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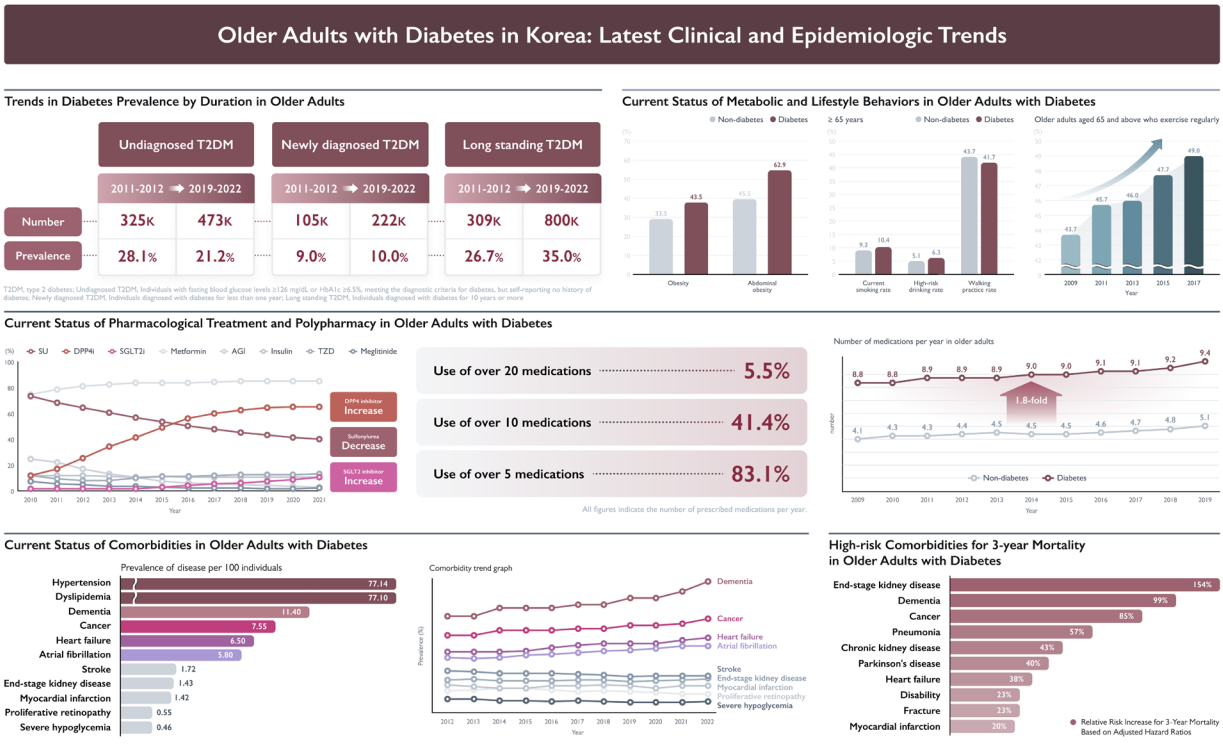

Highlights

- **Newly diagnosed and long-standing diabetes cases in older Koreans rose over 10 years.**
- **More older adults with diabetes now meet physical activity guidelines.**
- **By 2019, older adults with diabetes took 9.4 drugs on average, 1.8 times more than those without.**
- **Age-related comorbidities like dementia, HF, and CKD have increased.**
- **ESKD, dementia, cancer, and pneumonia were linked to a higher 3-year mortality risk.**

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Older Adults with Diabetes in Korea: Latest Clinical and Epidemiologic Trends

