PLOS ONE

RESEARCH ARTICLE

Association between daily sunlight exposure duration and diabetic retinopathy in Korean adults with diabetes: A nationwide population-based cross-sectional study

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Abstract

Purpose

To investigate the association between daily sunlight exposure duration and diabetic retinopathy in Korean adults with diabetes.

Methods

This study used data from the 2008–2011 Korea National Health and Nutrition Examination Survey. Overall, 1,089 patients with diabetes aged >40 years were included. The duration of daily sunlight exposure was assessed via health interviews. Comprehensive ophthalmic evaluations, including standard retinal fundus photography after pupil dilation, were conducted. Diabetic retinopathy was graded using the modified Airlie House Classification. Multivariate logistic regression analysis was performed to analyze the association between daily sunlight exposure duration and the diagnosis of diabetic retinopathy and non-proliferative diabetic retinopathy.

Results

The risk of diabetic retinopathy was 2.66 times higher in the group with ≥5 h of daily sunlight exposure than in the group with less exposure after adjusting for risk factors such as duration of diabetes, serum hemoglobin A1c level, hypertension, and dyslipidemia ($P = 0.023$). Furthermore, the risk of non-proliferative diabetic retinopathy was 3.13 times higher in the group with ≥5 h of daily sunlight exposure than in the group with less exposure ($P = 0.009$). In patients with diabetes for <10 years, the risks of diabetic retinopathy and non-proliferative diabetic retinopathy were 4.26 and 4.82 times higher in the group with ≥5 h of daily sunlight exposure than the group with less exposure, respectively ($P < 0.05$).

Conclusions

This study revealed that sunlight exposure for ≥5 h a day was significantly associated with an increased risk of diabetic retinopathy and non-proliferative diabetic retinopathy in Korean

patients with diabetes. The risks were significantly higher in patients with diabetes for <10 years. Therefore, reducing daily sunlight exposure could be an early preventive strategy against diabetic retinopathy in people with diabetes.

Introduction

Diabetes mellitus is one of the most common chronic metabolic diseases. Because of the high incidence of diabetes worldwide, the management of its chronic complications and glycemic control have become increasingly important. Diabetic retinopathy (DR) is the most common microvascular complication of diabetes and is the leading cause of blindness [1].

According to recent epidemiologic studies on DR in Korea, the prevalence of DR in patients diagnosed with diabetes is 11–19% [2]. The prevalence of severe complications such as severe macular edema and proliferative diabetic retinopathy (PDR) is approximately 5% [2]. Moreover, the risk of DR increased more than 15 times in patients with diabetes for 11 years [2–4].

The main mechanism underlying the development of DR is related to oxidative stress caused by hyperglycemia and also photooxidation of the retina owing to external environmental factors [5]. Previous studies have shown that ultraviolet (UV) radiation can exacerbate DR, especially in patients with diabetic hyperglycemia [6]. As UV radiation is present in sunlight, the amount of UV exposure increases with longer sunlight exposure [7].

In this study, we investigated the relationship between daily sunlight exposure duration and DR in Korean adults with diabetes using data from the Korea National Health and Nutrition Examination Survey (KNHANES). In addition, we analyzed differences in risk based on the duration of diabetes and types of DR. Considering that UV radiation can exacerbate DR and is dependent on the amount of sunlight exposure, we focused on quantitative figures of sunlight exposure duration that could reflect oxidative stress and photooxidation of retina as major causes of DR.

Materials and methods

Study population

This cross-sectional study assessed data from the 2008–2011 KNHANES. The KNHANES is a nationwide population-based survey that is being conducted by the Korean Ministry of Health and Welfare and the Division of Chronic Disease Surveillance of the Korean Centers for Disease Control and Prevention.

Among the 37,753 subjects of the 2008–2011 KNHANES, a total of 2,246 patients were diagnosed with diabetes or treated with oral hypoglycemic agents or insulin. As the incidence of diabetic complications, including DR, tends to be higher among Korean patients with diabetes who are >40 years old than among younger age groups [8], we set the age of >40 years as one of the inclusion criteria. For this study, subjects without data on daily sunlight exposure duration, duration of diabetes, or hemoglobin A1c (HbA1c) levels were excluded. Subjects aged <40 years and who had not undergone a retinal fundus examination were also excluded. Finally, a total of 1,089 subjects were included in the analysis (Fig 1).

