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Income and risk of type 2 diabetes incidence varied associations according to obesity status: a nationwide study

Jee Hee Yoo^{1†}, You-Bin Lee^{2*†} , Ji Eun Jun³, Kyu-Na Lee⁴ and Kyungdo Han^{5*}

Abstract

Background We investigated the association between income parameters and the risk of type 2 diabetes (T2D) influenced by obesity.

Methods We analyzed the Korean National Health Insurance Service data (2002–2022), including 3,462,002 adults (aged ≥ 30 years) without diabetes who underwent health examinations in 2012. Income status was assessed annually from 2008 to 2012, and sustained income status was defined as maintaining the same income category for all five consecutive years. Hazard ratios (HRs) for incident T2D were estimated according to income parameters, and stratified by obesity status and BMI categories.

Results During a mean follow-up of 8.73 years, 447,688 T2D cases were identified. Individuals with sustained very low-income (multivariable adjusted HR: 1.599; 95% CI: 1.556–1.642) had a higher hazard of T2D than those who had never been in this condition. These associations were stronger in participants without obesity, particularly those with underweight (HR: 2.223; 95% CI: 1.919–2.574 for sustained very low-income; p for interaction < 0.0001). Conversely, a reduced T2D hazard associated with sustained high-income (HR: 0.886; 95% CI: 0.880–0.893) and an increased hazard associated with high income variability (HR: 1.108; 95% CI: 1.098–1.117) were more pronounced in individuals with obesity (p for interaction < 0.0001).

Conclusion Low-income had a greater impact on incident T2D risk among individuals without obesity, whereas among those with obesity, the lower risk observed in sustained high-income groups and the adverse effect of income variability were more pronounced.

Keywords Adult, Cohort study, Diabetes mellitus, Type 2, Income, Obesity, Socioeconomic factor

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Background

Globally, type 2 diabetes (T2D) is one of the most significant causes of mortality and morbidity [1] and is also closely related to increased use of medical care and expenditures [2, 3]. Owing to its high prevalence and projected increase in prevalence [4], it is anticipated that the financial costs associated with T2D would rise further. Therefore, as an important global public health issue, identifying populations at high risk of T2D for whom preventive strategies should be concentrated is crucial.

The risk of T2D is influenced by various parameters, including social and environmental factors, collectively expressed as social determinants of health (SDOH) [5].

Income status is a key aspect of SDOH [5]. In previous studies, a low-income state and income decline were associated with excess T2D risk, whereas sustained high-income and income rise were related to a lower risk of T2D [6, 7].

Income status is closely related to obesity status, including the risk of underweight, overweight, or obesity [8, 9]. Furthermore, a systematic review and meta-analysis revealed significant associations between lower-income and the risk of obesity, as well as between obesity and subsequent income. This indicates a possible bidirectional link between social causation and reverse causality processes [10]. Additionally, the risk of T2D varies unequivocally with obesity status and having overweight or obesity pose significant increased risk [11]. Considering the potentially complicated links between the aforementioned factors, it is likely that the association between income status and T2D risk may be related to the obesity status. Nevertheless, the association between income and T2D risk in relation to obesity status categorized by body mass index (BMI) remains unclear.

Therefore, we aimed to determine the longitudinal associations between low- and high-income status and the risk of incident T2D, assessed both cross-sectionally and cumulatively using serial income measures over 5 years. We also examined whether the association between income parameters and incident T2D risk differed according to obesity status, as defined by BMI categories, among Korean adults without a prior history of T2D.

Methods

Data sources

We analyzed the data from the Korean National Health Insurance Service (KNHIS) from January 2002 to December 2022. The KNHIS, operated by the Korean government, is the sole nationwide insurer. This insurer provides coverage to all residents in Korea through two programs: the National Health Insurance (NHI), which covers approximately 97% of the population, and Medical Aid (MA), which supports the remaining 3% with the

lowest-income [12, 13]. The KNHIS constructs a public database by consolidating medical treatments, health-screening records, and eligibility data [14]. This comprehensive database includes demographics, monthly health insurance premiums determined by income status, residential region, diagnoses according to the International Classification of Diseases-10th Revision (ICD-10), prescription details, medical procedures, dates of hospital visits, and admissions for all residents of Korea, as well as dates of death for the deceased. Additionally, the KNHIS administers a nationwide health screening program, advocating standardized health examinations at least every 2 years. These health examinations, conducted exclusively by KNHIS-accredited hospitals, are also integrated into the database. The recorded data includes smoking and alcohol consumption history, physical activity metrics, height, weight, waist circumference, blood pressure, fasting plasma glucose (FPG) level, lipid profile, and estimated glomerular filtration rate (eGFR). A detailed description of this database is available in previous publications [12–14].

The study protocol was approved by the Institutional Review Board (IRB) of the Samsung Medical Center (SMC 2023-11-025). This study utilized anonymized public data that had already been secured for other purposes and only involved reviewing this anonymized database without any additional interventions. Thus, it falls under the category of minimal risk research with no additional risk to the subjects. Furthermore, the researchers received data from the KNHIS with all personal identification information removed, making it impossible to identify the participants included. As such, given that the data provided by the KNHIS was anonymized, the requirement for informed consent was waived by the IRB. After obtaining IRB approval, we accessed the data under the permission of the KNHIS for a limited period of utilization. All methods were performed in accordance with the relevant guidelines and regulations.

Study cohort, outcomes, and follow-up

This was a nationwide population-based longitudinal cohort study. Using systematic stratified random sampling with proportional allocation in each stratum, a sample cohort representing 40% of all adults (aged ≥ 20 years) who underwent at least one health examinations in 2012 was selected. The stratifications were based on age and sex. In this sample population, only individuals aged ≥ 30 years were selected to exclude economically inactive young adults. The timepoint of the health examination in 2012 was considered the baseline. We excluded individuals with any missing variable to assess household income status; those who had FPG ≥ 126 mg/dL or prescriptions for antidiabetes medication or claims under ICD-10 codes E11-14 at or before baseline; those with

missing data for at least one other variable; and those who died or developed T2D within a year after baseline data collection (Fig. 1).

The end point was incident T2D, which was defined as at least one claim per year for the prescription of anti-diabetes medication under ICD-10 codes E11–14 or having a FPG ≥ 126 mg/dL [15–17]. Follow-up data were collected from baseline until the date of outcome development, death, or December 31, 2022, whichever occurred first.

Assessment of income status

Each year, the KNHIS assesses the household income of all enrollees and designates the lowest-income individuals (bottom 3%) for enrollment in the MA. For the remaining 97% covered by the NHI, the monthly health insurance premium in each year is determined by household wage income (for employees insured) or by income and household property value (for the self-employed insured), making it a useful proxy for household income status [6, 18]. Low-income status included MA beneficiary individuals or those having health insurance premiums in the lowest quartile for a given year. Very low-income status was defined as qualifying as an MA recipient. High-income status was defined as having health insurance premiums in the highest quartile, and the very high-income group as those in the top 5% for a given year. To determine the prebaseline income status, income was assessed from the baseline year (2012) and preceding 4 years (until 2008) [18]. For income parameters, including the cumulative number of years in very low-, low-, or high-income status; income variability; and baseline income status, were used. Thus, sustained income status was defined as maintaining the same income category for

all five consecutive years. Parameter definitions as per previous studies [18] are summarized in Additional file 1: Table S1.