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Background: Diabetes in older adults is becoming a significant public burden to South Korea. However, a comprehensive understanding of epidemiologic trends and the detailed clinical characteristics of older adults with diabetes is lacking. Therefore, we evaluated epidemiologic trends and the metabolic and lifestyle characteristics of diabetes in Korean older adults.
Methods: We analyzed data from the Korea National Health and Nutrition Examination Survey to assess diabetes prevalence according to diabetes duration and lifestyle behaviors. In addition, we drew upon the National Health Information Database of the National Health Insurance System to assess physical activity levels, antidiabetic medication use, polypharmacy, medication adherence, and major comorbidities.
Results: The absolute number of newly diagnosed cases of diabetes among older adults doubled over the past decade. Management rates of metabolic indicators were higher in older adults with diabetes compared to those without diabetes. The proportion of older adults with diabetes meeting the minimum recommended physical activity increased over the years. Compared to 10 years before, the use of dipeptidyl peptidase-4 inhibitor or sodium-glucose cotransporter-2 inhibitor had increased, as had comorbidities such as dyslipidemia, dementia, cancer, heart failure, atrial fibrillation, and chronic kidney disease. Initial medication adherence was significantly lower in those with end-stage kidney disease or dementia, insulin use, high-risk alcohol use, and living alone. Continuing insulin use 1 year after diagnosis of diabetes was significantly higher in those who initiated insulin therapy at diagnosis, had retinopathy, were on triple antidiabetic medications, and had a history of cancer.
Conclusion: Comprehensive management of metabolic indicators and physical activity is essential for older adults with diabetes. Improvements in prescribing guidelines, personalized management of age-related comorbidities, and individualized approaches that consider the heterogeneous nature of older adults with diabetes are desirable. Further research, such as high-quality cohort and intervention studies specific to older adults, is needed to establish evidence-based management for older adults with diabetes.

Keywords: Aged; Comorbidity; Diabetes mellitus; Hypoglycemic agents; Insulin; Mortality; Polypharmacy

INTRODUCTION

Diabetes is a rapidly growing global public health concern, particularly regarding its impact on the older adult population. South Korea, with one of the fastest-growing life expectancies, is projected to become a leading longevity country by 2030 [1].

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This demographic shift is expected to significantly increase the burden of diabetes-related morbidity, mortality, and healthcare costs among older adults [2,3].

Older adults with diabetes often exhibit distinct clinical and metabolic profiles compared to the general older population. Managing diabetes in this group is particularly challenging due to physiological changes associated with aging, including frailty, high rates of comorbidities, polypharmacy, and varying levels of physical and cognitive function [4,5]. These complexities necessitate a tailored, older-adults-specific approach to the diagnosis, treatment, and monitoring of diabetes. Effective management of metabolic indicators such as blood glucose, blood pressure, lipid levels, and body composition is crucial. However, these factors are influenced by lifestyle habits, including physical activity, smoking, and alcohol consumption; accordingly, understanding metabolic and lifestyle management patterns in older adults with diabetes is essential for the development of effective strategies [6,7].

Over the past decade, advancements in pharmacological therapy, including the introduction of new antidiabetic agents and combination regimens, have transformed diabetes management [8,9]. However, the risks associated with polypharmacy—such as drug interactions and adverse effects—remain a significant concern, particularly in older adults with diabetes, who often require multiple medications [10]. Furthermore, older patients with diabetes frequently present with multiple chronic conditions, such as hypertension, dyslipidemia, cardiovascular disease, chronic kidney disease (CKD), and dementia. These comorbidities complicate disease management, increase the risk of complications, reduce quality of life, and escalate healthcare utilization. Despite these population-specific concerns, a comprehensive analysis of medication use trends and patterns in older adults with diabetes is still lacking. Furthermore, while the burden posed by diabetes in older patients is growing, evidence to guide optimal management strategies for this population remains limited. Current clinical guidelines often lack specificity for older patients, particularly in areas such as glycemic targets, medication selection, and the management of comorbidities and frailty [11,12].

This study examined epidemiological trends among older adults with diabetes in Korea and explored the metabolic and lifestyle characteristics, patterns of antidiabetic medication use, and trends in comorbidities. These findings offer valuable insights to inform clinical practice and public health policies.

METHODS

Study design

To analyze the prevalence of diabetes according to diabetes duration, data from the 5th (2011–2012), 6th (2013–2015), 7th (2016–2018), 8th (2019–2021), and 9th (2022) cycles of the Korea National Health and Nutrition Examination Survey (KNHANES) [13] were used. To assess the combined comorbidities and lifestyle behaviors related to diabetes, data from the 8th (2019–2021) and 9th (2022) cycles of the KNHANES were used.

