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Prevalence of Mortality and Vascular Complications in Older Patients with Diabetes in Korea

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Background: This study investigated the prevalence of diabetes mellitus (DM) and impaired fasting glucose, as well as their management and comorbidities among older Korean adults.

Methods: Data from 269,447 individuals aged 65 years and older from the Korean National Health Insurance Service between 2000 and 2019 were analyzed to evaluate trends in DM prevalence, healthcare utilization, mortality, and complications.

Results: Among 269,447 individuals, 18.6% (n=50,159/269,447) were diagnosed with DM and 27.0% (n=72,670/269,447) had impaired fasting glucose. The DM group had the highest body mass index, waist circumference, and prevalence of current smokers (P<0.001) but not the highest hypertension prevalence. From 2010 to 2019, the prevalence of DM and impaired fasting glucose increased from 15.5% to 21.9% and from 26.0% to 30.6%, respectively. Cancer-related mortality in DM was 1.15 times higher than in those with normal glucose tolerance (P<0.001), and cardiovascular disease-related mortality was 1.32 times higher (P<0.001); all mortalities were higher in female participants. Myocardial infarction (hazard ratio [HR], 1.34; P<0.001), stroke (HR, 1.24; P<0.001), and heart failure (HR, 1.13; P<0.001) were significantly higher in those with DM.

Conclusion: This is the first study to investigate the prevalence of DM and related complications in older individuals based on long-term representative data in Korea. These results highlight the necessity for targeted interventions to enhance management and outcomes in this population.

Keywords: Neoplasms; Cardiovascular diseases; Diabetes mellitus; Mortality

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INTRODUCTION

Diabetes mellitus (DM) is a global health crisis that poses significant economic and social challenges. The prevalence of DM has increased significantly, with the number of affected adults increasing from 151 million in 2000 to approximately 536.6 million in 2021; this corresponds to a prevalence rate of 10.5% among adults aged 20 to 79 years [1]. Globally, 136 million individuals aged ≥65 years live with diabetes [2]; by 2030, this number is expected to increase to 195.2 million and is expected to surpass 276.2 million by 2045 [3]. The increase in DM prevalence in older adults has been similar to that in younger populations and is driven by factors such as unhealthy diets that promote obesity, reduced physical activity associated with type 2 DM, and increased incidence of type 1 DM [4-7]. Improved DM diagnostic capabilities have further contributed to this increase. Natural aging processes, including altered glucose metabolism and islet cell dysfunction, play significant roles in increasing life expectancy [8]. Older adults living with DM have an increased risk of microvascular and macrovascular complications, including neuropathy, nephropathy, retinopathy, cardiovascular disease (CVD), and cognitive decline. These complications significantly contribute to the burden of diabetes, affecting the quality of life, health status, hospitalization rates, and outcomes of affected individuals. Approximately 60% of older individuals with diabetes have at least one comorbidity, with approximately 40% concurrently having four or more chronic conditions [9,10]. Concerns about hypoglycemia and the adverse effects of polypharmacy are notable in this population because of multiple comorbidities [11]. Understanding these demographic trends and the underlying pathophysiological mechanisms is essential for the effective management and prevention of adverse outcomes associated with DM in older adults. However, owing to the limits of this research, no study has robustly investigated the long-term demographic trends and the underlying pathophysiological mechanisms of DM and impaired fasting glucose (IFG) in older individuals in Korea.

This study aimed to thoroughly investigate the demographic and clinical characteristics as well as trends in DM prevalence among individuals aged 65 years and older using representative data from Korea.

METHODS

Study population and data collection

This retrospective cohort study utilized data from the Korean National Health Insurance Service (NHIS) database. South Korea has a unified insurance system that offers healthcare coverage to almost all residents. The NHIS recommends biennial medical check-ups for all enrollees. Over the past decade, health screening participation has steadily increased, with approximately 15 million individuals undergoing examinations annually; the average general health screening rate was approximately 98% during this period [12]. The NHIS database comprises several key components: a qualification database containing demographic details such as sex, age, income, area of residence, and types of qualifications; a claim database that includes specifications, consultation statements, and diagnosis statements according to the International Classification of Diseases, 10th revision (ICD-10), and prescription details; a health checkup database encompassing results from general health examinations and responses to lifestyle and behavior questionnaires; and information related to mortality.

The study included 269,447 participants aged 65 years and older who underwent a health examination between 2000 and 2019 (Supplemental Fig. S1). The baseline characteristics of participants were derived from their first health examination conducted during this period, at which point their initial diagnosis was made. This study complied with the ethical standards of the Declaration of Helsinki and was approved by the Catholic University of Korea, Catholic Medical Center, Seoul St. Mary's Hospital Institutional Review Board (IRB approval No. KC23 ZISI0777). Written informed consent was not required as the study utilized pre-existing anonymized data. All procedures adhered to applicable guidelines and regulations.

