function are known to contribute to the increased diabetes risk in South Asians [7]. Urbanization and immigration are also contributory factors with an observed gradient of higher diabetes prevalence in urban Indian settings compared with rural areas [8], and even higher diabetes prevalence with immigration to more affluent countries such as the United States and the United Kingdom, which may be attributed to diet and physical activity changes and psychosocial stressors [7]. However, few studies have measured several lifestyle, behavioral, psychosocial, and biologic factors concurrently in immigrant South Asians in the United States (US).

The authors have no conflicts of interest to disclose.

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Less is known about the association between nonbiologic factors and diabetes risk among South Asians. Therefore, we aimed to determine the nonbiologic correlates of prediabetes and type II diabetes in a community-based cohort of middle-aged South Asians in the United States, which is representative of the US South Asian population [9]. We hypothesized that sociodemographic, cultural, lifestyle, and psychological factors would be associated with diabetes in South Asians. Gaining a better understanding of modifiable risk factors for diabetes in US South Asians can help guide the delivery of tailored interventions to decrease their diabetes risk.

Materials and methods

Study design

We performed a cross-sectional analysis of a community-based cohort of South Asians without known CVD from the Mediators of Atherosclerosis in South Asians Living in America (MASALA) study. The MASALA study is modeled on the Multi-Ethnic Study of Atherosclerosis (MESA) study with similar recruitment methods, eligibility criteria, questionnaire, and clinical measurements. Detailed MASALA study methods have been published [9].

Study subjects

To be eligible for the study, participants had to self-report South Asian ethnicity, be between the ages of 40 to 84 years, and be able to speak and/or read English, Hindi, or Urdu [9]. Exclusion criteria included a physician diagnosed heart attack, stroke or transient ischemic attack, heart failure, angina, use of nitroglycerin; a history of cardiovascular procedures (coronary artery bypass graft, angioplasty, valve replacement, pacemaker or defibrillator implantation, or any surgery on the heart or arteries); current atrial fibrillation; active treatment for cancer; life expectancy less than 5 years due to a serious medical illness; impaired cognitive ability; plans to move out of the study region in the next 5 years; living in a nursing home or on a waiting list; and weight greater than 300 lbs [9].

Study subjects were recruited from two clinical sites—the San Francisco Bay Area through the University of California, San Francisco (UCSF) and the greater Chicago area through Northwestern University (NWU). Sampling methods have been reported [9]. Between October 2010 and March 2013, a total of 906 South Asian men and women were enrolled—496 were enrolled at the UCSF site and 410 were enrolled at the NWU site [9].

Study measurements

All participants completed a detailed questionnaire to ascertain sociodemographic information, medical history, family history, medication use, cultural practices, and behaviors [9]. Physical activity was assessed using the Typical Week's Physical Activity Questionnaire [10]. Dietary intake over the previous year was assessed using the Study of Health Assessment and Risk in Ethnic Groups (SHARE) food frequency questionnaire, which was created and validated among South Asians in Canada [11]. Several psychosocial scales were administered including the Spielberger trait anxiety scale [12], the Center for Epidemiologic Studies Depression Scale (CES-D) [13], and one to measure chronic psychological burden [14]. Traditional Indian beliefs were examined using a seven-item scale from prior qualitative research and scored using a Likert scale with higher scores representing weaker traditional beliefs [15].

Clinical measurements

Participant weight was measured on a standard balance-beam scale or digital weighing scale, and height was measured using a stadiometer. Weight and height measurements were used to calculate body mass index (BMI) [9]. Waist circumference was measured using a flexible tape measure at the site of maximum circumference midway between the lower ribs and the anterior superior iliac spine [9]. Abdominal computed tomography (Philips Medical Systems, Andover, MA; Toshiba Medical Systems, Tustin, CA; Siemens Medical Solution, Malvern, PA) was used to determine abdominal visceral and subcutaneous fat area. A trained radiology technician used a lateral scout image of the spine to establish the correct position (between the L4 and L5 vertebrae) for the abdominal computed tomography using standardized protocols [9]. Visceral and subcutaneous abdominal fat were measured at the L4–L5 level using the Medical Image Processing, Analysis, and Visualization (MIPAV) software from the National Institute on Aging of the National Institutes of Health [16]. The subcutaneous compartment is composed of tissue outside the visceral cavity but within the body contour. The muscles in the abdomen were segmented and then omitted from the calculation of subcutaneous fat. Visceral fat was defined as those pixels within the appropriate Hounsfield Unit (HU) range and within the contour of the visceral cavity.