To analyze trends in physical activity levels, a 60% sample cohort of adults aged 65 years and older with diabetes was extracted from the National Health Information Database (NHID) of the National Health Insurance System (NHIS) [14] between January 2009 and December 2017. We analyzed data from patients who underwent health checkups during the corresponding years. For the analysis of trends in antidiabetic medication use or comorbidities and mortality, we used a 60% sample cohort of adults aged 65 years and older with diabetes, extracted from the NHID between January 2012 and December 2022.

For analysis of trends in prescribed medication use and polypharmacy, we used NHIS-National Sample Cohort (NHIS-NSC), which includes one million individuals (approximately 2% of the total population). We analyzed data from adults aged 65 years and older between 2009 and 2019.

To assess adherence to antidiabetic medications within the first year following a diabetes diagnosis, as well as the continuation of insulin use after 1 year, we identified 2,616,828 diabetes patients who underwent health checkups through the NHIS between January 1, 2015 and December 31, 2016. We excluded patients younger than 65 years (n=1,699,522), those with missing key variables (n=19,948), those with a diabetes duration of more than 1 year (n=849,082), and those who died within 1 year after the health checkup (n=14,928), resulting in a total of 33,348 newly diagnosed older adults with diabetes.

To analyze factors associated with 3-year mortality, we identified 2,616,828 diabetes patients who underwent health checkups through the NHIS between January 1, 2015 and December 31, 2016. We excluded patients younger than 65 years (n=1,699,522) and those with missing key variables (n=47,309), leaving 869,997 patients. We then used a 70% sample of these 869,997 patients, resulting in a final sample of 608,998 patients.

Details of the data sources and study population used for each analysis are summarized in Supplementary Table 1.

This study was approved by the Institutional Review Board of The Catholic University of Korea, St. Vincent's Hospital (VC24ZISI0082). The requirement for informed consent was waived. The study was conducted in accordance with the principles of the Declaration of Helsinki.

Definition of variables

In the analysis using KNHANES data, diabetes was defined as fasting plasma glucose (FPG) ≥126 mg/dL, current use of diabetes medication, a previous diagnosis of diabetes, or glycosylated hemoglobin (HbA1c) ≥6.5%. Undiagnosed diabetes was defined as FPG ≥126 mg/dL or HbA1c ≥6.5%. without a previous diagnosis of diabetes. Hypertension was defined as systolic blood pressure (SBP) ≥140 mm Hg, diastolic blood pressure (DBP) ≥90 mm Hg, or current use of antihypertensive medication. Hypercholesterolemia was defined as low-density lipoprotein cholesterol (LDL-C) ≥100 mg/dL or current use of lipid-lowering medication. Control of hypertension was defined as SBP <140 mm Hg and DBP <85 mm Hg, and control of hypercholesterolemia was defined as an LDL-C level of <100 mg/dL. Body mass index (BMI) was used to categorized individuals as underweight (<18.5 kg/m^2), normal (18.5–22.9 kg/m^2), pre-obesity (23–24.9 kg/m^2), class 1 obesity (25–29.9 kg/m^2), class 2 obesity (30–34.9 kg/m^2), and class 3 obesity (≥35 kg/m^2). Abdominal obesity was defined as a waist circumference ≥90 cm for men and ≥85 cm for women [15]. Current smoking was defined as smoking at least five packs (or 100 cigarettes) in a lifetime and still smoking. High-risk alcohol consumption was defined as consuming at least seven drinks twice a week for men and at least five drinks twice a week for women. Regular walking was defined as walking for at least 30 minutes per day, 5 days per week.