Demographic variables and measurement

Demographic and lifestyle data were gathered using a standardized self-reported questionnaire to assess variables such as current smoking (having consumed at least five packs [or 100 cigarettes] and currently smoking) and high-risk drinking consumption (more than seven drinks twice a week for males and more than five drinks for females). Body weight, height, and waist circumference (WC) were measured at each visit. Body mass index (BMI) was calculated as weight in kilograms divided by the square of the height in meters (kg/m^2). Systolic and diastolic blood pressure were measured with participants seated after a rest period of at least 5 minutes. Laboratory tests included measurement of hemoglobin, alanine aminotransferase (ALT), aspartate aminotransferase (AST), and γ-glutamyl transpeptidase (γ-GTP) levels after overnight fasting for more than 8 hours. Patient income was surveyed and analyzed by dividing it into

10 deciles.

Definition of DM, comorbidities, and treatment outcome

The presence of DM was defined as fasting glucose ≥126 mg/dL or at least one claim per year under ICD-10 codes E10–14 and the prescription of antidiabetic medication. IFG was defined as a fasting glucose level between 100 and 125 mg/dL, without either a claim under ICD-10 codes E11–14 or a prescription for antidiabetic medication. Normal glucose tolerance (NGT) was defined as a fasting glucose level of less than 100 mg/dL. Both inpatient and outpatient claims were considered for the diagnosis of DM, ensuring that diagnoses from different healthcare settings were included. Primary and secondary diagnoses were both considered, and a diagnosis was deemed present if it appeared in at least two claims over a 12-month period to minimize the risk of misclassification due to coding errors. Hyperlipidemia was at least one annual claim for the prescription of lipid-lowering agents under ICD-10 code E78. Hypertension was defined as systolic/diastolic blood pressure ≥140/90 mm Hg or at least one claim per year under ICD-10 codes I10–13 or I15 and the prescription of antihypertensive agents. Cardiovascular complications were identified based on the first occurrence of any of the following ICD-10 codes: myocardial infarction (MI) (I21–22), stroke (I63.54), or heart failure (I50). This definition ensured the inclusion of only newly developed cardiovascular complications in the analysis. The treatment adherence rate was defined as the proportion of patients with diabetes who continuously took their prescribed antidiabetic medications during the follow-up period.

Statistical analysis

Continuous variables are presented as mean±standard deviation, and categorical variables are presented as numbers and percentages. An independent *t* test was conducted for continuous variables, and a chi-square test was conducted for categorical variables. The annual trends in the number of claimed cases and incidence were analyzed using the chi-square test for trends within the age-sex strata. The incidence rate (IR) of suicide-related deaths was calculated by dividing the number of events by the total follow-up duration, expressed per 1,000 person-years. Cox proportional hazard models were used to estimate hazard ratios (HRs) with 95% confidence intervals (CIs), adjusted for age, sex, BMI, systolic blood pressure, smoking status, alcohol consumption, physical activity, and income deciles. These variables were selected due to their known influence on DM progression and complications. A P value <0.05 was considered statistically significant. All the statistical analyses were performed using SAS version 9.4 (SAS Institute, Cary, NC, USA).

RESULTS

Baseline characteristics according to glycemia among individuals aged 65 and older

Among the 269,447 studied individuals aged 65 years or older, 18.6% (n=50,159) were diagnosed with DM and 27.0% (n=72,670) were diagnosed with IFG (Table 1). Participants with NGT were 54.4% (n=146,618). Owing to the large sample size, there were significant differences in the clinical parameters between the groups. Male participants were more prevalent in the IFG (53.4%) and DM (56.2%) cohorts, whereas there were more female participants (53% vs. 47%) in the NGT group. The mean age was slightly higher in the NGT and IFG group compared to the DM group (67.9±2.9 years in NGT, 67.8±2.8 years in IFG, and 67.7±2.7 years in DM, respectively; P<0.001). BMI was lowest in the NGT group (23.7±3.0 kg/m^2) compared to the IFG (24.3±3.0 kg/m^2) and DM (24.7±3.1 kg/m^2) groups (P<0.001). Additionally, WC was highest in the DM group and lowest in the NGT group (85.8±9.6 cm vs. 82.0±8.1 cm, respectively; P<0.001). The rate of current smokers was higher in the DM group (15.1%, 7,551/50,159) than in the NGT (12.9%, 18,912/146,618) and IFG (13.1%, 9,522/72,670) groups (P<0.001). The total cholesterol levels were higher in the IFG group (200±40 mg/dL) than in the NGT (197±38 mg/dL) or DM (188±45 mg/dL) group (P<0.001). The DM group had slightly lower hemoglobin levels (13.8±1.5 g/dL) compared to the IFG (13.9±1.4 g/dL) and NGT (13.6±1.4 g/dL) groups (P<0.001). The prevalence of albuminuria was higher in the DM group (6.3%) than in the IFG (2.6%) and NGT (2.0%) groups (P<0.001). Liver enzymes, including AST, ALT, and γ-GTP, were highest in the DM group.