All participants provided written informed consent before participation in the study, and the KNHANES was conducted following ethical approval by the Institutional Review Board of the Korea Centers for Disease Control and Prevention (No. 2008-04EXP-01-C, 2009-01CON-

Subjects of the 2008-2011 KNHANES

n = 37,753

Without diabetes, n = 35,507

Subjects diagnosed with diabetes

or currently treated with oral hypoglycemic agents

or insulin

n = 2,246

Without data on daily sunlight exposure duration, diabetes duration, or serum HbA1c level, n = 622

Subjects with data on daily sunlight exposure duration,

diabetes duration, and serum HbA1c level

n = 1,624

Without fundus photographs or aged under 40 years, n = 535

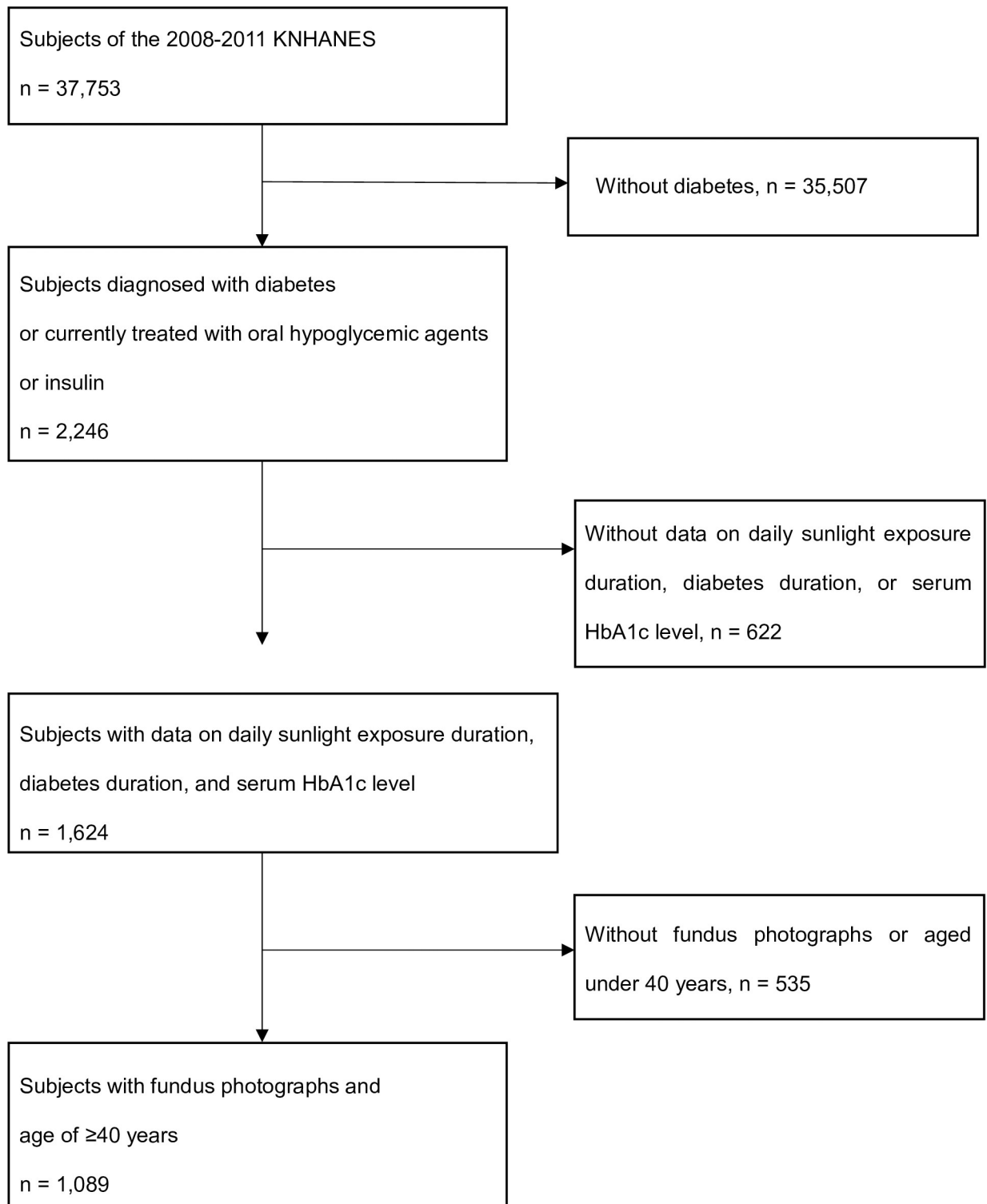Subjects with fundus photographs and

age of ≥40 years

n = 1,089

Fig 1. Flow diagram of the selection of study subjects. KNHANES, Korea National Health and Nutrition Examination Survey; HbA1c, hemoglobin A1c.

https://doi.org/10.1371/journal.pone.0237149.g001

03-2C, 2010-02CON-21-C, and 2011-02CON-06C). The protocol of this study was approved by the Institutional Review Board of Yonsei University, Seoul, Korea (No. 4-2020-0121).

Data collection

Subjects were interviewed by trained staff using standardized health questionnaires on demographic information, medical and drug history, smoking, alcohol intake, daily sunlight exposure duration, etc. Diabetes was defined as a self-report of physician-based diagnosis of diabetes or current treatment with oral hypoglycemic agents or insulin. Hypertension and dyslipidemia were also defined in the same manner with diabetes.

Seven standard photographs of both eyes were taken after pharmacological pupil dilatation according to the protocol of the Early Treatment for Diabetic Retinopathy Study in participants with a history of diabetes, a random blood glucose level of $\geq$200 mg/dL, or suspicious DR findings on nonmydriatic 45˚ digital fundus photographs (TRC-NW6S; Topcon, Tokyo, Japan). Two trained ophthalmologists blinded to the subjects' information analyzed the fundus photographs. DR was identified if any characteristic lesion defined by the Early Treatment for Diabetic Retinopathy Study severity scale was present; these