Seated resting blood pressure was measured three times using an automated blood pressure monitor (V100 Vital Signs Monitor; GE Healthcare, Fairfield, CT) with the average of the last two readings being used for analysis [9]. Hypertension was defined as a systolic blood pressure of 140 mm Hg or greater and/or diastolic blood pressure of 90 mm Hg or greater or use of antihypertensive medication.

Blood samples were obtained after a 12-hour fast. Total cholesterol, triglycerides, and high-density lipoprotein cholesterol (HDL-C) were measured using enzymatic methods; and low-density lipoprotein-cholesterol (LDL-C) was calculated. Alanine aminotransferase (ALT) and gamma glutamyl transferase (GGT) were measured using spectrophotometry (Quest Labs, San Jose, CA). Adiponectin and resistin levels were measured using the Millipore Luminex adipokine panel A (EMD Millipore, Billerica, MA). The interassay coefficient of variations (CV) was 2.34% to 4.12% for adiponectin and 3.25% to 5.03% for resistin.

Glucose metabolism measurements

After obtaining fasting blood samples, a 75-g oral glucose load was administered to participants who were not taking diabetes medications, and blood samples were drawn 30 minutes and 2 hours after the glucose challenge. Fasting plasma glucose (FPG) and 2-hour postchallenge glucose were measured using a hexokinase method (Quest Labs, San Jose, CA). Fasting serum samples were batched for insulin, measured by the sandwich immunoassay method (Roche Elecsys 2010; Roche Diagnostics, Indianapolis, IN). The homeostasis model assessment (HOMA)-IR was used to measure IR and calculated as [$\text{Insulin}_0(\mu\text{IU/mL}) \times \text{Glucose}_0$ (mmol/L)/22.5], and HOMA-β was used to measure β-cell function and was calculated as [$20 \times \text{Insulin}_0(\mu\text{IU/mL})/\text{Glucose}_0(\text{mmol/L}) - 3.5$] [17]. We excluded participants taking exogenous insulin from the analyses of HOMA-IR and HOMA-β.

Individuals were categorized with normal glucose tolerance (NGT), prediabetes, or diabetes based on the American Diabetes Association criteria. [18] NGT was defined as having a FPG of less than 100 mg/dL and 2-hour glucose of less than 140 mg/dL; prediabetes was defined as having a FPG of 101 to 125 mg/dL or 2-hour glucose of 140 to 199 mg/dL; and type II diabetes was defined as having a FPG of 126 mg/dL or greater, or 2-hour glucose of 200 mg/dL or greater, or use of medications for diabetes. We had FPG, 2-hour postchallenge glucose, and diabetes medication use information on 899 of the study participants.