Regarding comorbidities, hyperlipidemia was prevalent in 52.7% of the total population, with the highest proportion found in the DM group (70.3%), followed by the IFG (52.9%) and NGT (46.5%) groups (P<0.001). Hypertension was also common, affecting 56.1% of the overall cohort, with a higher prevalence in the DM group (74.1%) compared to the IFG (57.2%) and NGT (49.5%) groups (P<0.001). Heart failure was noted in 6.5% of the participants, with the DM group showing the highest occurrence (9.1%, P<0.001). Additionally, MI and stroke were more frequently observed in the DM group (5.8% and 1.0%, respectively) compared to the NGT group (3.1% and 0.5%, P<0.001). Cancer-related comorbidities also varied significantly

Table 1. Baseline Participant Characteristics (n=269,447)

Parameter	Total	NGT	IFG	DM	P value
Number	269,447 (100.0)	146,618 (54.4)	72,670 (27.0)	50,159 (18.6)	
Male sex	135,870 (50.4)	68,864 (47.0)	38,976 (53.4)	28,210 (56.2)	<0.001
Age, yr	67.9±2.8	67.9±2.9	67.8±2.8	67.7±2.7	<0.001
SBP, mm Hg	130±17	129±17	131±17	132±17	<0.001
DBP, mm Hg	79±11	78±11	79±10	78±10	<0.001
BMI, kg/m^2	24.1±3.1	23.7±3.0	24.3±3.0	24.7±3.1	<0.001
Waist circumference, cm	83.3±8.6	82.0±8.1	84.0±8.1	85.8±9.6	<0.001
Smoking					<0.001
Current-smoker	35,985 (13.4)	18,912 (12.9)	9,522 (13.1)	7,551 (15.1)	
Ex-smoker	40,340 (15.0)	18,880 (12.9)	12,340 (17.0)	9,120 (18.2)	
Never-smoker	187,431 (69.6)	105,508 (72.0)	49,363 (67.9)	32,560 (64.9)	
No answer	5,691 (2.1)	3,318 (2.3)	1,445 (2.0)	928 (1.9)	
Laboratory finding					
Hemoglobin, g/dL	13.7±1.4	13.6±1.4	13.9±1.4	13.8±1.5	<0.001
AST, U/L	28±19	27±16	28±18	29±24	<0.001
ALT, U/L	24±19	23±17	25±20	28±24	<0.001
γ-GTP, U/L	35±52	30±41	38±57	43±68	<0.001
TC, mg/dL	196±40	197±38	200±40	188±45	<0.001
Urine positive protein	7,937 (2.9)	2,907 (2.0)	187 (2.6)	3,163 (6.3)	<0.001
Comorbidities					
Hyperlipidemia	141,881 (52.7)	68,165 (46.5)	38,465 (52.9)	35,251 (70.3)	<0.001
Hypertension	151,285 (56.1)	72,523 (49.5)	41,586 (57.2)	37,176 (74.1)	<0.001
Gastric cancer	5,872 (2.2)	3,035 (2.1)	1,563 (2.2)	1,274 (2.5)	<0.001
Heart failure	17,457 (6.5)	8,274 (5.6)	4,613 (6.3)	4,570 (9.1)	<0.001
Lung cancer	4,473 (1.7)	2,296 (1.6)	1,215 (1.7)	962 (1.9)	<0.001
Colorectal cancer	7,445 (2.8)	3,688 (2.5)	2,041 (2.8)	1,716 (3.4)	<0.001
MI	9,941 (3.7)	4,516 (3.1)	2,509 (3.5)	2,916 (5.8)	<0.001
Stroke	1,587 (0.6)	665 (0.5)	419 (0.6)	503 (1.0)	<0.001
GB/BT cancer	1,106 (0.4)	517 (0.4)	292 (0.4)	297 (0.6)	<0.001
Thyroid cancer	3,235 (1.2)	1,705 (1.2)	923 (1.3)	607 (1.2)	0.093
Liver cancer	7,581 (2.8)	3,515 (2.4)	2,082 (2.9)	1,984 (4.0)	<0.001
Kidney cancer	1,071 (0.4)	528 (0.4)	284 (0.4)	259 (0.5)	<0.001
Pancreatic cancer	3,725 (1.4)	1,712 (1.2)	954 (1.3)	1,059 (2.1)	<0.001
Regular exercise					<0.001
No	148,400 (55.1)	82,861 (56.5)	39,054 (53.7)	26,485 (52.8)	
Yes	117,389 (43.6)	61,405 (41.9)	32,819 (45.2)	23,165 (46.2)	
No answer	3,658 (1.4)	2,352 (1.6)	797 (1.1)	509 (1.0)	
Alcohol					<0.001
Heavy drinker	11,186 (4.2)	5,182 (3.5)	3,574 (4.9)	2,430 (4.8)	
Mild	74,514 (27.7)	37,495 (25.6)	22,336 (30.7)	14,683 (29.3)	
None	183,747 (68.2)	103,941 (70.9)	46,760 (64.3)	33,046 (65.9)	

Values are expressed as number (%) or mean±standard deviation.
NGT, normal glucose tolerance; IFG, impaired fasting glucose; DM, diabetes mellitus; SBP, systolic blood pressure; DBP, diastolic blood pressure; BMI, body mass index; AST, aspartate aminotransferase; ALT, alanine aminotransferase; γ-GTP, γ-glutamyl transpeptidase; TC, total cholesterol; MI, myocardial infarction; GB/BT, gall bladder and biliary tract.

between groups, with liver cancer being more prevalent in the DM group (4.0%) than in the NGT group (2.4%, $P<0.001$), and pancreatic cancer showing a similar trend (DM 2.1%, NGT 1.2%, $P<0.001$).