lesions included microaneurysm, hemorrhage, hard exudates, cotton wool spots, intraretinal microvascular abnormalities, venous beading, and development of new vessels (i.e., neovascularization at the disc and neovascularization elsewhere) [9]. DR was further classified into PDR and non-PDR (NPDR). A DR severity score was assigned to each eye according to a modified version of the Airlie House Classification system [10]. DR was defined as having a severity score >14. In particular, PDR was defined as a score >60 and NPDR as a score <60 [10]. As the number of PDR cases from the KNHANES data was very small (n = 17), these cases were excluded from the analysis.

Sunlight exposure duration was assessed using surveys and categorized as <5 h or $\geq$5 h. The duration of diabetes was calculated as the number of years since the patient was diagnosed with diabetes. Body mass index (BMI) was calculated by dividing weight (kg) by the square of height (m^2). Blood pressure was measured three times by an experienced nurse using a sphygmomanometer with the patient in the sitting position; the average of the second and third measurements was used for analysis. Smoking was defined as current, past, or never, whereas monthly alcohol intake was defined as drinking more than once a month during the past year.

Fasting blood glucose, total cholesterol, and triglyceride levels were measured using an automatic analyzer (Hitachi 7600; Hitachi, Tokyo, Japan), and HbA1c levels were measured using an automated glycohemoglobin analyzer (HLC-723G7; Tosoh, Tokyo, Japan). Serum 25-hydroxyvitamin D levels were measured with a radioimmunoassay kit (DiaSorin Inc., Stillwater, MN, USA) using a gamma counter (1470 WIZARD; PerkinElmer Inc., Waltham, MA, USA).

Statistical analysis

The characteristics of the subjects classified according to the presence of DR, PDR and NPDR were expressed as means and standard deviations for continuous variables and as numbers and percentages for categorical variables. They were compared using an independent t-test for continuous variables and a chi-squared test for categorical variables. Differences in daily sunlight exposure duration were evaluated using a chi-squared test based on the presence of DR, PDR and NPDR.