Measurements and definitions

Smoking/alcohol consumption history and physical activity data were collected using questionnaires. Venous samples drawn after overnight fasting, were used for blood tests, including FPG and lipid profiles. eGFR was calculated using the Chronic Kidney Disease Epidemiology Collaboration Eqs. [19, 20]. Definitions of BMI, abdominal obesity, alcohol consumption status, regular exercise, hypertension, dyslipidemia, and chronic kidney disease (CKD) are presented in Additional file 1: Table S2.

Statistical analysis

Statistical analyses were performed using the SAS software (version 9.4; SAS Institute, Cary, NC, USA). Two-sided p -values < 0.05 were considered significant. Baseline characteristics are presented according to income parameter groups. We depicted continuous variables with normal distributions as mean $\pm$ standard deviation, those with non-normal distributions as geometric means [95% confidence intervals (CIs)], and categorical variables as frequency (percentage).

The incidence rates of T2D were determined by the number of incident cases divided by the total follow-up duration (person-years). Multivariable Cox regression analysis was used to calculate the hazard ratios (HRs) and 95% CIs for the incidence of T2D in the groups of income parameters. Model 1 was unadjusted (crude model); Model 2 was adjusted for age, sex, and residential area (metropolitan, urban, and rural areas); and Model

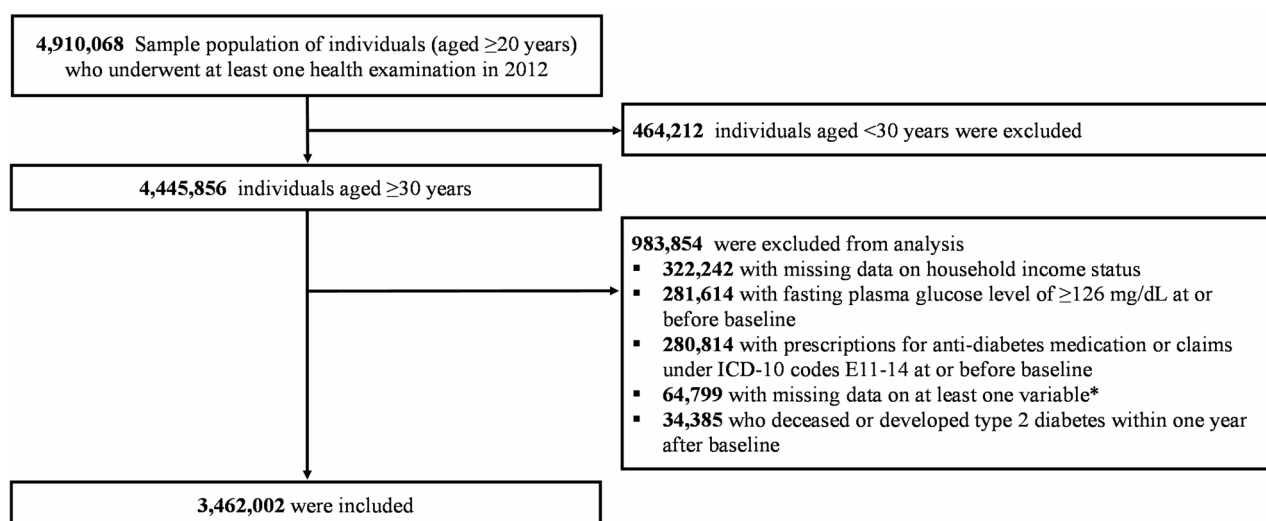


Fig. 1 Flow chart depicting the study population.*At least one variable indicates one or more of the following variables: region, fasting plasma glucose, body mass index (height and weight), waist circumference, lifestyle factors (smoking status, alcohol consumption, regular exercise), blood pressure, lipid profile (total cholesterol, high-density lipoprotein cholesterol, low-density lipoprotein cholesterol, triglycerides), liver enzymes, and serum creatinine

3, in addition to the variables included in Model 2, was adjusted for BMI, smoking history, alcohol consumption, regular exercise, FPG, presence of hypertension, dyslipidemia, and CKD. To examine the potential effect modification by the presence of obesity (defined as a $\text{BMI} \geq 25 \text{ kg/m}^2$) [21] and categories of BMI in detail, the HRs (95% CIs) of T2D incidence according to the groups of income parameters were estimated after stratifying the study population by the BMI categories, and p for interaction was calculated.

Results

Baseline characteristics

A total of 3,462,002 individuals (aged ≥ 30 years) without diabetes mellitus at baseline were included in this study (Fig. 1). Among them, during the 5 years (2008–2012), 2,309,458 (66.7%) had never been in a low-income status, while 234,248 (6.8%) had been consistently in the low-income status. Baseline characteristics are presented according to the cumulative number of years of very low-, low-, high, or very high-income status (Table 1). Compared to individuals who had never been in very low- or low-income status, those who had ever been in very low- or low-income states were more likely to be female, having higher eGFR levels, and were less likely to have CKD. As the cumulative number of years in the very low- or low-income status advanced, while an increasing trend toward the proportions of those who were underweight ($\text{BMI} < 18.5 \text{ kg/m}^2$) [22], never smokers, and non-drinkers was noted, a trend of decrease was noted in the proportion of alcohol consumers (heavy drinkers and mild to moderate drinkers). Individuals being in very low-income status for longer duration were more likely to have class II or III obesity ($\text{BMI} \geq 30.0 \text{ kg/m}^2$) [22] and abdominal obesity, and were less likely to exercise regularly. Furthermore, as the cumulative duration of high and very-high-income status increased, trends toward an increase were observed in the proportion of men, those categorized in class I obesity ($\text{BMI} 25\text{--}29.9 \text{ kg/m}^2$) [22], ex-smokers, mild to moderate drinkers, those exercising regularly, and those with CKD. Conversely, individuals with a longer duration of high-income status were less likely to be current smokers, underweight, or have class II or III obesity.

Groups of income parameters and T2D incidence

During a mean follow-up period of 8.73 years (30,213,293 person-years), the cohort had 447,688 cases of T2D (12.9% of the study participants). A significant dose-response relationship was observed across baseline income percentiles, with a monotonic increase in the hazard of type 2 diabetes toward the lowest income categories (p for trend < 0.001 , Table S3 and Fig. S1). The accumulated number of years of very low- or low-income

status was significantly associated with an increased hazard of T2D; the increase being dose-responsive (Table 2). Compared to individuals who had never been in the very low- or low-income status (reference), the highest hazards were demonstrated in those with sustained very low- or low-income status for 5 years [Model 3, HR (95% CI): 1.599 (1.556–1.642) in those with sustained very low-income and 1.148 (1.136–1.160) in those with sustained low-income status]. In contrast, individuals with consecutive high-income status for 5 years had an 11.3% lower hazard of T2D incidence (Model 3, 95% CI 0.880–0.893). Similar findings were observed among those in the very-high-income status. With respect to baseline status, when individuals in the high-income status were used as a reference, those in lower-income status were seen to be associated with increased hazards of T2D [HR, 1.678 (95% CI, 1.640–1.717) among MA beneficiaries]. Likewise, higher income variability was also associated with increased hazards of T2D [Model 3, Q1 vs. Q4 for SD: HR 1.108 (95% CI 1.098–1.117)] (Table S4).