Distribution of normal, IFG, and diagnosed DM

There was an increasing prevalence of IFG and DM in individuals aged 65 years and older from 2010 to 2019 (Fig. 1). In 2019, the prevalence of DM was 21.9% and that of IFG was 30.6%; the prevalence of undiagnosed cases (from 3.6% to 3.1%) and normoglycemic participants (from 54.9% to 44.4%) decreased over the study period.

Hospital visit rates for newly diagnosed patients with DM

The hospital visits rates for newly diagnosed patients with DM aged 65 years and older were analyzed. As shown in Fig. 2A,

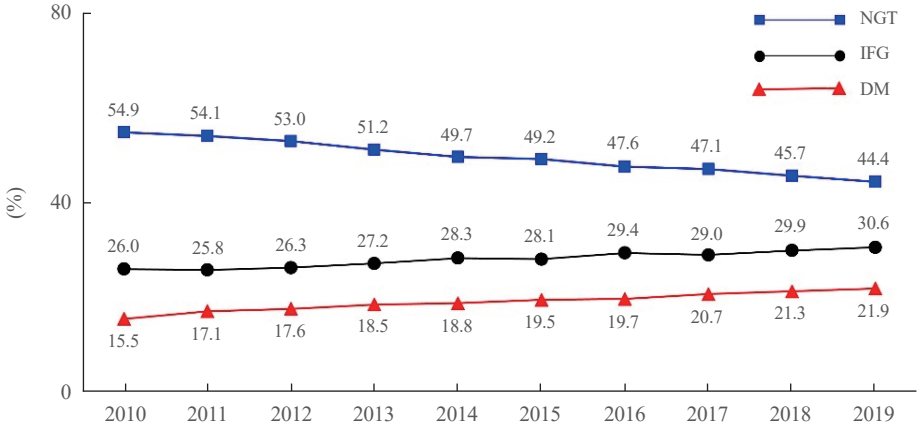

Fig. 1. Distribution of normal glucose tolerance (NGT), impaired fasting glucose (IFG), and diagnosed diabetes mellitus (DM) among health checkup participants aged 65 years and older.

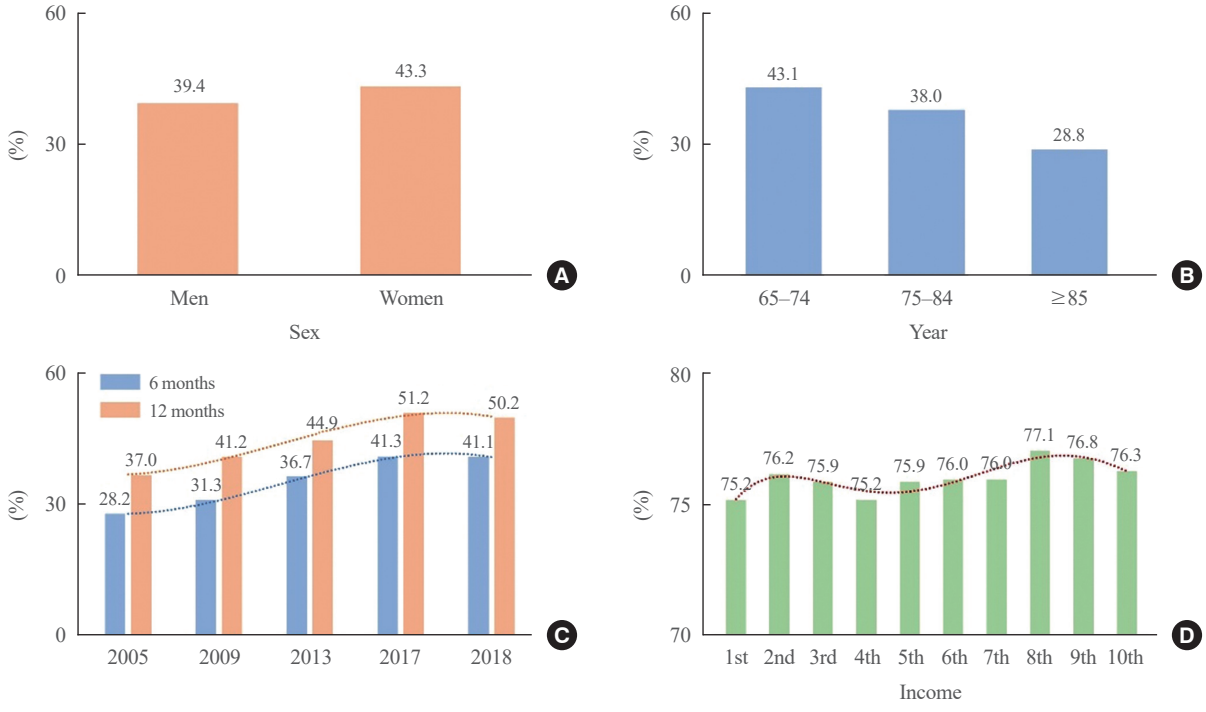

Fig. 2. The hospital visits rates according to (A) sex or (B) age group. (C) Hospital visits rates for newly diagnosed diabetic patients aged 65 years and older within 6 and 12 months (2005–2018). (D) Sustained treatment rate according to income.