Multivariate logistic regression analysis was performed to analyze the association between daily sunlight exposure duration and the risk of DR and NPDR. Relative risks were estimated in terms of odds ratios (ORs) and 95% confidence intervals (CIs). We adjusted for multiple variables that showed significant associations in the univariate analysis and those based on

clinical relevance. After calculating the crude ORs (Model 1), Model 2 was adjusted for age, sex, duration of diabetes, serum HbA1c level, and BMI. Model 3 was further adjusted for serum 25-hydroxyvitamin D level, hypertension, dyslipidemia, smoking, and alcohol intake. All logistic regression analysis variables were examined for multicollinearity, and only those variables with a variance inflation factor <5 were used. All statistical analyses were performed using IBM SPSS version 25 (Armonk, NY, USA). The level of statistical significance was set at $P < 0.05$, and P values were two-tailed.

Results

Demographic characteristics of the subjects

A total of 1,089 subjects were included in this study (Fig 1). Table 1 shows the demographic characteristics of the subjects according to the DR classification. The prevalence rates of DR, PDR and NPDR were 21.40% (n = 233), 1.56% (n = 17), and 19.83% (n = 216), respectively. The mean age was 63.49 ± 9.33 years, and the number of males was 546 (50.1%).

Serum HbA1c, fasting blood glucose, total cholesterol, and triglyceride levels were higher in the DR and NPDR groups than in the group without any DR or NPDR, whereas BMI and diastolic blood pressure were lower in the DR and NPDR groups (all $P < 0.05$). In addition, the duration of diabetes was longer and hypertension was more prevalent in subjects with DR and NPDR (all $P < 0.05$). However, there were no significant differences in age, serum 25-hydroxyvitamin D levels, systolic blood pressure, dyslipidemia, daily sunlight exposure duration, smoking, and alcohol intake between the two groups (all $P > 0.05$).

Table 2 shows the demographics associated with each variable according to daily sunlight exposure duration. The group exposed to sunlight for ≥5 h a day had 167 males (60.5%) and had higher serum 25-hydroxyvitamin D levels, lower total cholesterol levels, and higher prevalence rates of smoking and alcohol intake than the group exposed to sunlight for <5 h (all $P < 0.05$).

Association between daily sunlight exposure duration and DR

Table 3 shows the ORs and 95% CIs for DR and NPDR according to daily sunlight exposure duration in 1,089 subjects with diabetes aged >40 years. The model was adjusted for age, sex, duration of diabetes, serum HbA1c level, serum 25-hydroxyvitamin D level, BMI, hypertension, dyslipidemia, smoking, and alcohol intake. As a result, the risk of DR was 2.66 times higher in the group with ≥5 h of daily sunlight exposure than in the group with <5 h of exposure (95% CI 1.14–6.21 for Model 3). Moreover, the risk of NPDR was 3.13 times higher in the group with ≥5 h of daily sunlight exposure than in the group with <5 h of exposure (95% CI 1.33–7.40 for Model 3).

Association between daily sunlight exposure duration and DR based on a 10-year duration of diabetes

Table 4 shows the ORs and 95% CIs for DR and NPDR according to daily sunlight exposure duration divided by a 10-year duration of diabetes. Among the 1,089 subjects, 393 (36.1%) were diagnosed with diabetes for >10 years. This model was also adjusted for age, sex, duration of diabetes, serum HbA1c level, serum 25-hydroxyvitamin D level, BMI, hypertension, dyslipidemia, smoking, and alcohol intake.

In patients with diabetes for >10 years, daily sunlight exposure was not significantly associated with the risk for DR or NPDR. However, in patients with diabetes for <10 years, the risk of DR was 4.26 times higher in the group with ≥5 h of daily sunlight exposure than in the

Table 1. Demographic characteristics according to the presence of diabetic retinopathy and proliferative diabetic retinopathy in Korean adults with diabetes.