Similar results were observed in individuals aged < 65 and ≥ 65 years (Table S5 and S6).

Stratified analyses according to obesity status and BMI categories

We further investigated the association between various income parameters and the hazards of T2D after stratifying the study population according to the presence of obesity (Fig. 2, Table S7). Regardless of the presence of obesity, increased hazard of T2D in individuals with higher cumulative durations of very-low-income status was consistently observed. Thus, individuals with obesity and sustained very-low-income status demonstrated the highest hazard [0 years without obesity vs. 5 years with obesity: HR 2.715 (95% CI 2.612–2.823)] in the fully adjusted model (Model 3). However, the associations between cumulative duration in the very-low-income group and the hazard of T2D were more prominent in individuals without obesity (p for interaction < 0.0001). While a sustained very low-income status for 5 years was associated with a 51.8% increased hazard in the subpopulation with obesity [Model 3, 0 vs. 5 years: (95% CI 1.460–1.578)], it was associated with a 69.8% higher hazard in the subpopulation without obesity [0 vs. 5 years: (95% CI 1.636–1.763)]. The analyses replacing the income parameter with the cumulative number of years in the low-income group yielded similar patterns of interaction by the presence of obesity (p for interaction < 0.0001). In addition, the increased hazard of T2D associated with baseline very-low-income status was more pronounced in participants without obesity (p for interaction < 0.0001).

In contrast, the lower hazard of T2D associated with advanced cumulative duration in the high-income status

Table 1 Baseline characteristics by cumulative number of years being in the very low-, low-, and high-income groups

	Cumulative number of years being in the very low-income status				Cumulative number of years being in the low-income income status				Cumulative number of years being in the very high-income status				p-value
	0	1-4	5	p-value	0	1-4	5	p-value	0	1-4	5	p-value	
Total													
No.	3,462,002	32,500	26,441		2,309,458	918,296	234,248		3,089,254	276,437	96,311		
Categorical variables, n(%)													
Age, ≥65 years	388,107 (11.41)	5,564 (17.12)	1,269 (4.80)	<0.0001	260,852 (11.29)	94,637 (10.31)	39,451 (16.84)	<0.0001	332,959 (10.78)	43,583 (15.77)	18,398 (19.1)	<0.0001	<0.0001
Sex													
Male	1,862,636 (53.80)	11,083 (64.10)	9,807 (37.09)	<0.0001	1,397,221 (60.5)	379,543 (41.33)	85,872 (36.66)	<0.0001	1,646,785 (53.31)	155,839 (56.37)	60,012 (62.31)	<0.0001	<0.0001
Female	1,599,366 (46.20)	21,417 (65.90)	16,634 (62.91)		912,237 (39.5)	538,753 (58.67)	148,376 (63.34)		1,442,469 (46.69)	120,598 (43.63)	36,299 (37.69)		
Health insurance type													
Self-employed	751,236 (21.70)	10,282 (31.64)	-		532,502 (23.06)	177,845 (19.37)	40,889 (17.46)		644,984 (20.88)	78,271 (28.31)	27,981 (29.05)		
Employee	2,672,535 (77.20)	2,662,107 (78.23)	-		1,776,956 (76.94)	732,848 (79.81)	162,731 (69.47)		2,406,188 (77.89)	198,017 (71.63)	68,330 (70.95)		
MAB	38,231 (1.10)	11,790 (36.28)	26,441 (100)	<0.0001	-	7,603 (0.83)	30,628 (13.08)	<0.0001	38,082 (1.23)	149 (0.05)	-	<0.0001	<0.0001
Baseline Income													
MAB	382,31 (1.10)	11,790 (36.28)	26,441 (100)		-	7,603 (0.83)	30,628 (13.08)		38,082 (1.23)	149 (0.05)	-		
Q1	578,605 (16.71)	568,788 (16.71)	-		-	374,985 (40.83)	203,620 (86.92)		560,883 (18.16)	17,722 (6.41)	-		
Q2	668,388 (19.31)	661,578 (19.44)	-		361,650 (15.66)	306,738 (33.4)	-		650,449 (21.06)	17,939 (6.49)	-		
Q3	937,374 (27.08)	934,290 (27.45)	-		780,598 (33.8)	156,776 (17.07)	-		914,407 (29.6)	22,967 (8.31)	-		
Q4	1,239,404 (35.80)	1,238,405 (36.39)	-		1,167,210 (50.54)	721,947 (86)	-		925,433 (29.96)	217,660 (78.74)	96,311 (100)		
Residential area, Urban	1,585,058 (45.78)	1,560,285 (45.85)	-		1,062,750 (46.02)	415,363 (45.23)	106,945 (45.65)	<0.0001	1,396,673 (45.21)	135,376 (48.97)	53,009 (55.04)	<0.0001	<0.0001
BMI level, kg/m ²													
<18.5	1,071,54 (31.0)	104,298 (30.6)	1,353 (4.16)		67,294 (2.91)	31,276 (3.41)	8,584 (3.66)		98,264 (3.18)	6,898 (2.5)	1,992 (2.07)		
18.5-22.9	1,355,081 (39.14)	1,331,751 (39.13)	-		877,570 (38)	382,121 (41.61)	95,390 (40.72)		1,216,699 (39.38)	103,800 (37.55)	34,582 (35.91)		
23.0-24.9	874,382 (25.26)	861,151 (25.31)	-		595,263 (25.78)	222,065 (24.18)	57,054 (24.36)		771,637 (24.98)	75,023 (27.14)	27,722 (28.78)		
25.0-29.9	1,006,626 (29.08)	990,025 (29.09)	-		692,347 (29.98)	249,534 (27.17)	64,745 (27.64)		893,745 (28.93)	83,073 (30.05)	29,808 (30.95)		
≥30.0	1,187,59 (34.3)	1,158,86 (34)	-		76,984 (3.33)	33,300 (3.63)	8,475 (3.62)		108,909 (3.53)	7,643 (2.76)	2,207 (2.29)		
Abdominal obesity	646,269 (18.67)	633,129 (18.6)	-		436,324 (18.89)	163,764 (17.83)	46,181 (19.71)	<0.0001	571,270 (18.49)	54,904 (19.86)	20,095 (20.86)	<0.0001	<0.0001
Smoking status													
Never	2,061,184 (59.54)	20,202,579 (59.38)	-		1,283,435 (55.57)	612,013 (66.65)	165,736 (70.75)		1,837,609 (59.48)	166,970 (60.4)	56,605 (58.77)		
Former	555,307 (16.04)	550,153 (16.17)	-		426,630 (18.46)	104,092 (11.34)	24,865 (10.61)		475,530 (15.39)	56,199 (20.33)	23,578 (24.48)		
Current	845,511 (24.42)	832,329 (24.46)	-		599,673 (25.97)	202,191 (22.02)	43,647 (18.63)		776,115 (25.12)	53,268 (19.27)	16,128 (16.75)		

Table 1 (continued)