In the analysis using NHID, a 60% sample cohort from NHID, and NHIS-NSC, diabetes was defined as FPG ≥126 mg/dL during health checkups or having at least one annual claim for antidiabetic medication prescribed under the International Classification of Diseases, 10th Revision codes E11–E14. Physical activity levels were assessed using the NHIS self-management questionnaire, with weekly physical activity calculated in metabolic equivalent of task (MET) and expressed as MET-min/week. Details of the survey content on physical activity and the calculation of METs are summarized in Supplementary Table 1. The use of antidiabetic medications across eight classes (metformin, sulfonylurea [SU], meglitinide, dipeptidyl peptidase-4 inhibitor [DPP4i], sodium-glucose co-transporter-2 inhibitor [SGLT2i], α-glucosidase inhibitor, thiazolidinedione, and insulin) was determined based on at least one prescription per year, except for insulin, which was identified if prescribed at least three times per year. Among glucagon-like peptide-1 receptor agonist (GLP-1 RA), only data for exenatide, lixisenatide, and albiglutide were available, so the use of GLP-1 RA could be significantly underestimated. Therefore, the GLP-1 RA was not included in this analysis. To analyze the number of prescribed medications, we collected the Korean general drug codes for the medications prescribed. The code consists of nine digits, including six numbers and three letters. The first four digits represent the active ingredient of the medication. We counted the number of unique active ingredients prescribed for at least 60 days per year, regardless of continuity. To analyze medication adherence, we used the medication possession ratio (MPR), because it is one of the most common measured for assessing adherence, and it is easy to use and calculate [16]. MPR was calculated by dividing the total days supplied of medication during observation period by the number of days in observation period. If the MPR ≥80%, it is considered as adherence. Information on deaths was obtained from the National Death Registry. The variables used to analyze trends in comorbidities and mortality, as well as factors associated with adherence to antidiabetic medications, continuation of insulin use (defined as at least 3 insulin prescriptions per year), and 3-year mortality risk, are summarized in Supplementary Table 1.

Statistical analysis

For the KNHANES data, sampling weights were used to obtain nationally representative prevalence estimates. All analyses were adjusted for survey year to minimize variation between years. The weighted prevalence of diabetes, combined comorbidities, and lifestyle behaviors were presented as percentages with standard error. The number of diabetes cases among older adults was compared between periods using analysis of variance (ANOVA). Combined comorbidities and lifestyle behaviors were compared between those with diabetes and those without diabetes using chi-square tests.

For the data of NHID, a 60% sample cohort from NHID, and NHIS-NSC, physical activity levels and use of antidiabetic medications were presented as percentages. Number of prescribed medications was presented as mean±standard deviation, median with interquartile range, or percentages. We used multivariable logistic regression models to analyze the factors

associated with adherence to antidiabetic medications or continued insulin use, calculating adjusted odds ratio with 95% confidence interval (CI) after adjusting for all variables (age, sex, income, smoking, drinking, regular exercise, BMI, waist circumference, insulin use, number of antidiabetic medications ≥3, severe hypoglycemia, diabetic retinopathy, hypertension, dyslipidemia, myocardial infarction, stroke, kidney function, depression, dementia, Parkinson's disease, cancer, chronic obstructive pulmonary disease, chronic liver disease, disabilities, living in a one-person household, pneumonia, heart failure, and fracture), except for the variable being examined. We also used multivariable Cox proportional hazards regression models to analyze the factors associated with 3-year mortality, calculating adjusted hazard ratio (HR) with 95% CI after adjusting for the same set of variables mentioned above. All analyses were performed using SAS software version 9.4 (SAS Institute, Cary, NC, USA). A two-sided *P* value of <0.05 was considered statistically significant without adjustment for multiple comparisons.

RESULTS

Trends in diabetes prevalence by duration in older adults

Table 1 demonstrates a substantial increase in the number of undiagnosed diabetes patients aged 65 years and older, rising from approximately 326,000 in 2011–2012 to 474,000 in 2019–2022. Similarly, the number of newly diagnosed diabetes cases within 1 year of diagnosis in this population more than doubled, from 105,042 to 222,966 during the same period. While the absolute number of undiagnosed diabetes cases increased, the prevalence of undiagnosed diabetes displayed a declining trend. Notably, the proportion of long-term diabetes cases, defined as a disease duration of 10 years or more, showed a significant rise, increasing from 26.7% in 2011–2012 to 35.0% in 2019–2022.