Characteristic	DR		P value	PDR		P Value	NPDR		P Value	Total (n = 1089)
	No (n = 856)	Yes (n = 233)		No (n = 1072)	Yes (n = 17)		No (n = 873)	Yes (n = 216)		
Age (years)	63.45 ± 9.37	63.65 ± 9.18	0.775	63.53 ± 3.53	61.53 ± 1.53	0.379	63.42 ± 9.36	63.81 ± 9.19	0.570	63.49 ± 9.33
Male (%)	431 (50.4)	115 (49.4)	0.788	537 (50.1)	9 (52.9)	0.816	440 (50.4)	106 (49.1)	0.727	546 (50.1)
BMI (kg/m^2)	24.91 ± 3.34	23.82 ± 2.86	<0.001	24.70 ± 4.70	22.89 ± 2.89	0.034	24.87 ± 3.35	23.89 ± 2.82	<0.001	24.67 ± 3.27
HbA1c (%)	7.20 ± 1.33	8.15 ± 1.62	<0.001	7.39 ± 3.91	8.26 ± 2.61	0.014	7.22 ± 1.35	8.14 ± 1.60	<0.001	7.40 ± 1.45
FBG (mg/dL)	142.85 ± 55.82	165.41 ± 55.84	<0.001	150.33 ± 56.86	165.00 ± 54.86	0.380	137.43 ± 47.51	159.57 ± 53.20	<0.001	141.82 ± 49.46
Vit D (ng/mL)	19.36 ± 9.36	18.81 ± 6.80	0.279	19.28 ± 9.28	16.94 ± 66.53	0.161	19.32 ± 7.11	18.96 ± 6.81	0.497	19.25 ± 7.05
TChol (mg/dL)	180.74 ± 37.82	189.08 ± 44.56	0.004	182.51 ± 82.51	182.94 ± 82.94	0.968	180.78 ± 37.92	189.56 ± 44.66	0.003	182.52 ± 39.48
TG (mg/dL)	163.94 ± 106.57	188.11 ± 88.11	0.017	169.48 ± 69.48	145.06 ± 45.06	0.158	163.58 ± 105.94	191.51 ± 221.65	0.007	169.10 ± 137.11
SBP (mmHg)	126.44 ± 16.82	128.72 ± 28.72	0.075	126.88 ± 26.88	130.39 ± 30.39	0.515	126.52 ± 16.92	128.59 ± 18.89	0.142	126.93 ± 17.34
DBP (mmHg)	74.96 ± 9.87	73.08 ± 10.45	0.015	74.58 ± 10.05	72.98 ± 8.23	0.439	74.92 ± 9.83	73.09 ± 10.62	0.022	74.56 ± 10.02
DM duration (years)	7.47 ± 7.30	12.14 ± 8.77	<0.001	8.36 ± 3.61	15.24 ± 5.24	0.003	7.62 ± 7.46	11.89 ± 8.53	<0.001	8.47 ± 7.87
<10 years	601 (70.2)	95 (40.8)		691 (64.5)	5 (29.4)		606 (69.4)	90 (41.7)		696 (63.9)
≥10 years	255 (29.8)	138 (59.2)		381 (35.5)	12 (70.6)		267 (30.6)	126 (58.3)		393 (36.1)
Hypertension[†]	524 (99.4)	119 (97.5)	0.049	634 (99.1)	9 (100.0)	0.770	533 (99.4)	110 (97.3)	0.034	643 (99.1)
Dyslipidemia[‡]	268 (97.8)	65 (98.5)	0.729	328 (97.9)	5 (100.0)	0.774	273 (97.8)	60 (98.4)	0.799	333 (97.9)
Smoking			0.195			0.331			0.175	
Current	164 (19.2)	54 (23.2)		216 (20.2)	2 (11.8)		166 (19.0)	52 (24.1)		218 (20.0)
Past	242 (28.3)	54 (23.2)		293 (27.4)	3 (17.6)		245 (28.1)	51 (23.6)		296 (27.2)
Never	449 (52.5)	125 (53.6)		562 (52.5)	12 (70.6)		461 (52.9)	113 (52.3)		574 (52.8)
Monthly alcohol intake			0.216			0.286			0.348	
Yes	366 (43.1)	89 (38.5)		450 (42.3)	5 (29.4)		371 (42.8)	84 (39.3)		455 (42.1)
No	484 (56.9)	142 (61.5)		614 (57.7)	12 (70.6)		496 (57.2)	130 (60.7)		626 (57.9)
Daily sunlight exposure			0.741			0.698			0.826	
<5 h	641 (74.9)	172 (73.8)		801 (74.7)	12 (70.6)		653 (74.8)	160 (74.1)		813 (74.7)
≥5 h	215 (25.1)	61 (26.2)		271 (25.3)	5 (29.4)		220 (25.2)	56 (25.9)		276 (25.3)

DR, diabetic retinopathy; PDR, proliferative diabetic retinopathy; NPDR, non-proliferative diabetic retinopathy; BMI, body mass index; HbA1c, hemoglobin A1c; FBG; fasting blood glucose; Vit D, 25-hydroxyvitamin D; TChol, total cholesterol; TG, triglycerides; SBP; systolic blood pressure; DBP, diastolic blood pressure; DM, diabetes mellitus.