Total	Cumulative number of years being in the very low-income status			Cumulative number of years being in the low-income status			Cumulative number of years being in the very high-income status			Cumulative number of years being in the high-income status		
	0	1-4	5	p-value	0	1-4	5	p-value	0	1-4	5	p-value
Alcohol consumption				<0.0001				<0.0001				<0.0001
Non	1,739,653 (51.12)	21,708 (66.79)	19,417 (73.44)		1,111,256 (48.12)	518,643 (56.48)	150,879 (64.41)		1,590,194 (51.34)	141,919 (51.34)	48,665 (50.53)	
Mild to moderate	1,432,936 (41.39)	8,908 (27.41)	5,686 (21.5)		1,017,472 (44.06)	343,704 (37.43)	71,760 (30.63)		1,276,664 (41.33)	115,401 (41.75)	40,871 (42.44)	
Heavy	2,482,888 (71.7)	1,884 (5.8)	1,338 (5.06)		180,730 (7.83)	559,49 (6.09)	116,09 (4.96)		222,396 (7.2)	19,117 (6.92)	6,775 (7.03)	
Regular exercise	669,455 (19.34)	4,886 (15.03)	3,807 (14.4)	<0.0001	460,338 (19.93)	164,218 (17.88)	44,899 (19.17)	<0.0001	581,995 (18.84)	63,508 (22.97)	23,952 (24.87)	<0.0001
Hypertension	843,663 (24.37)	825,168 (24.25)	10,693 (32.9)	<0.0001	552,130 (23.91)	219,605 (23.91)	71,928 (30.71)	<0.0001	742,422 (24.03)	72,551 (26.25)	28,394 (29.48)	<0.0001
Dyslipidemia	631,748 (18.25)	618,115 (18.16)	7,492 (23.05)	<0.0001	416,449 (18.03)	164,482 (17.91)	50,817 (21.69)	<0.0001	551,485 (17.85)	57,669 (20.86)	22,568 (23.43)	<0.0001
KD	108,971 (3.15)	105,895 (3.11)	1,833 (5.64)	<0.0001	69,713 (3.02)	288,73 (3.14)	10,385 (4.43)	<0.0001	94,236 (3.05)	10,462 (3.78)	4,273 (4.44)	<0.0001
Continuous variables, mean ± SD or geometric means (95% CI)												
Age, years	49.12 ± 11.95	53.26 ± 11.79	51.09 ± 8.23	<0.0001	48.73 ± 12	49.01 ± 11.81	53.45 ± 11.13	<0.0001	48.66 ± 11.91	52.13 ± 11.75	55.21 ± 10.55	<0.0001
BMI, kg/m²	23.74 ± 3.15	23.73 ± 3.45	23.71 ± 3.66	0.343	23.81 ± 3.11	23.61 ± 3.22	23.63 ± 3.23	<0.0001	23.73 ± 3.17	23.81 ± 2.96	23.87 ± 2.82	<0.0001
WC, cm	80.14 ± 8.89	80.15 ± 8.88	79.63 ± 9.24	<0.0001	80.66 ± 8.78	79.05 ± 9.02	79.35 ± 9.03	<0.0001	80.03 ± 8.92	80.91 ± 8.65	81.69 ± 8.33	<0.0001
SBP, mmHg	121.75 ± 14.54	121.76 ± 14.53	122.03 ± 15.57	<0.0001	121.84 ± 14.39	121.35 ± 14.73	122.47 ± 15.22	<0.0001	121.79 ± 14.55	121.39 ± 14.5	121.34 ± 14.28	<0.0001
DBP, mmHg	76.19 ± 9.95	76.18 ± 10.25	75.81 ± 10.28	<0.0001	76.31 ± 9.91	75.85 ± 9.99	76.3 ± 10.13	<0.0001	76.22 ± 9.95	75.85 ± 9.91	75.94 ± 9.79	<0.0001
Fasting glucose, mg/dL	93.46 ± 10.97	93.45 ± 10.96	93.49 ± 11.54	0.0105	93.58 ± 10.89	93.07 ± 11.07	93.73 ± 11.3	<0.0001	93.38 ± 11.01	93.91 ± 10.68	94.45 ± 10.55	<0.0001
Total cholesterol, mg/dL	197.55 ± 35.77	197.58 ± 35.72	194.5 ± 38.79	<0.0001	197.68 ± 35.49	196.98 ± 36.14	198.51 ± 36.99	<0.0001	197.33 ± 35.82	199.27 ± 35.37	199.88 ± 34.86	<0.0001
HDL-C, mg/dL	55.63 ± 17.46	55.62 ± 17.44	55.29 ± 18.22	<0.0001	55 ± 17.15	56.93 ± 18.08	56.64 ± 17.69	<0.0001	55.72 ± 17.62	54.93 ± 16.51	54.49 ± 14.64	<0.0001
LDL-C, mg/dL	116.70 ± 33.45	116.74 ± 33.42	115.21 ± 34.89	<0.0001	117 ± 33.3	115.84 ± 33.62	117.15 ± 34.18	<0.0001	116.35 ± 33.53	119.36 ± 32.82	120.23 ± 32.21	<0.0001
eGFR, mL/min/1.73m²	91.32 ± 34.39	91.32 ± 34.43	92.5 ± 33.83	<0.0001	91.05 ± 35.67	92.21 ± 31.72	90.58 ± 31.43	<0.0001	91.61 ± 33.82	89.34 ± 36.36	87.69 ± 44.76	<0.0001
*Triglyceride, mg/dL	109.76 (109.69-109.82)	109.75 (109.69-109.82)	110.07 (109.35-110.8)	0.6893	112.09 (112.01-112.17)	104.82 (104.71-104.94)	106.87 (106.64-107.11)	<0.0001	109.69 (109.63-109.76)	110.02 (109.8-110.24)	111.05 (110.68-111.42)	<0.0001

*This variable exhibited a non-normal distribution and is therefore presented as geometric means (95% confidence intervals)

Abbreviations: BMI body mass index, CI confidence interval, CKD chronic kidney disease, DBP diastolic blood pressure, eGFR estimated glomerular filtration rate, HDL-C high-density lipoprotein cholesterol, IQR interquartile range, LDL-C low-density lipoprotein cholesterol, MAB Medical Aid beneficiaries indicating the very low-income status, Q1 health insurance premium quartile 1 (the lowest quartile), Q2 health insurance premium quartile 2, Q3 health insurance premium quartile 3, Q4 health insurance premium quartile 4 (the highest quartile), SBP systolic blood pressure, SD standard deviation, WC waist circumference

Table 2 Hazard ratios and 95% confidence intervals for incident type 2 diabetes according to income parameters