Table 1
Baseline characteristics* of MASALA study participants, 2010 to 2013

Characteristic	Normal glucose tolerance, $n = 375$	Prediabetes, $n = 295$	Diabetes, $n = 229$	P value
Sociodemographic measures				
Age (y)	53.4 ± 9.2	55.8 ± 9.6	57.7 ± 8.7	**<.001**
Male sex	174 (46)	170 (58)	139 (61)	**.001**
Clinical site				**<.001**
Northwestern University	130 (32)	168 (41)	111 (27)	
UCSF	245 (50)	127 (26)	118 (24)	
Country of birth				.68
India	310 (41)	252 (34)	190 (25)	
Other South Asian countries	23 (39)	20 (34)	16 (27)	
US and other Diaspora countries	42 (48)	23 (26)	23 (26)	
Years in the US	27 ± 10	27 ± 11	28 ± 11	.32
Religious affiliation				.64
Hindu and Jain	282 (43)	211 (32)	167 (25)	
Sikh	30 (44)	21 (31)	17 (25)	
Islam	19 (30)	26 (41)	19 (30)	
Other	17 (35)	19 (39)	13 (27)	
None	27 (47)	18 (31)	13 (22)	
Level of education				**.02**
≥Bachelor's degree	339 (90)	261 (88)	190 (83)	
Incomes, <$100,000	106 (29)	111 (38)	105 (47)	**<.001**
Behavioral factors and dietary intake				
Total calories (kcal/d)	1695 ± 517	1707 ± 515	1630 ± 472	.19
Carbohydrate, % energy intake	57 ± 5	56 ± 6	56 ± 6	.25
Total protein, % energy intake	15 ± 2	15 ± 2	15 ± 2	.60
Total fat, % energy intake	29 ± 5	29 ± 5	30 ± 6	.30
Dietary pattern				.86
Western diet	123 (33)	99 (34)	72 (32)	
Sweets and refined grains	122 (33)	99 (34)	83 (37)	
Fruits and vegetables	125 (34)	94 (32)	68 (30)	
Current smoking	13 (3)	9 (3)	9 (4)	.40
Alcohol consumption, ≥1 drink/wk	121 (32)	105 (36)	72 (31)	.54
Total exercise (MET-min/wk)	1102.5 (390, 2205)	900 (315, 1575)	810 (315, 1680)	**.006**
TV watching (min/wk)	420 (210, 840)	420 (210, 840)	420 (300, 840)	**<.001**
Psychological measures				
CES-D score	6 (3, 10)	6 (2, 11)	7 (3, 11)	.21
Spielberger anxiety score	16.3 ± 4.3	15.8 ± 4.3	16.2 ± 4.6	.33
Presence of chronic stress	188 (50)	145 (49)	119 (52)	.81
Presence of chronic stress in the last 6 mo	175 (47)	135 (46)	109 (48)	.92
Cultural measures				
Frequency of fasting, ≥1×/mo	64 (17)	62 (21)	36 (16)	.24
Type of food eaten at home				.79
Only and mostly South Asian	195 (52)	159 (54)	128 (56)	
Equally South Asian and other food	151 (40)	118 (40)	83 (36)	
Only and mostly other food	29 (8)	18 (6)	17 (7)	
Cultural traditions scale score	14.4 ± 6.2	14.0 ± 6.1	13.6 ± 6.5	.33
Health and family history				
History of gestational diabetes	15 (8)	11 (9)	14 (16)	.07
Family history of diabetes	158 (43)	155 (53)	155 (69)	**<.001**
Clinical measures				
Body mass index, kg/m^2	25.3 ± 4.4	26.4 ± 4.1	26.8 ± 4.2	**<.001**
Waist circumference, cm	90.0 ± 9.7	94.0 ± 10.2	95.8 ± 10.4	**<.001**
Subcutaneous fat area, cm^2	233 ± 91	232 ± 83	248 ± 110	.12
Visceral fat area, cm^2	117 ± 50	142 ± 55	153 ± 59	**<.001**
Systolic blood pressure, mm Hg	121 ± 15	126 ± 17	129 ± 15	**<.001**
Diastolic blood pressure, mm Hg	72 ± 10	74 ± 10	74 ± 9	**.006**
Hypertension	100 (27)	121 (41)	147 (64)	**<.001**
Total cholesterol, mg/dL	192 ± 35	190 ± 35	176 ± 40	**<.001**
HDL-cholesterol, mg/dL	53 ± 15	49 ± 12	47 ± 12	**<.001**
Triglycerides, mg/dL	108 (77, 143)	124 (95, 159)	131 (95, 179)	**<.001**
LDL-cholesterol, mg/dL	116 ± 31	114 ± 31	99 ± 33	**<.001**
ALT, mg/dL	17 (14, 24)	19 (15, 25)	19 (15, 27)	**.004**
GGT, mg/dL	18 (14, 25)	21 (15, 28)	22 (17, 32)	**<.001**
eGFR, mL/min/1.73 m^2	95.2 ± 19.4	92.3 ± 17.2	93.6 ± 21.5	.15
Adiponectin, ng/mL	11,578 (7496; 16,220)	10,368 (7230; 15,182)	9449 (6013; 13,574)	**<.001**
Resistin, ng/mL	19.5 (16.1, 24.5)	20.7 (16.6, 25.2)	19.8 (16.2, 25.8)	.35
Glucose metabolism measures				
Fasting glucose, mg/dL	91 (86, 94)	101 (94, 106)	120 (107, 145)	**<.001**
2-h postchallenge glucose, mg/dL	104 (89, 120)	147 (122, 162)	223 (208, 253)	**<.001**