Data from the 2008–2011 Korean National Health and Nutrition Examination Survey.

P values were calculated using an independent t-test or chi-squared test.

Continuous variables are expressed as means and standard deviations, and categorical variables are expressed as numbers and percentages.

[†]Hypertension was defined as a self-report of physician-based diagnosis of hypertension or current treatment with antihypertensive medication.

[‡]Dyslipidemia was defined as a self-report of physician-based diagnosis of dyslipidemia or current treatment with antidyslipidemic medication.

group with less exposure (95% CI 1.20–15.16 for Model 3). In the case of NPDR, when the duration of diabetes was <10 years, the risk of NPDR was 4.82 times higher in the group with ≥5 h of daily sunlight exposure than in the group with less exposure (95% CI 1.32–17.59 for Model 3).

Discussion

This cross-sectional study of data from the 2008–2011 KNHANES showed that a longer sunlight exposure of ≥5 h increased the risk of DR and NPDR in Korean patients with diabetes. In particular, a duration of diabetes of <10 years was associated with higher risks of DR and

Table 2. Demographic characteristics according to daily sunlight exposure duration in Korean adults with diabetes.

Variable	Daily Sunlight Exposure Duration		P Value
	<5 h (n = 813)	≥5 h (n = 276)	
Age (years)	63.65 ± 9.44	63.03 ± 8.97	0.329
Male (%)	379 (46.6)	167 (60.5)	<0.001
BMI (kg/m^2)	24.75 ± 3.28	24.45 ± 3.24	0.184
HbA1c (%)	7.40 ± 1.46	7.39 ± 1.41	0.924
FBG (mg/dL)	140.65 ± 48.47	145.26 ± 52.19	0.181
Vit D (ng/mL)	18.70 ± 7.01	20.87 ± 6.92	<0.001
TChol (mg/dL)	184.15 ± 40.15	177.67 ± 37.07	0.018
TG (mg/dL)	171.38 ± 145.69	162.35 ± 107.79	0.345
SBP (mmHg)	127.10 ± 17.09	126.43 ± 18.06	0.588
DBP (mmHg)	74.65 ± 9.91	74.27 ± 10.36	0.594
DM duration (years)	8.47 ± 7.90	8.46 ± 7.78	0.980
<10 years	516 (63.5)	180 (65.2)	
≥10 years	297 (36.5)	96 (34.8)	
Hypertension[†]	492 (99.2)	151 (98.7)	0.572
Dyslipidemia[‡]	273 (98.2)	60 (96.8)	0.474
Smoking			0.005
Current	145 (17.9)	73 (26.4)	
Past	220 (27.1)	76 (27.5)	
Never	447 (55.0)	127 (46.0)	
Monthly alcohol intake			0.008
Yes	320 (39.8)	135 (48.9)	
No	485 (60.2)	141 (51.1)	
DR	172 (21.2)	61 (22.1)	0.741
PDR	12 (1.5)	5 (1.8)	0.698
NPDR	160 (19.7)	56 (20.3)	0.826

BMI, body mass index; HbA1c, hemoglobin A1c; FBG; fasting blood glucose; Vit D, 25-hydroxyvitamin D; TChol, total cholesterol; TG, triglycerides; SBP; systolic blood pressure; DBP, diastolic blood pressure; DM, diabetes mellitus; DR, diabetic retinopathy; PDR, proliferative diabetic retinopathy; NPDR, non-proliferative diabetic retinopathy.

Data from the 2008–2011 Korean National Health and Nutrition Examination Survey.

P values were calculated using an independent t-test or chi-squared test.

Continuous variables are expressed as means and standard deviations, and categorical variables are expressed as numbers and percentages.

[†]Hypertension was defined as a self-report of physician-based diagnosis of hypertension or current treatment with antihypertensive medication.

[‡]Dyslipidemia was defined as a self-report of physician-based diagnosis of dyslipidemia or current treatment with antidyslipidemic medication.