Income parameters	N	Events (n)	Duration Person-years	Incidence rate, per 1000 person-years	Hazard ratios (95% CIs)		
					Model 1	Model 2	Model 3
Cumulative number of years being in the very low-income status							
0	3,403,061	435,754	29,728,852	14.66	1 (Ref.)	1 (Ref.)	1 (Ref.)
1	9,805	1,890	81,101	23.30	1.600 (1.529, 1.674)	1.409 (1.347, 1.474)	1.345 (1.285, 1.407)
2	9,570	2,135	76,664	27.85	1.919 (1.839, 2.002)	1.509 (1.446, 1.575)	1.355 (1.299, 1.414)
3	6,266	1,187	52,478	22.62	1.551 (1.465, 1.641)	1.624 (1.534, 1.719)	1.504 (1.420, 1.592)
4	6,859	1,359	56,362	24.11	1.657 (1.571, 1.748)	1.499 (1.421, 1.581)	1.409 (1.336, 1.486)
5	26,441	5,363	217,837	24.62	1.689 (1.644, 1.735)	1.763 (1.716, 1.811)	1.599 (1.556, 1.642)
p for trend					< 0.0001	< 0.0001	< 0.0001
Cumulative number of years being in the low-income status							
0	2,309,458	289,849	20,212,831	14.34	1 (Ref.)	1 (Ref.)	1 (Ref.)
1	360,725	44,740	3,160,362	14.16	0.987 (0.977, 0.997)	1.075 (1.064, 1.085)	1.072 (1.061, 1.083)
2	238,446	30,215	2,083,986	14.5	1.011 (0.999, 1.023)	1.079 (1.066, 1.092)	1.082 (1.069, 1.095)
3	175,687	23,580	1,529,117	15.42	1.076 (1.062, 1.091)	1.110 (1.096, 1.125)	1.111 (1.096, 1.126)
4	143,438	20,544	1,239,908	16.57	1.158 (1.141, 1.174)	1.113 (1.097, 1.129)	1.115 (1.099, 1.131)
5	234,248	38,760	1,987,089	19.51	1.367 (1.353, 1.382)	1.175 (1.162, 1.187)	1.148 (1.136, 1.160)
p for trend					< 0.0001	< 0.0001	< 0.0001
Cumulative number of years being in the very high-income status							
0	3,089,254	395,248	26,979,230	14.65	1 (Ref.)	1 (Ref.)	1 (Ref.)
1	114,951	15,242	1,001,646	15.22	1.039 (1.022, 1.056)	0.908 (0.894, 0.923)	0.934 (0.919, 0.949)
2	65,310	9,019	567,033	15.91	1.086 (1.063, 1.109)	0.908 (0.889, 0.927)	0.935 (0.916, 0.955)
3	50,008	7,109	434,142	16.37	1.118 (1.092, 1.144)	0.899 (0.878, 0.921)	0.933 (0.911, 0.955)
4	46,168	6,689	399,969	16.72	1.142 (1.115, 1.170)	0.890 (0.869, 0.912)	0.918 (0.896, 0.941)
5	96,311	14,381	831,273	17.3	1.182 (1.163, 1.202)	0.851 (0.837, 0.866)	0.888 (0.873, 0.903)
p for trend					< 0.0001	< 0.0001	< 0.0001
Cumulative number of years being in the high-income status							
0	1,540,014	200,863	13,413,730	14.97	1 (Ref.)	1 (Ref.)	1 (Ref.)
1	311,780	38,322	2,732,846	14.02	0.935 (0.925, 0.946)	0.943 (0.933, 0.954)	0.954 (0.943, 0.964)
2	228,445	28,321	2,001,681	14.15	0.944 (0.932, 0.956)	0.929 (0.917, 0.941)	0.948 (0.936, 0.960)
3	214,657	26,963	1,879,507	14.35	0.957 (0.945, 0.969)	0.919 (0.907, 0.931)	0.943 (0.931, 0.955)
4	214,021	27,601	1,869,582	14.76	0.985 (0.972, 0.997)	0.909 (0.897, 0.920)	0.930 (0.919, 0.942)
5	953,085	125,618	8,315,948	15.11	1.008 (1.001, 1.015)	0.854 (0.848, 0.860)	0.886 (0.880, 0.893)
p for trend					0.0113	< 0.0001	< 0.0001
Baseline income status							
MAB	38,231	7,728	315,354	24.51	1.656 (1.618, 1.694)	1.881 (1.838, 1.924)	1.678 (1.640, 1.717)
Q1	578,605	83,444	4,995,409	16.70	1.124 (1.115, 1.133)	1.134 (1.124, 1.143)	1.116 (1.107, 1.126)
Q2	668,388	82,783	5,848,218	14.16	0.951 (0.943, 0.959)	1.120 (1.111, 1.130)	1.096 (1.086, 1.105)
Q3	937,374	112,505	8,229,330	13.67	0.918 (0.911, 0.925)	1.094 (1.086, 1.102)	1.057 (1.049, 1.065)
Q4	1,239,404	161,228	10,824,983	14.89	1 (Ref.)	1 (Ref.)	1 (Ref.)
p for trend					< 0.0001	< 0.0001	< 0.0001

Baseline income status was categorized as MAB (very low-income status) and health insurance premium quartiles 1 (the lowest quartile), 2, 3, and 4 (the highest quartile), constructing a total of five groups

Model 1: Unadjusted

Model 2: Adjusted for age, sex, and residential area (metropolitan, urban, and rural)

Model 3: Adjusted for the variables included in Model 2 and body mass index, smoking history, drinking, regular exercise, fasting plasma glucose, hypertension, dyslipidemia, and chronic kidney disease

Abbreviations: CI confidence interval, MAB Medical Aid beneficiaries indicating a very low-income status, Q1 quartile 1 (the lowest quartile), Q2 quartile 2, Q3 quartile 3, Q4 quartile 4

was more prominent in the group with obesity than in the group without obesity (*p* for interaction < 0.0001). The increased hazard of T2D associated with higher income variability was more pronounced in individuals with

obesity (*p* for interaction < 0.0001) (Table S8). In analyses stratified by age group (Tables S9 and S10), the results among adults aged < 65 years—who are largely unaffected by retirement—were consistent with our initial findings.

Income parameters and risk of type 2 diabetes according to the presence of obesity (BMI ≥ 25 kg/m²),