(*continued on next page*)

Table 1 (*continued*)

Characteristic	Normal glucose tolerance, $n = 375$	Prediabetes, $n = 295$	Diabetes, $n = 229$	P value
Fasting insulin, pmol/L	50 (36, 70)	70 (48.4, 96)	69.4 (47, 112.9)	**<.001**
2-h postchallenge insulin, pmol/L	394 (253, 684.9)	699 (440.3, 1116)	682.7 (426, 1021.2)	**<.001**
HOMA-IR, (pmol/L*mg/dL)†	1.81 (1.33, 2.63)	2.91 (1.99, 3.98)	3.43 (2.30, 6.00)	**<.001**
HOMA-β, ([pmol/L]/[mg/dL])†	116.2 (79.4, 161.2)	112.4 (76.9, 154.9)	75.8 (52.6, 117.9)	**<.001**

ALT = alanine aminotransferase; CES-D = Centers for Epidemiologic Studies Depression Scale; eGFR = estimated glomerular filtration rate; GGT = gamma glutamyl transferase; HDL = high-density lipoprotein; HOMA = homeostasis model assessment; IR = insulin resistance; LDL = low-density lipoprotein; MET = metabolic equivalent. *P*-values less than 0.05 are in bold.

* Values represent *n* (%) for χ^2 analyses, mean ± SD for analysis of variance and median (25th percentile, 75th percentile) for the Kruskal-Wallis test. *P* values resulted using the χ^2 test, analysis of variance, or Kruskal-Wallis test as appropriate.

† These analyses exclude participants who were using insulin.

Statistical analysis

Characteristics of the MASALA participants were compared by glycemic category using χ^2, analysis of variance, or Kruskal-Wallis tests as appropriate. Variance inflation factors were used to assess collinearity.

We used a directed acyclic graph (DAG) to summarize our prior understanding of the causal relationships between exposures of interest and prediabetes and diabetes. We then analyzed the DAG using an online tool [19] to identify a minimal sufficient adjustment set (MSAS) of confounders for each exposure of interest. Under the causal assumptions encoded in the DAG and provided that the regression model for the outcome is correctly specified, adjusting for an MSAS is sufficient to obtain an unconfounded estimate of the overall effect of each exposure of interest on the outcome, without adjusting away indirect effects via mediators [19,20]. Predictors included a traditional cultural beliefs scale (the base question was "How much would you wish these traditions from South Asia would be practiced in America?" and the seven items included: performing religious ceremonies; serving sweets at ceremonies; fasting on specific occasions; living in a joint family; having an arranged marriage; eating a staple diet of chapatis, rice, dal, vegetable, and yogurt; using spices for health and healing), socioeconomic status (SES; education and family income), fasting and dietary pattern, chronic burden and psychological disorders (depression and anxiety), sedentary behavior (time spent watching television) and physical activity (total exercise in metabolic equivalent-min/wk). Multinomial logistic regression was used to estimate the causal effects of each exposure of interest on pre-diabetes and type II diabetes, adjusting for the exposure-specific MSAS detailed in the Appendix. All models were further adjusted for study site, a strong independent correlate of these outcomes, and a potential marker for unmeasured confounding (Appendix). If nonlinearity was detected in the effects of continuous variables, they were spline or log transformed. For categorical predictors, tests of heterogeneity were performed. The relative risk ratio (RRR) with 95% confidence intervals was used to summarize model results. We used STATA (version 13.1; College Station, TX: StataCorp LP) for our analyses.