NPDR in the group that was exposed to sunlight for ≥5 h than in the group that was exposed to sunlight for <5 h.

To our knowledge, this is the first study to confirm a direct association between sunlight exposure duration and DR. In this study, serum 25-hydroxyvitamin D levels were significantly higher in patients with daily sunlight exposure of ≥5 h than in those with less exposure. The risks of DR and NPDR also increased in patients exposed to sunlight for ≥5 h. These findings suggest that in addition to the effects of serum 25-hydroxyvitamin D on DR, sunlight exposure may affect DR in other ways.

Oxidative stress is thought to be a major cause of the pathogenesis of DR [5]. As the retina is the most metabolically activated tissue in the body, it is easily affected by diabetic conditions and is vulnerable to oxidative stress [11]. Exogenous sources of oxidative stress include

Table 3. Unadjusted and adjusted odds ratios and 95% confidence intervals for diabetic retinopathy and non-proliferative diabetic retinopathy according to daily sunlight exposure duration in Korean adults with diabetes.

Multivariate Model	Model 1 OR (95% CI)	Model 2 OR (95% CI)	Model 3 OR (95% CI)
DR			
Sunlight exposure <5 h	Reference	Reference	Reference
Sunlight exposure ≥5 h	2.33 (1.09–4.97) *P* = 0.029	2.63 (1.14–6.09) *P* = 0.024	2.66 (1.14–6.21) *P* = 0.023
NPDR			
Sunlight exposure <5 h	Reference	Reference	Reference
Sunlight exposure ≥5 h	2.74 (1.27–5.92) *P* = 0.010	3.13 (1.34–7.32) *P* = 0.008	3.13 (1.33–7.40) *P* = 0.009

OR, odds ratio; CI, confidence interval; DR, diabetic retinopathy; NPDR, non-proliferative diabetic retinopathy.

Data from the 2008–2011 Korean National Health and Nutrition Examination Survey.

Model 1 was crude.

Model 2 was adjusted for age, sex, duration of diabetes, hemoglobin A1c level, and body mass index.

Model 3 was adjusted for serum 25-hydroxyvitamin D level, hypertension, dyslipidemia, smoking, and alcohol intake in addition to the variables adjusted in Model 2.

https://doi.org/10.1371/journal.pone.0237149.t003

environmental toxins such as UV radiation from sunlight and smoke [5]. Especially during sunlight exposure, UV A light (wavelength 320–400 nm) is absorbed by the eyes, passing through all optic media to produce reactive oxygen species and cause mitochondrial dysfunction, DNA damage, and apoptotic activity of retinal pigment epithelial cells. These conditions can eventually lead to irreversible cellular necrosis of the retina [12–16]. The accumulation of reactive oxygen species can also damage blood vessels surrounding the retina, causing retinal capillary apoptosis, hypoxia, and neovascularization [17–20]. Therefore, reducing sunlight exposure by wearing protective equipment such as sunglasses can be a useful, inexpensive, and convenient way to prevent DR by reducing phototoxicity (photooxidation damage) and

Table 4. Unadjusted and adjusted odds ratios and 95% confidence intervals for diabetic retinopathy and non-proliferative diabetic retinopathy according to the daily sunlight exposure duration divided by the duration of diabetes in Korean adults.

Multivariate Model	Model 1 OR (95% CI)	Model 2 OR (95% CI)	Model 3 OR (95% CI)
Diabetic duration <10 years			
DR			
Sunlight exposure <5 h	Reference	Reference	Reference
Sunlight exposure ≥5 h	2.18 (0.75–6.33) *P* = 0.150	3.58 (1.08–11.88) *P* = 0.037	4.26 (1.20–15.16) *P* = 0.025
NPDR			
Sunlight exposure <5 h	Reference	Reference	Reference
Sunlight exposure ≥5 h	2.37 (0.81–6.95) *P* = 0.115	3.86 (1.14–13.02) *P* = 0.030	4.82 (1.32–17.59) *P* = 0.017
Diabetic duration ≥10 years			
DR			
Sunlight exposure <5 h	Reference	Reference	Reference
Sunlight exposure ≥5 h	1.26 (0.64–2.50) *P* = 0.507	1.09 (0.53–2.25) *P* = 0.825	1.20 (0.56–2.60) *P* = 0.636
NPDR			
Sunlight exposure <5 h	Reference	Reference	Reference
Sunlight exposure ≥5 h	1.32 (0.66–2.65) *P* = 0.440	1.16 (0.56–2.40) *P* = 0.691	1.21 (0.55–2.62) *P* = 0.638

OR, odds ratio; CI, confidence interval; DR, diabetic retinopathy; NPDR, non-proliferative diabetic retinopathy.