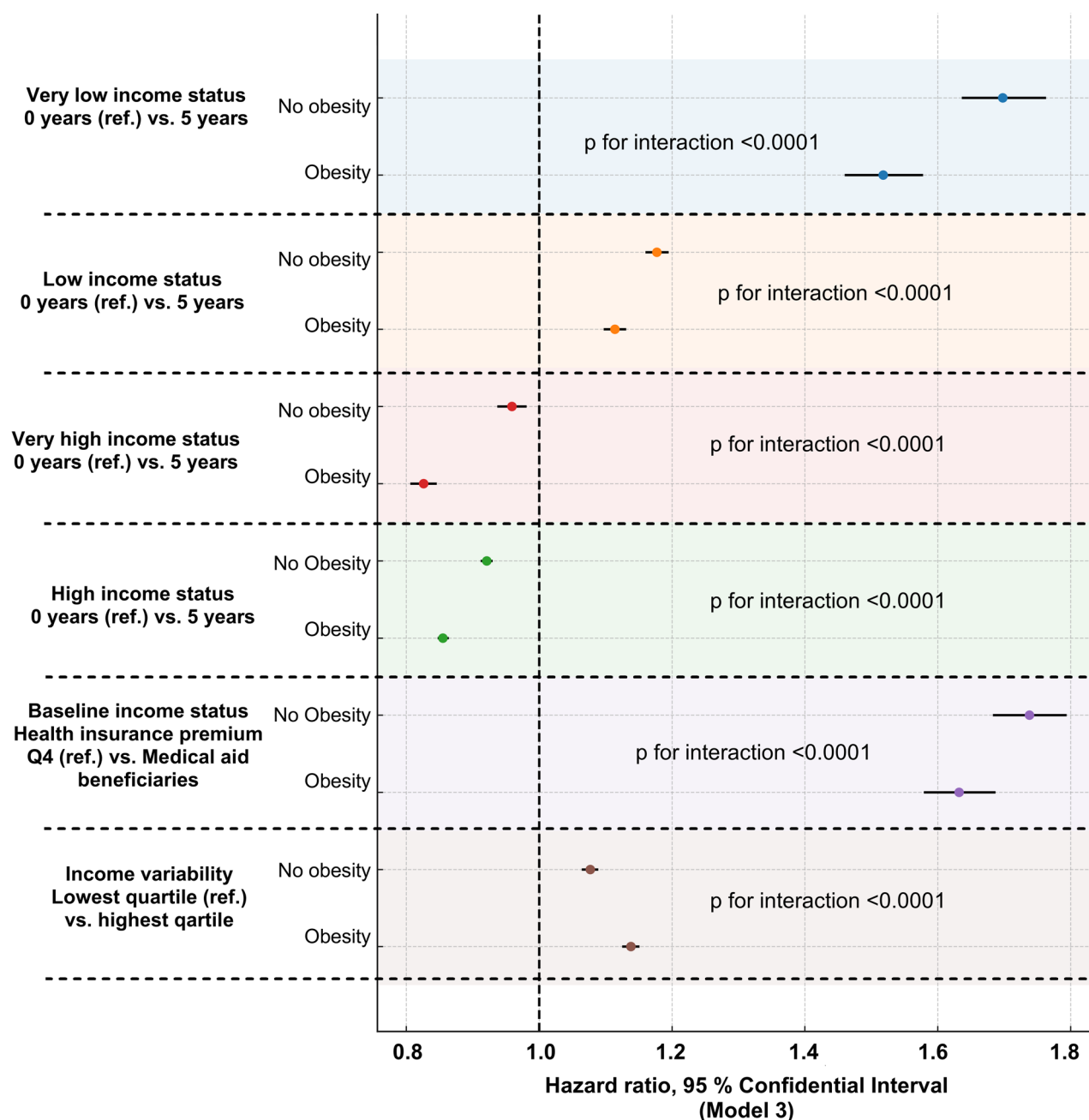
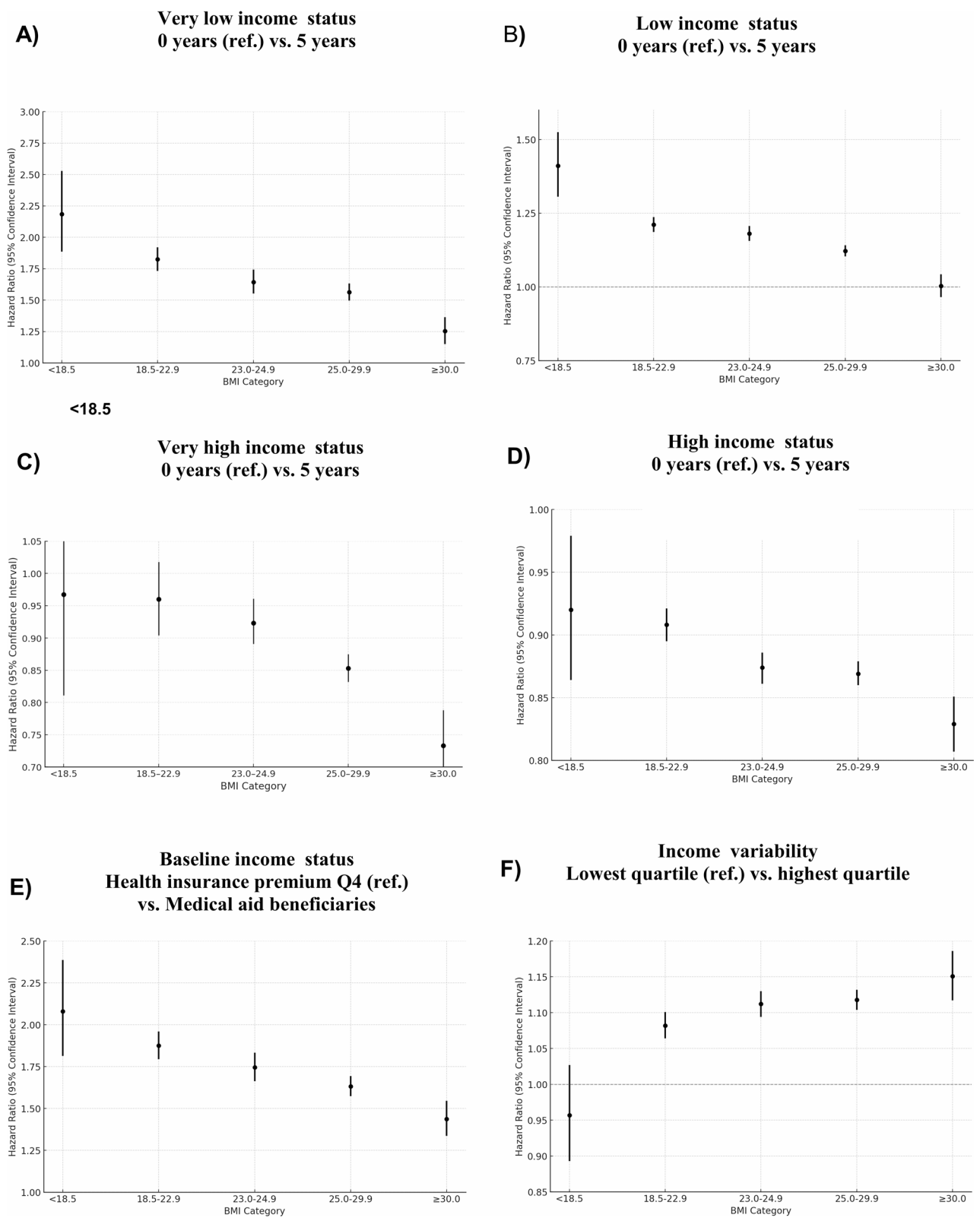


Fig. 2 Hazard ratios and 95% confidence intervals for incident type 2 diabetes according to income parameter groups, stratified by the presence of obesity (BMI ≥ 25 kg/m²). Reference groups: individuals within each obesity category (non-obesity and obesity) who had never been in the very low-, low-, high-, or very high-income statuses, or those who were in baseline health insurance premium quartile 4 (the highest income group) or the lowest quartile of income variability. Baseline income status was categorized as MAB (very low-income status) and health insurance premium quartiles 1 (the lowest quartile), 2, 3, and 4 (the highest quartile), constructing a total of five groups Adjusted for age, sex, residential area (metropolitan, urban, and rural areas), body mass index, smoking history, drinking, regular exercise, fasting plasma glucose, hypertension, dyslipidemia, and chronic kidney disease

After stratifying the study population by BMI category, the HRs (95% CIs) of T2D according to income parameter groups were further evaluated in detail (Fig. 3 and Additional file 1: Table S11). In terms of the income

parameters of the cumulative number of years being in the very low- or low-income status and baseline very low-income status, the associations with the hazard of T2D were stronger in individuals with lower BMI



(See figure on previous page.)