Metabolic and lifestyle indices in older adults with diabetes

The prevalence of hypertension and concomitant hypertension and hypercholesterolemia was 72.6% and 52.0%, respectively, in older adults with diabetes, both of which were higher than

Table 1. Weighted prevalence of diabetes according to diabetes duration among adults aged 65 years and older, KNHANES 2011 to 2022

Year	2011–2012	2013–2015	2016–2018	2019–2022
Undiagnosed diabetes				
No. of patients aged ≥65 years	325,978	349,391	392,219	473,645
Prevalence, %	28.1±2.2	27.4±2.0	22.1±1.4	21.2±1.1
Diabetes duration <1 year				
No. of patients aged ≥65 years	105,042	89,065	175,846	222,966
Prevalence, %	9.0±1.4	7.0±1.0	9.9±1.0	10.0±0.9
Diabetes duration 1 to <3 years				
No. of patients aged ≥65 years	120,689	122,825	140,812	288,384
Prevalence, %	10.4±1.5	9.6±1.4	7.9±0.9	10.2±0.8
Diabetes duration 3 to <5 years				
No. of patients aged ≥65 years	89,930	116,928	151,592	168,264
Prevalence, %	7.7±1.3	9.2±1.1	8.5±0.9	7.5±0.6
Diabetes duration 5 to <10 years				
No. of patients aged ≥65 years	210,507	235,653	304,979	358,138
Prevalence, %	18.1±1.9	18.5±1.7	17.2±1.3	16.1±1.0
Diabetes duration ≥10 years				
No. of patients aged ≥65 years	309,727	360,478	611,741	799,820
Prevalence, %	26.7±2.1	28.3±1.7	34.4±1.7	35.0±1.3

Values are presented as mean±standard error.
KNHANES, Korea National Health and Nutrition Examination Survey.

in older adults without diabetes. The prevalence of hypercholesterolemia was 70.5% in older adults with diabetes, which was lower than in older adults without diabetes. The control rate for hypertension was 61.8%, while that for hypercholesterolemia was 67.5%, both higher than in older adults without diabetes (56.8% for hypertension and 42.4% for hypercholesterolemia). The respective prevalences of obesity and abdominal obesity were 43.5% and 62.9%, also significantly high compared to older adults without diabetes (33.5% for obesity and 45.5% for abdominal obesity). The rates of smoking, high-risk alcohol consumption, and regular walking did not show significant differences between older adults with and without diabetes (Table 2). According to trends in physical activity levels among older adults with diabetes, the proportion of those with minimal activity (METs=0) gradually decreased, while the proportion of those meeting the minimum recommended physical activity of 500 METs per week steadily increased over the years. Notably, the proportion of individuals achieving 1,500 METs or more per week was found to be 8.0% among those aged 65 years and older and 6.0% among those aged 75 years and older (Supplementary Table 2).

Current status of antidiabetic medication use among older adults with diabetes

Among older adults with diabetes, the use of insulin and SU has decreased, while the use of DPP4i and SGLT2i has increased from 2012 to 2022. The proportion of older adults with diabetes using combination therapy with three or more oral antidiabetic agents has also risen in the same period, comprising 34.4% as of 2022 (Supplementary Table 3, Supplementary Fig. 1). As of 2019, the average number of prescribed medications for older adults with diabetes increased to 9.4 among

Table 2. Combined comorbidity and lifestyle behaviors among adults aged 65 years and older, KNHANES 2019 to 2022