Data from the 2008–2011 Korean National Health and Nutrition Examination Survey.

Model 1 was crude.

Model 2 was adjusted for age, sex, duration of diabetes, hemoglobin A1c level, and body mass index.

Model 3 was adjusted for serum 25-hydroxyvitamin D level, hypertension, dyslipidemia, smoking, and alcohol intake in addition to the variables adjusted in Model 2.

https://doi.org/10.1371/journal.pone.0237149.t004

oxidative stress on the retina. According to a previous study, wearing sunglasses with yellow UV light protective lenses can block short wavelengths of light in patients with diabetes, reduce scatter, and increase contrast, resulting in an improved subjective vision [21]. Furthermore, a study on cataracts showed that proper UV-filtering glasses can prevent the progression of photo-induced lens damage in patients with pre-cataractous molecular changes in the lens [22, 23].

Our study also suggests the importance of early prevention of DR in patients with diabetes. We found that the risk of DR from exposure to UV radiation was higher in patients diagnosed with diabetes for <10 years. The exact mechanism is unknown. However, previous studies [24–26] showed a high incidence of microvascular complications, including DR, in patients who had diabetes for <10 years. The increased incidence was due to lower medication compliance, poor glycemic control, and a lower rate of complication screening, which are consistent with our findings. Therefore, DR prevention is very important in patients with diabetes.

This study had some limitations. First, this was a cross-sectional study, so it could not assess the causal relationship between daily sunlight exposure duration and DR. A prospective longitudinal study with a large sample must be conducted to verify this relationship. Second, a self-reported questionnaire was used to assess the duration of sun exposure during the day, which served as our basis for measuring UV exposure. There may be differences in the absorption of sunlight among different races and factors such as frequency of UV exposure, the use of sun protection, occupation, season, and latitude [27]. Therefore, further studies with quantitative methods for measuring the degree of UV exposure are required.

Nevertheless, this is the first study to quantitatively investigate the association between sunlight exposure duration and DR in patients with diabetes. By presenting environmental factors, we suggest that sunlight exposure could be a novel risk factor for DR and provide an important theoretical basis for various treatments and preventive approaches for DR. The importance of early prevention, by reducing sunlight exposure, is also suggested because of the increased risk of DR even in patients with a relatively short duration of diabetes, based on our findings. The implications of our findings could be further developed in future prospective and longitudinal studies.

In conclusion, this quantitative cross-sectional analysis of data from the 2008–2011 KNHANES revealed that longer sunlight exposure in patients with diabetes aged >40 years was associated with higher risks of DR and NPDR. The risks of DR and NPDR were particularly higher by 2.66 and 3.13 times, respectively, in the group with daily sunlight exposure of ≥5 h than in the group with less sunlight exposure (P = 0.023 and 0.009). Additionally, even if the duration of diabetes was <10 years, the risks of DR and NPDR were higher by 4.26 and 4.82 times, respectively, in patients exposed to sunlight for ≥5 h daily than in those exposed to sunlight for <5 h daily ($P < 0.05$). Hence, reducing the daily levels of sunlight exposure could be an early preventive strategy against DR in individuals with diabetes.

Author Contributions

Conceptualization: Hye Jun Lee, Choon Ok Kim, Duk Chul Lee.

Data curation: Hye Jun Lee, Choon Ok Kim.

Formal analysis: Hye Jun Lee, Choon Ok Kim.

Investigation: Hye Jun Lee.

Methodology: Hye Jun Lee.

Project administration: Choon Ok Kim, Duk Chul Lee.

Supervision: Choon Ok Kim, Duk Chul Lee.

Visualization: Hye Jun Lee.

Writing – original draft: Hye Jun Lee.

Writing – review & editing: Choon Ok Kim, Duk Chul Lee.

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