Results

Among the 899 participants with categorized glycemic status, the mean age was 55 ± 9 years and 54% were men. Forty-two percent of participants had NGT, 33% had prediabetes, and 25% had type II diabetes. Of those with type II diabetes, 65% had known diabetes and were taking diabetes medications, whereas 35% were newly diagnosed. Baseline characteristics of the study participants by glycemic category are shown in Table 1. Participants with prediabetes and diabetes were older, more likely to be male, be from the NWU site, and have lower SES than those with NGT. Those with prediabetes and diabetes reported less total exercise and a greater number of minutes of watching television per week than those with NGT.

Table 2 shows the independent associations of social, behavioral or lifestyle, psychological, and cultural factors with prediabetes and diabetes estimated using multinomial models adjusting for the MSAS for each factor. Living in the greater Chicago area (Northwestern study site) was associated with a greater prevalence of prediabetes and diabetes after adjusting for age and sex. Compared to never fasting, fasting monthly or annually was associated to a lower prevalence of diabetes ($P = .005$ for test of heterogeneity). Of the socioeconomic variables, lower income (<$40,000 annually) and having less than a bachelor's degree were associated with a greater prevalence of diabetes although the tests of heterogeneity were not statistically significant. Higher chronic psychological burden score was associated with a greater prevalence of diabetes. Of the lifestyle behaviors, we found that exercise was associated with a lower prevalence of prediabetes, whereas greater time spent watching television was associated with a greater prevalence of diabetes. These associations were not modified by country or region of birth.

Discussion

In this cross-sectional analysis of a large community-based cohort of US South Asians without known CVD, there was a high prevalence of prediabetes (33%) and diabetes (25%). In multinomial logistic regression models, lower income, less education, increased chronic psychological burden, and greater time spent watching television were associated with a greater prevalence of prediabetes and diabetes. On the other hand, more exercise and fasting monthly or annually were associated with a lower prevalence of prediabetes and diabetes.

Although the MASALA cohort was recruited from two urban areas in the United States, it is grossly representative of the middle- to older-age South Asian population in the United States when compared to the 2010 US Census. The MASALA cohort was 84% Asian Indian, which is comparable with the 83% reported in the 2010 US Census [9]. There was a somewhat lower proportion of Pakistanis (5% vs. 10.6% in the 2010 Census) and a higher proportion of Bangladeshis and Sri Lankans [9].

The prevalence of diabetes in the MASALA study was 25% (in Asian Indians, 25%; in non-Asian Indians, 26.5%), and diabetes prevalence has ranged from 17.4% to 35.4% in other studies of US South Asians [21,22], considerably higher than the estimated diabetes prevalence of 9.1% in India, 10.3% to 10.4% in South India, and 9.1% in North India [2,23,24]. Compared with other ethnic groups, South Asians have a higher prevalence of prediabetes and diabetes [22,25–27]. Since the MASALA study excluded individuals with CVD, our prevalence estimates may be lower than those in the overall population of middle-older aged US South Asians. Therefore, understanding the risk factors for diabetes in US South Asians is critical.