Variable	Non-diabetes (n=4,389)	Diabetes (n=1,843)	P value
Weight status, %			
Underweight (BMI <18.5 kg/m^2)	3.2±0.3	1.8±0.4	
Normal (BMI 18.5–22.9 kg/m^2)	36.8±0.9	28.3±1.3	
Pre-obesity (BMI 23.0–24.9 kg/m^2)	26.5±0.7	26.4±1.3	
Class 1 obesity (BMI 25.0–29.9 kg/m^2)	30.4±0.8	37.9±1.3	
Class 2 obesity (BMI 30.0–34.9 kg/m^2)	2.9±0.3	4.9±0.6	
Class 3 obesity (BMI ≥35.0 kg/m^2)	0.2±0.1	0.7±0.2	
Obesity, %	33.5±0.4	43.5±0.7	<0.001
Abdominal obesity, %	45.5±1.0	62.9±1.3	<0.001
Hypertension, %			
Prevalence	58.6±0.9	72.6±1.2	<0.001
Control rate	56.8±1.2	61.8±1.6	0.013
Hypercholesterolemia, %			
Prevalence	78.8±0.7	70.5±1.3	<0.001
Control rate	42.4±0.9	67.5±1.3	<0.001
Concomitant hypertension and hypercholesterolemia, %	46.1±0.9	52.0±1.4	<0.001
HbA1c <6.5%+BP <140/85 mm Hg+LDL-C level <100 mg/dL, %	31.5±0.8	15.2±1.0	<0.001
HbA1c <7.5%+BP <140/85 mm Hg+LDL-C level <100 mg/dL, %	31.5±0.8	40.1±1.3	<0.001
Current smoker, %	9.3±0.6	10.4±0.8	0.297
High-risk alcohol consumption, %	5.1±0.4	6.3±0.7	0.136
Regular walking, %	43.7±1.0	41.7±1.4	0.227

Values are presented as mean±standard error. P value for comparing older adults with diabetes vs. those without diabetes.
KNHANES, Korea National Health and Nutrition Examination Survey; BMI, body mass index; HbA1c, glycosylated hemoglobin; BP, blood pressure; LDL-C, low-density lipoprotein cholesterol.

those aged 65 years and older, which is approximately 1.8 times higher than the average for non-diabetic individuals. Among those aged 65 years and older, 5.5% were prescribed 20 or more medications (Supplementary Table 4).

Among 33,348 newly diagnosed adults with diabetes aged 65 years and older between 2015 and 2016, 67.8% had a MPR of 80% or higher. The odds of MPR ≥80% within the first year were higher in women, those with a BMI ≥23.0 kg/m^2, those with dyslipidemia, those with hypertension, and those on triple oral therapy. Conversely, the odds were lower in heavy drinkers, those with a BMI <18.5 kg/m^2, insulin users, those with end-stage kidney disease (ESKD), those with myocardial infarction, depression, dementia, or fracture, and those living alone (Supplementary Table 5). One year after the initial diagnosis, 369 patients (1.1%) continued insulin use. The odds of continuing insulin use after 1 year were significantly higher in those who initiated insulin therapy at diagnosis, had retinopathy, were on triple antidiabetic medications, had a history of cancer or CKD, were smokers, or were male (Supplementary Table 6).

Current status of comorbidities among older adults with diabetes

An examination of comorbidities in older adults with diabetes reveals that, as of 2022, the prevalence of hypertension, stroke, and proliferative retinopathy had decreased compared to 10 years ago, while the prevalence of dyslipidemia, dementia, cancer, heart failure, atrial fibrillation, and CKD had increased. In 2022, the prevalence rates of hypertension and dyslipidemia were 77.1% and 77.1%, respectively, with dementia, cancer, and heart failure following as the most common comorbidities (Fig. 1, Supplementary Table 7). Among adults with diabetes aged 65 years and older, the comorbidity most strongly associated with 3-year mortality risk was ESKD (HR, 2.54; 95% CI, 2.33 to 2.77). Other conditions associated with increased mortality risk included dementia, cancer, pneumonia, and CKD (Fig. 2, Supplementary Table 8).

DISCUSSION

Principal findings

In this study, we identified a marked increase in the absolute number of newly diagnosed diabetes and the prevalence of long-standing diabetes over the past 10 years among older adults with diabetes in Korea. Management rates of hypertension and hypercholesterolemia were higher in older adults with diabetes compared to those without diabetes. The proportion of older adults with diabetes using combination therapy with three or more oral antidiabetic medications has increased over the years. In addition, comorbidities such as dementia, cancer, heart failure, and CKD have increased compared to 10 years before. Factors associated with poor initial medication adherence included having major comorbidities like ESKD or dementia, being an insulin user, high-risk alcohol use, and living alone. Factors associated with continuing insulin use 1 year after diagnosis of diabetes included initial insulin use at diag-