Fig. 3 Adjusted hazard ratios and 95% confidence intervals for incident type 2 diabetes according to income status, stratified analyses by the BMI categories. Comparison between (A) cumulative number of years being in the very low-income status: 5 years versus 0 years (ref.); (B) cumulative number of years being in the low-income status: 5 years versus 0 years (ref.); (C) cumulative number of years being in the very high-income status: 5 years versus 0 years (ref.); (D) cumulative number of years being in the high-income status: 5 years versus 0 years (ref.); (E) baseline income: very low-income status (medical aid beneficiaries) versus health insurance premium quartile 4 (the highest quartile, ref.); (F) income variability: quartile 4 (the highest quartile) versus quartile 1 (the lowest quartile, ref.)

categories; the most prominent association being demonstrated in participants with underweight (p for interaction < 0.0001). The sustained very low-income status for 5 years exhibited 2.223-fold (95% CI 1.919–2.574), 1.803-fold (95% CI 1.712–1.899), 1.629-fold (95% CI 1.537–1.727), 1.535-fold (95% CI 1.470–1.604), and 1.239-fold (95% CI 1.138–1.350) increased risk of T2D compared to those who never experienced the very low-income status in individuals with BMI < 18.5 , 18.5–22.9, 23.0–24.9, 25.0–29.9, and ≥ 30.0 kg/m², respectively (All Model 3). With respect to the cumulative number of years in the high-income status and income variability groups, the association was stronger in individuals with a higher BMI (all p for interaction < 0.0001). Compared to individuals who never experienced high-income status, those with sustained high-income status for 5 years had a 16.9% lower risk of T2D (Model 3, 95% CI 0.810–0.853) in those with a BMI of ≥ 30 kg/m², and a 6.5% lower risk (Model 3, 95% CI 0.878–0.995) in participants with underweight. Similar results were observed in the sustained very-high-income group.

Sensitivity analyses

Sensitivity analyses excluding participants with myocardial infarction, stroke, and/or cancer (Tables S12 and S13), sub-distribution HRs accounting for all-cause deaths as competing events using the Fine and Gray method [23] (Tables S14 and S15), sensitivity analyses excluding those who died or developed T2D within two years after baseline data collection (Table S16 and S17) showed results consistent with those from the main analyses.

Discussion

This nationwide study, which included 3,462,002 Korean adults aged ≥ 30 years, including those 65 years and above, demonstrated an increased risk of T2D associated with cumulative exposure to very low- or low-income status, baseline low-income status, and higher income variability. Conversely, a reduced risk of T2D was observed with an increased cumulative duration in high-income status. Furthermore, stratified analyses by BMI category revealed that participants in lower BMI categories had a more pronounced increased risk of T2D associated with cumulative exposure to very low- or low-income status and very low-income status at baseline. Among participants with obesity and higher BMI categories, the

reduced risk of T2D associated with cumulative duration in high-income status was more prominent, as was the increased risk associated with higher income variability.

Consistent with our findings, a previous study that included a Korean population demonstrated an elevated T2D risk in individuals who experienced sustained low-income status or income decline and a reduced T2D risk in those with consecutive high-income status or income rise [6]. The authors also found a more prominent impact of sustained low-income in individuals without obesity than those with obesity. However, unlike in the present study, their analysis did not include individuals aged ≥ 65 years. Furthermore, their study did not stratify obesity status in as much detail as ours and considered only the presence of obesity (BMI ≥ 25 kg/m²). To the best of our knowledge, our study is the first to comprehensively examine how the relationship between various income parameters and T2D risk differs according to detailed obesity categories.

With respect to the obesity status, compared to those with prominent obesity, the impact of sustained very low- and low-income status was more pronounced in the population without obesity and not at risk of T2D. In our analysis, among individuals with underweight, sustained exposure to a very low-income status was associated with a 2.184-fold higher hazard of T2D when compared to nonexposure. This value is significantly higher than the HR of 1.253 associated with sustained exposure to very low-income status in individuals with a BMI ≥ 30.0 kg/m². Moreover, the value was comparable to the HR of T2D (1.843) observed in overweight individuals (BMI 23.0–24.9 kg/m²) who had never experienced a very low-income status when compared to their underweight counterparts. The key to preventing the increasing global burden of T2D is identifying high-risk individuals who could benefit from diabetes screening and prevention, similar to considering BMI as a significant factor. Our findings indicate that individuals experiencing sustained very low-income status for 5 years face a risk of T2D similar to those who are overweight (BMI ≥ 23 kg/m²), despite not being at risk of diabetes due to obesity.

Several factors may explain the strong relationship between low-income status and excess T2D risk in individuals without obesity. First, unhealthy dietary and physical activity patterns may have contributed [24, 25]. Earlier studies have hypothesized that poor diet quality and food insecurity, despite a lower overall caloric

intake, play significant role [26, 27]. Individuals with lower-incomes are more likely to choose cheaper, calorie-rich foods over a balanced diet with protein and fiber. Additionally, the financial and time constraints necessary for maintaining employment may hinder regular exercise, potentially leading to reduced muscle mass [28]. Stress might force them into harmful habits such as physical inactivity [29, 30]. Thus, individuals consistently exposed to lower-income conditions may be more prone to developing unhealthy body composition than their nonexposed counterparts with similar BMI. The impact of differences in body composition may be more pronounced in individuals with a lower BMI than in those already living with obesity and at risk of T2D. In addition, C-reactive protein, an inflammatory marker, has also been reported to be associated with low socioeconomic status (SES), including low-income, resulting in unhealthy outcomes including T2D [31, 32]. The association of this elevated inflammation with low-income may be partly mediated by the development of obesity [32]. Further, regardless of exposure to low-income status, as obesity itself is closely related to systemic inflammation [33], the impact of low-income conditions may have been even more pronounced in participants without obesity.

The finding that sustained high-income status attenuated the risk of T2D, particularly in those with a $\text{BMI} \geq 30 \text{ kg/m}^2$, is notable. A previous Korean study also reported a similar significant interaction, indicating that the reduction in T2D risk associated with sustained exposure to high-income status, was more pronounced in individuals with obesity compared to nonexposure [6]. However, as the authors had classified obesity status solely by the presence of obesity ($\text{BMI} \geq 25 \text{ kg/m}^2$), only a minimal difference in HR (0.87 in individuals without obesity vs. 0.83 in those with obesity) was observed. Notably, through detailed stratification of obesity status, we found that 5 years of sustained high-income status reduced the hazard of T2D by twice as much in individuals with a $\text{BMI} \geq 30.0 \text{ kg/m}^2$ (17.1% reduction) than those with a $\text{BMI} < 18.5 \text{ kg/m}^2$ (8.0% reduction). This suggests that the protective effects of regular exercise and high-quality, nutrient-balanced food beyond total calorie intake [34, 35] related to high-income conditions may be more pronounced in individuals with obesity and already at high risk for T2D. Additionally, individuals with obesity may generally be more susceptible to stigma and discrimination owing to negative stereotypes, which can lead to stress, reduced psychological resources, and mental health problems, potentially increasing the risk of adverse outcomes, including T2D [10]. However, those with a high SES who maintain a sustained high-income despite having obesity may experience much less social discrimination, which could provide an additional protective effect.

We also found that high income variability was associated with an increased T2D risk. This association was stronger in individuals in the advanced BMI category, with a 15.1% higher risk in those with a $\text{BMI} \geq 30 \text{ kg/m}^2$. However, no such association was noted in the those with underweight. As in prior studies that reported the link between income variability and various adverse outcomes [36–41], those with high income variability might experience unpredictable and episodic low-income, which may lack the protective benefit of social resources and is associated with psychological depression [37]. According to previous systematic reviews and meta-analyses [10], obesity may be associated with subsequent income, with underlying mechanisms potentially including negative stereotypes about obesity and weight penalties in the labor market, leading to higher job insecurity. The high income variability in the population with obesity is likely to stem from these stigma effects more than in the population without obesity. Therefore, higher income variability may be closely linked to increased experiences of discrimination, maladaptive stress, and the loss of psychological resources, particularly in individuals with obesity. This could explain the more pronounced association between income variability and T2D risk observed in populations with obesity.