Table 2
Multivariate analysis—results of multinomial logistic regression

Primary predictor	Prediabetes		Diabetes		Test of heterogeneity (*P* value)
	RRR (95% CI)	*P* value	RRR (95% CI)	*P* value	
Northwestern Univ. site[*]	2.50 (1.82–3.43)	**<.001**	1.79 (1.27–2.53)	**.001**	—
Cultural practices[†,‡,§]	1.04 (0.93–1.15)	.50	0.99 (0.89–1.10)	.84	—
Dietary pattern (reference: Western)[‖]					.97
Sweets and refined grains	1.02 (0.65–1.60)	.93	1.01 (0.62–1.64)	.98	—
Fruits and vegetables	0.93 (0.60–1.44)	.75	0.87 (0.53–1.40)	.56	—
Fasting (reference: never/almost never)[‖]					**.005**
Monthly/annually	0.73 (0.49–1.08)	.12	0.47 (0.30–0.74)	**.001**	—
Weekly	1.40 (0.80–2.48)	.24	0.78 (0.41–1.47)	.44	—
Family income (reference >$100K annually)[¶]					.11
<40K	1.51 (0.87–2.64)	.14	2.34 (1.33–4.11)	**.003**	—
40–75K	1.22 (0.74–2.03)	.44	1.55 (0.92–2.64)	.10	—
75–100K	0.82 (0.48–1.43)	.49	1.04 (0.58–1.86)	.90	—
Education (reference > Bachelor's)[¶]					.26
<Bachelor's	1.11 (0.64–1.90)	.72	1.79 (1.04–3.07)	**.04**	—
Bachelor's	0.92 (0.64–1.33)	.65	1.10 (0.74–1.64)	.63	—
Chronic burden[#]					.46
Burden score 1	0.97 (0.67–1.42)	.89	1.01 (0.67–1.54)	.95	—
Burden score 2	1.22 (0.74–2.04)	.44	1.42 (0.81–2.46)	.22	—
Burden score 3–5	1.47 (0.74–2.91)	.27	2.10 (1.04–4.21)	**.04**	—
Depression[†,‡,#]	1.00 (0.93–1.08)	.98	1.04 (0.96–1.12)	.34	—
Anxiety[†,‡,#]	0.78 (0.60–1.02)	.07	0.83 (0.62–1.10)	.20	—
Exercise (MET-min/wk)[‡,**]	0.81 (0.68–0.97)	**.02**	0.87 (0.72–1.06)	.17	—
TV watching (min/wk)[‡,**]	0.93 (0.77–1.13)	.46	1.23 (1.02–1.49)	**.03**	—

P-values less than 0.05 are in bold.
[*] Adjusts for age and sex.
[†] Per standard deviation.
[‡] RRR reported for 50% increase in log-transformed predictors.
[§] Adjusts for age, sex, site, country of birth, religion, and years in the United States.
[‖] Adjusts for age, sex, site, country of birth, religion, cultural practices, chronic burden, anxiety, depression, income, education, and years in the United States.
[¶] Adjusts for age, sex, site, and cultural practices.
[#] Adjusts for age, sex, site, income, education, years in the United States, religion, and cultural practices.
[**] Adjusts for: age, sex, site, country of birth, religion, cultural practices, chronic burden, anxiety, depression, income, education, years in the United States, dietary pattern, and fasting.

Our study suggests geographic differences in diabetes prevalence among US South Asians. Participants from the Chicago area had higher rates of prediabetes and diabetes than those in the San Francisco Bay Area. Although there were differences in country of birth, religion, SES, and cultural practices between the two study sites [9], this association remained significant after adjusting for these factors. Lifestyle or behavioral and biologic factors did not differ by study site. Further investigations to elucidate the factors contributing to this difference are important.

Lower family income and lower educational attainment were strongly associated with diabetes. This inverse association has been demonstrated in the United States and other developed countries including the United Kingdom (UK), Germany, France, and Canada [28–32]. South Asians in the UK Whitehall Study had higher odds of diabetes (4.2; 95% CI, 3.0–5.8) compared to Caucasians, and SES was found to be an important confounding factor for this difference [33]. On the other hand, studies from South Asia show a positive relationship between SES and diabetes prevalence; a Pakistani study showed that diabetes prevalence was 4.5% in an affluent population compared to 1.8% in a less affluent population, with urbanization and obesity playing mediating roles [34]. A nationally representative survey of residents of urban and rural areas in India demonstrated that those in the richest quintile of household wealth had 2.58 times the odds of self-reported diabetes compared to those in the poorest quintile [35]. The pathways through which lower SES influences diabetes prevalence in US South Asians are likely multifactorial. A conceptual framework developed by Brown et al. [36] found that health care, behavioral, psychological, and contextual (neighborhood) factors linked SES with diabetes risk.

Greater chronic psychological burden was associated with diabetes independent of SES. Higher levels of stress are associated with abnormal glucose metabolism and diabetes in other ethnic groups although the association appears stronger in women than in men in these studies [37,38].