the visit rate for newly diagnosed male participants with diabetes was 39.4%, whereas that for female participants was 43.3%. The frequency of hospital visits for patients with DM between 65 and 74 years of age was the highest (43.1%) (Fig. 2B); this was followed by the 75–84 years age group (38.0%) and the ≥85 age group (28.8%). The visit rate within 6 months was lower than that within 12 months (Fig. 2C). The treatment adherence rate was higher in the 6th to 10th income deciles than in the 1st to 5th income deciles. The treatment adherence rate was the lowest among healthcare benefit recipients (Fig. 2D).

Major causes of mortality

Among patients with DM aged 65 years and older, major causes of death included all-cause, cancer-related, and CVD-related

Table 2. Causes of Mortality in Patients with DM Aged 65 Years and Older

Variable	Category	Number	Events	Person-year	IR	Unadjusted HR model (95% CI)	*P* value	Adjusted HR model (95% CI)	*P* value
All-cause mortality									
Total	NGT	146,618	27,358	1,260,976	21.70	Ref		Ref	
	IFG	72,670	12,069	548,469	22.00	1.06 (1.04–1.09)	<0.001	1.08 (1.05–1.10)	<0.001
	DM	50,159	9,890	342,531	28.87	1.50 (1.46–1.53)	<0.001	1.59 (1.55–1.62)	<0.001
Male	NGT	68,864	16,414	569,391	28.83	Ref		Ref	
	IFG	38,796	7,446	275,973	26.98	0.99 (0.96–1.02)	0.470	1.07 (1.04–1.10)	<0.001
	DM	28,210	5,945	177,135	33.56	1.32 (1.28–1.36)	<0.001	1.51 (1.46–1.56)	<0.001
Female	NGT	77,754	10,944	691,585	15.82	Ref		Ref	
	IFG	33,874	4,623	272,496	16.97	1.11 (1.07–1.15)	<0.001	1.08 (1.04–1.11)	<0.001
	DM	21,949	3,945	165,396	23.85	1.67 (1.61–1.74)	<0.001	1.69 (1.63–1.76)	<0.001
Cancer-related mortality									
Total	NGT	146,618	8,912	1,372,844	6.49	Ref		Ref	
	IFG	72,670	3,960	598,046	6.62	1.04 (1.00–1.08)	<0.050	1.04 (1.00–1.08)	1.000
	DM	50,159	2,875	386,400	7.44	1.19 (1.14–1.24)	<0.001	1.23 (1.18–1.29)	<0.001
Male	NGT	68,864	6,238	634,251	9.84	Ref		Ref	
	IFG	38,796	2,832	305,043	9.28	0.97 (0.93–1.01)	0.170	1.02 (0.98–1.07)	0.340
	DM	28,210	2,042	201,942	10.11	1.08 (1.02–1.13)	<0.001	1.20 (1.14–1.26)	<0.001
Female	NGT	77,754	2,674	738,593	3.62	Ref		Ref	
	IFG	33,874	1,128	293,002	3.85	1.08 (1.01–1.16)	0.020	1.08 (1.00–1.15)	<0.050
	DM	21,949	833	184,458	4.52	1.29 (1.19–1.39)	<0.001	1.33 (1.23–1.44)	<0.001
CVD-related mortality									
Total	NGT	146,618	6,321	1,393,928	4.53	Ref		Ref	
	IFG	72,670	2,738	607,530	4.51	1.03 (0.99–1.08)	0.160	1.02 (0.98–1.07)	0.370
	DM	50,159	2,167	391,525	5.53	1.31 (1.25–1.38)	<0.001	1.27 (1.26–1.34)	<0.001
Male	NGT	68,864	3,132	657,732	4.76	Ref		Ref	
	IFG	38,796	1,439	315,221	4.57	1.00 (0.94–1.07)	0.940	1.03 (0.96–1.09)	0.420
	DM	28,210	1,144	208,064	5.50	1.25 (1.17–1.34)	<0.001	1.25 (1.17–1.34)	<0.001
Female	NGT	77,754	3,189	736,196	4.33	Ref		Ref	
	IFG	33,874	1,299	292,309	4.44	1.05 (0.99–1.12)	0.120	1.00 (0.94–1.07)	0.970
	DM	21,949	1,023	183,461	5.58	1.36 (1.27–1.46)	<0.001	1.28 (1.19–1.37)	<0.001