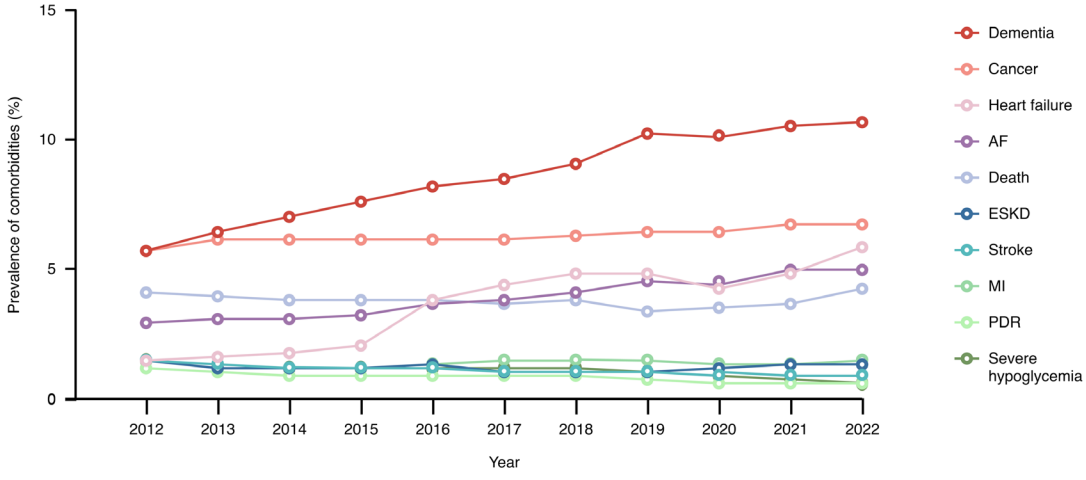

Fig. 1. Trends of comorbidities (excluding hypertension and dyslipidemia) among adults with diabetes aged 65 years and older, 60% sample cohort from National Health Information Database 2012 to 2022. AF, atrial fibrillation; ESKD, end-stage kidney disease; MI, myocardial infarction; PDR, proliferative diabetic retinopathy.

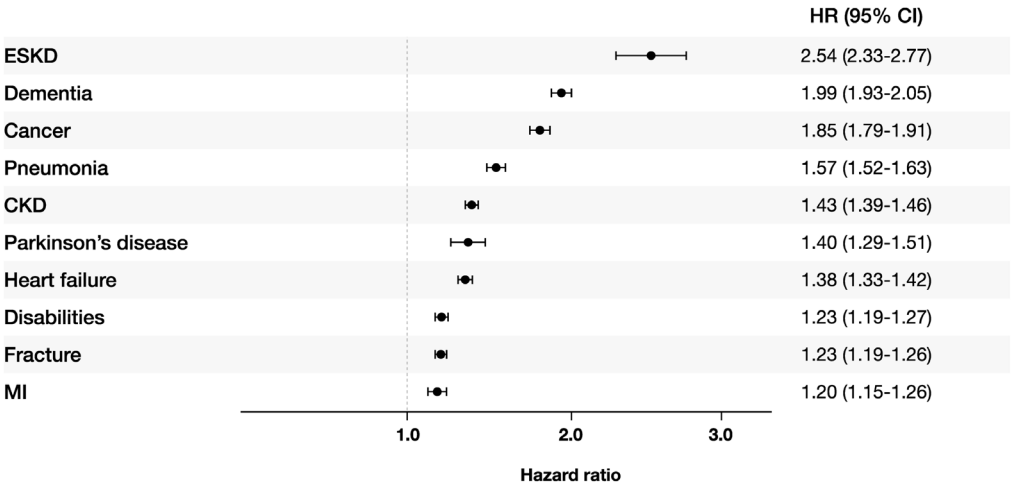

Fig. 2. Mortality risk within 3 years of major comorbidities among adults with diabetes aged 65 years and older, National Health Information Database 2015 to 2016. HR, hazard ratio; CI, confidence interval; ESKD, end-stage kidney disease; CKD, chronic kidney disease; MI, myocardial infarction.

nosis, presence of retinopathy, use of triple oral therapy, and a history of cancer. Comorbidities associated with 3-year mortality included ESKD, dementia, cancer, pneumonia, and CKD.