Although we did not find an association between cultural beliefs and diabetes risk, we did find that fasting monthly or annually was associated with a lower prevalence of diabetes compared with never fasting. Studies looking at the effect of fasting on glucose and diabetes risk have been contradictory. In our pilot study, fasting on specific occasions was associated with higher odds of diabetes [15]. And one prospective study of patients with diabetes showed that there was a deterioration in glycemic control when fasting during Ramadan [39]. However, other studies have shown that insulin sensitivity improved in men with the metabolic syndrome who fast during Ramadan [40,41]. Routine periodic fasting (fasting for 24 hours once a month) in a primarily Caucasian population was associated with a lower prevalence of diabetes [42]. It is possible that differences in duration and frequency of fasting differentially impact diabetes risk and understanding what aspects of fasting impact diabetes risk will be important.

Sedentary behavior, measured by greater time spent watching television, was associated with diabetes, whereas exercise was inversely associated with prediabetes. Sedentary lifestyle is a stronger and more important predictor of the high prevalence of diabetes [43]. Although the impact of television watching on diabetes risk in South Asians has not been investigated before, a large prospective study conducted in Europe found that the amount of time spent watching television was an independent predictor of incident diabetes [44]. In addition, South Asian migrants to the United States and United Kingdom often fall below minimum physical activity recommendations, and results from our pilot study showed that US South Asians participated in less exercise compared to Caucasians and African Americans [15,45–47]. Level of physical activity is inversely correlated with blood glucose and insulin

[45,46]. Therefore, culturally tailored interventions to reduce sedentary behavior will likely impact diabetes prevalence in US South Asians.

Indian migrants to the United States have also increased their consumption of processed foods [48], and compared to a European meal, a South Asian meal has more calories and a higher percentage of carbohydrates [49]. Furthermore, total carbohydrate intake, glycemic load, and glycemic index are associated with an increased diabetes risk in South Indians [50]. Interestingly, results from our pilot study found that higher levels of protein intake [51] were associated with higher odds of diabetes, whereas another study found that lower vegetarianism and greater westernization of the diet was associated with a greater prevalence of the metabolic syndrome in South Asian migrants to the United Kingdom [52]. However, neither macronutrient intake nor dietary pattern ("sweets and refined grains" and "fruits and vegetables" patterns being primarily vegetarian) was associated with diabetes in this present study; and therefore, further investigation is needed to determine the impact of diet on diabetes prevalence in US South Asians.

This study has several strengths as it is the largest, deeply phenotyped cohort of migrant South Asians in the United States with standardized clinical and behavioral or lifestyle measures. In addition, robust epidemiologic and statistical methods were used to derive our multivariate models. There are also several notable limitations. As this is a cross-sectional study, causal inferences cannot be determined. The sociodemographic, cultural, and dietary data were obtained through an interviewer administered questionnaire, which may be limited by recall or social desirability bias. In addition, MASALA was not a nationally representative sample although it was grossly representative of the US South Asian population. There was little variability by SES and few participants from each of the South Asian countries which limited subgroup analyses by SES and nativity.

Conclusions

In conclusion, in a large cohort of US South Asians, we found that lower income, less education, increased chronic psychological burden, and more time spent watching television were associated with a higher prevalence of prediabetes and diabetes, whereas exercise and fasting monthly or annually were associated with a lower prevalence. We have identified several modifiable risk factors which can serve as targets for intervention in this high-risk group.

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Appendix. MSAS for each exposure

- Socioeconomic status (income, education): age, sex, site, and cultural practices
- Psychological disorders (depression, anxiety) and chronic psychological burden: age, sex, site, income, education, years in the United States, religion, cultural practices
- Cultural practices and beliefs: age, sex, site, country of birth, religion, years in the United States
- Fasting frequency and dietary pattern: age, sex, site, country of birth, religion, cultural practices, chronic burden, anxiety, depression, income, education, years in the United States
- Sedentary behavior (time spent watching television, decreased physical activity): age, sex, site, country of birth, religion, cultural practices, chronic burden, anxiety, depression, income, education, years in the United States, dietary pattern, fasting