HR (95% CI) was adjusted for age, sex, body mass index, systolic blood pressure, smoking status, alcohol consumption, physical activity, and income deciles. Person-years were obtained by summing the follow-up periods (number of days) of individuals and dividing by 365. IR represents the number of events per person-year, calculated by dividing the number of events by person-years and multiplying by 1,000.
DM, diabetes mellitus; IR, incidence rate; HR, hazard ratio; CI, confidence interval; NGT, normal glucose tolerance; IFG, impaired fasting glucose; CVD, cardiovascular disease.

mortality (Table 2). The IR of all-cause mortality, cancer-related mortality, and CVD-related mortality increased progressively from NGT to IFG and DM. Patients with DM showed a significantly higher risk of all-cause (adjusted HR, 1.59; 95% CI, 1.55 to 1.62; $P<0.001$), cancer-related (adjusted HR, 1.23; 95% CI, 1.18 to 1.29; $P<0.001$), and CVD-related (adjusted HR, 1.27; 95% CI, 1.26 to 1.34; $P<0.001$) mortality compared with patients in the NGT group. This trend was consistent across both sexes, with DM showing a significantly higher risk of all-cause mortality (1.51 [95% CI, 1.46 to 1.56] in male participants, 1.69 [95% CI, 1.63 to 1.76] in female participants, $P<0.001$), cancer-related mortality (1.20 [95% CI, 1.14 to 1.26] in male participants, 1.33 [95% CI, 1.23 to 1.44] in female participants, $P<0.001$), and CVD-related mortality (1.25 [95% CI, 1.17 to 1.34]

Table 3. Vascular Complications in Patients with DM Aged 65 Years and Older

Variable	Category	Number	Events	Person-year	IR	Unadjusted HR model (95% CI)	*P* value	Adjusted HR model (95% CI)	*P* value
Myocardial infarction									
Total	NGT	142,102	11,041	1,330,645	8.30	Ref		Ref	
	IFG	70,161	4,832	578,636	8.35	1.01 (0.98–1.05)	0.400	0.98 (0.94–1.01)	0.210
	DM	47,243	4,081	362,259	11.27	1.38 (1.33–1.43)	<0.001	1.25 (1.20–1.30)	<0.001
Male	NGT	66,440	5,298	625,646	8.47	Ref		Ref	
	IFG	37,271	2,555	298,557	8.56	1.02 (0.97–1.07)	0.480	0.99 (0.93–1.05)	0.690
	DM	26,336	2,093	191,753	10.92	1.30 (1.24–1.37)	<0.001	1.20 (1.14–1.27)	<0.001
Female	NGT	75,662	5,743	704,999	8.15	Ref		Ref	
	IFG	32,890	2,277	280,079	8.13	1.00 (0.96–1.05)	0.840	0.96 (0.91–1.02)	0.160
	DM	20,907	1,988	170,506	11.66	1.45 (1.38–1.53)	<0.001	1.30 (1.23–1.37)	<0.001
Stroke									
Total	NGT	133,893	27,879	1,118,501	24.93	Ref		Ref	
	IFG	65,810	11,952	486,460	24.57	0.99 (0.97–1.01)	0.370	0.99 (0.96–1.01)	0.280
	DM	42,901	8,930	290,306	30.76	1.24 (1.22–1.27)	<0.001	1.19 (1.16–1.22)	<0.001
Male	NGT	63,110	12,725	533,464	23.85	Ref		Ref	
	IFG	35,298	6,020	255,824	23.53	0.99 (0.96–1.02)	0.550	0.99 (0.95–1.03)	0.590
	DM	24,295	4,542	157,142	28.90	1.22 (1.18–1.26)	<0.001	1.18 (1.14–1.23)	<0.001
Female	NGT	70,783	15,154	585,036	25.90	Ref		Ref	
	IFG	30,512	5,932	230,636	25.72	1.00 (0.97–1.03)	0.850	0.98 (0.95–1.02)	0.340
	DM	18,606	4,388	133,165	32.95	1.28 (1.24–1.32)	<0.001	1.19 (1.15–1.24)	<0.001
Heart failure									
Total	NGT	138,344	27,005	1,215,605	22.22	Ref		Ref	
	IFG	68,057	11,908	528,405	22.54	1.03 (1.01–1.05)	<0.050	0.98 (0.95–1.00)	0.050
	DM	45,589	8,694	331,788	26.20	1.21 (1.18–1.24)	<0.001	1.05 (1.02–1.08)	<0.001
Male	NGT	65,490	12,202	588,910	20.72	Ref		Ref	
	IFG	36,604	5,955	281,285	21.17	1.04 (1.01–1.08)	<0.050	0.98 (0.95–1.02)	0.420
	DM	25,882	4,534	180,926	25.06	1.26 (1.21–1.30)	<0.001	1.06 (1.02–1.10)	<0.050
Female	NGT	72,854	14,803	626,695	23.62	Ref		Ref	
	IFG	31,453	5,953	247,120	24.09	1.03 (1.00–1.06)	0.060	0.97 (0.93–1.00)	0.050
	DM	19,707	4,160	150,863	27.57	1.19 (1.15–1.23)	<0.001	1.04 (1.00–1.08)	0.060

HR (95% CI) was adjusted for age, sex, body mass index, systolic blood pressure, smoking status, alcohol consumption, physical activity, and income deciles. Person-years were obtained by summing the follow-up periods (number of days) of individuals and dividing by 365. IR represents the number of events per person-year, calculated by dividing the number of events by person-years and multiplying by 1,000.
DM, diabetes mellitus; IR, incidence rate; HR, hazard ratio; CI, confidence interval; NGT, normal glucose tolerance; IFG, impaired fasting glucose.

in male participants, 1.28 [95% CI, 1.19 to 1.37] in female participants, $P<0.001$) compared with NGT, with a higher risk observed in female participants than in male participants.