The limitations of this study should be acknowledged. First, clarifying the causal relationships was not possible due to the observational design. Second, as our study population included only Korean adults, extrapolation of the findings to other ethnicities or populations with different policies and/or healthcare systems need to be performed with caution. Third, although we demonstrated robust associations between income variability and T2D risk using multiple variability metrics (SD, CV, ARV, and VIM), these measures do not capture the directional nature of income changes (i.e., increasing vs. decreasing patterns), which could have distinct implications for T2D risk. Future studies incorporating trajectory analyses may better clarify the temporal and directional aspects of income dynamics in relation to diabetes risk. Finally, other social determinants of health, including education, occupation, and housing in addition to income, could not be captured due to the inherent structure of the KNHIS dataset. Because such information is unavailable in this administrative database, income level was the only feasible indicator that could be used as a proxy for socioeconomic status. Nevertheless, our study has several strengths. This study was based on a large sample size of >3.4 million people from a representative nationwide cohort database run by the Korean government and included diverse variables of demographics, lifestyle, comorbidities, and laboratory findings. This permitted adjustment for these potential confounders. Furthermore, we examined the cumulative income status

in terms of repeated serial measures, thus demonstrating a dose-response relationship. Additionally, through detailed stratified analyses according to obesity status, the findings emphasized the implications of various income parameters as potential risk factors for the incidence of T2D across different obesity statuses.

Conclusions

In conclusion, this real-world, nationwide, population-based study of Korean adults demonstrated that various income parameters significantly affect the risk of T2D. Additionally, the data reveal that the effects of these factors vary by obesity status, with individuals without obesity being more affected by low-income exposure. Among those with obesity, sustained high income appears to mitigate the risk more prominently, while they remain more vulnerable to income variability. These findings underscore the importance of considering both socioeconomic and obesity status in diabetes prevention strategies.

Abbreviations

T2D	Type 2 diabetes
SDOH	Social determinants of health
BMI	Body mass index
KNHIS	Korean National Health Insurance Service
NHI	National Health Insurance
MA	Medical Aid
ICD-10	International Classification of Diseases-10th Revision
FPG	Fasting plasma glucose
eGFR	Estimated glomerular filtration rate
IRB	Institutional Review Board
CKD	Chronic kidney disease
Cis	Confidence intervals
HRs	Hazard ratios
SES	Socioeconomic status

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s12889-026-26986-1>.

Additional file 1: Figure S1. The dose-response relationship between baseline income percentiles and the risk of incident type 2 diabetes Table S1. Definitions of income parameters. Table S2. Definitions of covariates. Table S3. The dose-response relationship between baseline income percentiles and the risk of incident type 2 diabetes. Table S4. Hazard ratios and 95% confidence intervals for incident type 2 diabetes according to income variability. Table S5. Hazard ratios and 95% confidence intervals for incident type 2 diabetes according to income parameters in individuals aged <65 years. Table S6. Hazard ratios and 95% confidence intervals for incident type 2 diabetes according to income parameters in individuals aged 65 years or older. Table S7. Hazard ratios and 95% confidence intervals for incident type 2 diabetes according to income parameters, stratified by the presence of obesity (BMI ≥ 25 kg/m²). Table S8. Hazard ratios and 95% confidence intervals for incident type 2 diabetes according to income variability, stratified by the presence of obesity (BMI ≥ 25 kg/m²). Table S9. Hazard ratios and 95% confidence intervals for incident type 2 diabetes according to income parameters, stratified by the presence of obesity (BMI ≥ 25 kg/m²) in individuals aged <65 years. Table S10. Hazard ratios and 95% confidence intervals for incident type 2 diabetes according to income parameters, stratified by the presence of obesity (BMI ≥ 25 kg/m²) in individuals aged 65 years or older. Table S11. Hazard ratios and 95% confidence intervals for incident type 2 diabetes according to income parameter groups, stratified analyses by the BMI categories. Table S12. Sensitivity analysis after excluding participants with myocardial infar-

tion, stroke, and/or cancer: Hazard ratios and 95% confidence intervals for incident type 2 diabetes according to income parameters. Table S13. Sensitivity analysis after excluding participants with myocardial infarction, stroke, and/or cancer: Hazard ratios and 95% confidence intervals for incident type 2 diabetes according to income parameters, stratified by the presence of obesity (BMI ≥ 25 kg/m²). Table S14. Sensitivity analysis accounting for all-cause mortality as a competing event: Sub-distribution hazard ratios and 95% confidence intervals for incident type 2 diabetes according to income parameters. Table S15. Sensitivity analysis accounting for all-cause mortality as a competing event: Sub-distribution hazard ratios and 95% confidence intervals for incident type 2 diabetes according to income parameters, stratified by the presence of obesity (BMI ≥ 25 kg/m²). Table S16. Sensitivity analysis after excluding individuals who died or developed T2D within two years after baseline data collection: Hazard ratios and 95% confidence intervals for incident type 2 diabetes according to income parameters. Table S17. Sensitivity analysis after excluding individuals who died or developed T2D within two years after baseline data collection: Hazard ratios and 95% confidence intervals for incident type 2 diabetes according to income parameters, stratified by the presence of obesity (BMI ≥ 25 kg/m²)

Acknowledgements

This study was conducted in collaboration with the Korean National Health Insurance Service (KNHIS). The National Health Information Database constructed by the KNHIS was used and the study results do not necessarily represent the opinions of the KNHIS.

Authors' contributions

J.H.Y. and Y.B.L. drafted the manuscript. K.H., and K. L. contributed to study design and participated in data analysis planning and statistical analysis. Y.B.L., J.H.Y. and J.E.J. performed literature searches and contributed to conception of the hypothesis. J.H.Y. and Y.B.L. critically edited the manuscript. All authors contributed important intellectual content during manuscript drafting or revision and approved the final version of the manuscript.

Funding

This research was supported by the Chung-Ang University Research Grants in 2024. The funders had no role in the study design, data collection and analysis, decision to publish, or manuscript preparation.

Data availability

The data that support the findings of this study are available from the Korean National Health Insurance Service (KNHIS) but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are however available from the corresponding authors upon reasonable request and with permission of the KNHIS.

Declarations

Ethics approval and consent to participate

The study protocol was approved by the Institutional Review Board (IRB) of the Samsung Medical Center (SMC 2023-11-025). This study utilized anonymized public data that had already been secured for other purposes and only involved reviewing this anonymized database without any additional interventions. Thus, it falls under the category of minimal risk research with no additional risk to the subjects. Furthermore, the researchers received data from the KNHIS with all personal identification information removed, making it impossible to identify the participants included. As such, given that the data provided by the KNHIS was anonymized, the requirement for informed consent was waived by the IRB. After obtaining IRB approval, we accessed the data under the permission of the KNHIS for a limited period of utilization. All methods were performed in accordance with the relevant guidelines and regulations. The study was conducted in accordance with the Declaration of Helsinki.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Received: 28 June 2025 / Accepted: 9 March 2026

Published online: 18 March 2026

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