IFG was associated with a high risk of all-cause mortality (1.08; 95% CI, 1.05 to 1.10; $P<0.001$). When stratified by sex, male and female participants with DM had an elevated risk of all-cause mortality (males: 1.07 [95% CI, 1.04 to 1.10], $P<0.001$; females: 1.08 [95% CI, 1.04 to 1.11], $P<0.001$). However, IFG was not significantly associated with increased cancer-related risk. IFG showed a modest but significant association (HR, 1.08; 95% CI, 1.00 to 1.15; $P<0.05$) in female participants. CVD-related mortality was not associated with IFG in the total population or in either sex.

Vascular complications

Among the major complications of DM, vascular complications such as MI, ischemic stroke, and heart failure were analyzed (Table 3); these complications showed the highest IR in the DM group than in the NGT or IFG group. In patients with DM, MI (adjusted HR, 1.25; 95% CI, 1.20 to 1.30; $P<0.001$), stroke (1.19; 95% CI, 1.16 to 1.22; $P<0.001$), and heart failure (1.05; 95% CI, 1.02 to 1.08; $P<0.001$) were all significantly increased compared to the NGT group. This pattern was observed in both male and female participants. The risk was significantly higher in women than in men (MI, 1.20 [95% CI, 1.14 to 1.27] in men vs. 1.30 [95% CI, 1.23 to 1.37] in women; stroke, 1.18 [95% CI, 1.14 to 1.23] in men vs. 1.19 [95% CI, 1.15 to 1.24] in women).

IFG was associated with a slightly higher IR of MI, stroke, and heart failure compared to NGT. In the unadjusted model, IFG showed an increased risk for heart failure (1.03; 95% CI, 1.01 to 1.05; $P<0.05$). However, after adjusting for covariates, the associations between IFG and vascular complications were attenuated and became nonsignificant in the total population or when stratified by sex.

DISCUSSION

This study aimed to comprehensively investigate the demographic and clinical characteristics and prevalence trends of DM among individuals aged 65 years and older in South Korea. We found that the prevalence of DM, as defined by ICD-10 codes, fasting blood glucose levels (≥126 mg/dL), and the use of antidiabetic medication, was 18.6%, whereas IFG was prevalent in 27.0% of this age group. Similarly, a global study estimated a prevalence of approximately 19.3% among individuals aged 65 to 99 years in 2019, based on 255 high-quality data sources [13]. In contrast, our findings were lower than those of a previous study utilizing data from the Korea National Health and Nutrition Examination Survey (KNHANES), which reported a prevalence of 26.0% based on fasting glucose levels alone and 29.6% when including glycated hemoglobin (HbA1c) levels [14]. Compared with younger populations, the prevalence of DM in older adults is significantly higher. A recent study in the UK examined 23,501 participants and found that 2,791 (11.9%) had diabetes. The prevalence of DM was 5.3% in the younger age group, 18.1% in the middle-aged group, and 29.1% in the older age group [15]. Although the prevalence continued to rise between the younger and middle-aged individuals, a notable decline was observed in the older adult group. This increased prevalence is closely associated with multiple cardiovascular risk factors, including hypertension and hyperlipidemia, which are more common in older adults. These challenges highlight the importance of developing targeted healthcare strategies to improve early detection and management of DM and its associated complications in older adults.

A study using data from The Global Burden of Disease Study 2019 reported that an estimated 110.1 million individuals aged 70 years and older were living with diabetes (types 1 and 2), indicating a global prevalence of 23.7% [16]. The global prevalence of diabetes is expected to continue to increase with this age group [17]. However, there are discrepancies in the prevalence rates reported in the literature resulting from differences in the study periods, methodologies, and diagnostic criteria between our administrative data-based study and the direct measurement and survey-based KNHANES. Our study leveraged administrative data from the Korean NHI and provided insights into diagnosed cases and healthcare utilization patterns among older adults. Conversely, the KNHANES captures a broader spectrum of undiagnosed and pre-diabetic conditions through direct measurements of glucose and HbA1c levels, potentially resulting in higher reported prevalence rates. These methodological differences demonstrate the complementary nature of different data sources in epidemiological research.

The clinical visit rate within a year refers to hospital or clinic visits for diabetes management or related complications within 12 months after diagnosis. The visit rate within 12 months was higher than that within 6 months, ranging from 8.2% to 9.2%, indicating an increasing trend from 2005 to 2018. The clinical visit rate within 6 months was higher in the 65–74 years age group than in the 75–84 and ≥85 years age groups. This suggests that younger older adults may demonstrate greater proactivity or capability for accessing healthcare services more fre-

quently, possibly due to better overall health and mobility, than their older counterparts. Older individuals have a higher prevalence of comorbidities, leading to more frequent medical visits and increased awareness of their health status, including the presence of DM [18]. The observed higher clinical visit rates among women compared to men are consistent with previous research, highlighting significant sex disparities in healthcare utilization [19,20]. Our study found that income deciles did not significantly influence healthcare visit rates, except for recipients of basic livelihood assistance. Consistent with our study, a tendency towards lower perceptions and acceptance of healthcare has previously been identified [21]. Regardless of personal attitudes towards individuals from lower socioeconomic backgrounds, healthcare providers must recognize how patients perceive their treatment based on their socioeconomic status. This understanding fosters increased empathy toward patients' experiences and aids in identifying potential perceptual barriers that may influence patient satisfaction and adherence to effective healthcare management strategies.

This study demonstrates that among patients aged 65 and older, DM is associated with a significantly increased risk of all-cause and CVD-related mortality compared with patients with NGT. The presence of comorbidities such as MI, stroke, and heart failure was significantly higher in older adults with DM than in those without DM [22,23]. In the prospective GERODIAB (Gérodiab: évaluation de l'influence de l'équilibre glycémique sur la morbi-mortalité à 5 ans des diabétiques de type 2 âgés de 70 ans et plus) observational study involving 997 participants with type 2 DM aged 70 years or older (median age, 77 years), the IR of all cardiovascular complications increased from 47% at baseline to 67% over a 5-year follow-up period [24]. In this demographic context, solely assessing glycemic status may not effectively stratify individuals at the highest risk of all-cause or cardiovascular mortality. DM is linked to increased mortality rates, with risks escalating with longer disease duration; numerous studies have quantified these mortality risks to be primarily attributed to CVD, ranging from 1.15 to 3.15 across various populations [25-28]. These findings are consistent with our result of a combined HR of 1.50 for all-cause mortality, encompassing cancer and CVD. Our findings revealed sex-based differences in cardiovascular complications with DM among adults aged 65 years and above; female patients with DM in this age group exhibited a higher susceptibility to complications than male patients. Mechanistically, several factors may have contributed to these disparities. Hormonal influences, such as estrogen fluctuations, have been implicated in modifying cardiovascular risk in female patients with DM; estrogen has been shown to have cardioprotective effects, and its decline after menopause could predispose women to increased cardiovascular complications [29]. Additionally, differences in body fat distribution and metabolic responses to insulin resistance between sexes may also play a role in exacerbating complications in women with DM [30]. Our study demonstrated that the IR and risk of vascular complication were lower in the IFG group than in the DM group. However, the risk of vascular complication was not significantly associated with IFG after adjustment for covariates. Previous studies have shown a lower incidence of macrovascular and microvascular complications in individuals with IFG (HR, 1.03; 95% CI, 1.09 to 1.28) relative to those with DM (HR, 1.39; 95% CI, 1.33 to 1.46) [31]. Although IFG is recognized as an intermediary state, it still presents a substantial risk for the development of vascular complications. Therefore, early detection and intervention in individuals with IFG is important to prevent the progression of DM and its associated complications. Nonetheless, our findings suggest that after adjusting for covariates, the risk of vascular complications in individuals with IFG is not as pronounced as in those with DM, emphasizing the need for tailored risk management strategies based on an individual's glycemic status.

Because this study used retrospectively accumulated data, it has various limitations. Owing to the nature of the study, it was difficult to determine causal relationships, meaning that only correlations could be inferred [32]. The retrospective nature of the study and reliance on administrative databases may have introduced biases and limitations to data completeness and accuracy. In particular, self-report questionnaires for individuals aged 65 years or older may be subject to recall bias and underreporting, potentially resulting in lower prevalence than expected. For example, family history was a very important factor in the results of this study, but more than half of the respondents could not respond, so it was excluded from the analysis of this study. A lot of data, including WC, was also missing and could not be used for analysis. This area needs to be supplemented with future large-scale prospective studies.

As HbA1c levels were not available in the database, we also could not assess the severity of DM. In addition, there is a possibility that some of the information obtained through patient questionnaires may not be objective. Because of this, future comparative studies using standardized methodologies across diverse populations should be performed to further elucidate global trends and disparities in DM epidemiology and outcomes [33,34]. Despite its limitations, this study may have great sig-

nificance in that it uses large-scale real-world NHI data that are representative of the Korean population.

To our knowledge, this is the first study to investigate the prevalence of DM and related complications in individuals over 65 years of age based on long-term representative data in Korea. The insights gained from this study contribute to the understanding of DM epidemiology in older adults, informing clinical practices and public health strategies aimed at effectively managing this growing health challenge.

CONFLICTS OF INTEREST

No potential conflict of interest relevant to this article was reported.

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AUTHOR CONTRIBUTIONS

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