Increased number of diabetes cases in older adults

In this analysis, we observed a significant increase in the absolute number of diabetes cases among individuals aged 65 years and older, irrespective of diabetes duration. According to a recent study, the estimated prevalence of diabetes among individuals aged 65 and older was 29.3% from 2019 to 2022 in Korea [17]. This prevalence was higher than that in individuals aged 30 years and older [18]. These can be attributed to a combination of aging-related physiological changes, lifestyle and environmental factors, psychological influences, and socioeconomic conditions. As aging progresses, individuals become more susceptible to the onset and progression of diabetes. Age-related decline in pancreatic function results in decreased insulin secretion, while factors such as reduced muscle mass, increased visceral fat, mitochondrial dysfunction in muscles, and increased inflammation contribute to decreased insulin sensitivity and inhibition of insulin signaling, thereby promoting diabetes onset in older adults [19]. Additionally, decreased physical activity and increased sedentary behavior in older adults reduces energy expenditure and increases insulin resistance, heightening the risk of diabetes [20,21]. Finally, other common issues among older adults, such as depression, cognitive impairment, reduced income, and living alone, also negatively impact lifestyle management and restrict access to healthcare services [22].

The prevalence of diabetes among individuals aged 65 and older has increased globally, with an estimated rate of 18.8% in 2017, and it is projected to reach 19.6% by 2030 [23]. Compared to the global prevalence of diabetes among individuals aged 65 and older, the prevalence of diabetes in Korea for the same age group was higher. This could be explained by the increasing prevalence of diabetes with age and the growing aging population in Korea [24].

Although expanded screening programs, and heightened awareness of diabetes in Korea have contributed to a decline in undiagnosed diabetes among older adults [25], the rising number of newly diagnosed older adults with diabetes and those with long-standing diabetes due to population aging and increased life expectancy is expected to further intensify the medical, economic, and societal burden of diabetes in this population. In this context, the importance of developing integrated and sustainable management systems for older adults with diabetes has become increasingly apparent. Strengthening tailored, multidimensional approaches that consider disease progression, comorbidities, functional decline, cognitive status, and quality of life is essential for effective management of diabetes in older adults [4].

Management rates of metabolic indicators in older adults with diabetes

Although prevalence of new-onset diabetes among older adults and estimated number of older adults with any diabetes

duration are high, it is encouraging that we identified control rates of hypertension and hypercholesterolemia in older adults with diabetes as favorable compared to those of the non-diabetic population. In addition, we found that the proportion of individuals meeting the minimum recommended physical activity of 500 METs per week increased over the years. These results may be attributed to the excellent healthcare accessibility in Korea, which has led to expanded diabetes screening in older adults, appropriate metabolic management, and improvements in standardized clinical guidelines, effective medication use, and management approaches [26-28]. Improvements in health literacy and education levels, and government programs such as the Community-based Hypertension and Diabetes Registry Program and the Chronic Disease Management Program may have also contributed to these positive outcomes [29,30]. From another perspective, the more favorable control rates of hypertension and hypercholesterolemia in older adults with diabetes compared to those without diabetes can be explained by the more frequent use of antihypertensive combination medications and a higher use of lipid-lowering medications in individuals with diabetes [31,32].

Medication use in older adults with diabetes

Recent pattern of diabetes medication use in older adults has not shown significant differences compared to that in the general diabetes population [33]. Although there are currently no specific guidelines for diabetes medication therapy tailored for older adults, various unique factors must be considered when prescribing medications to older patients [12]. Therefore, it is essential to develop additional, distinct guidelines based on evidence from older rather than younger adults, with personalized medication strategies tailored to the health status of older adults. Polypharmacy in older patients is associated with decreased medication adherence, an increased risk of drug-drug interactions and adverse effects, and a prescribing cascade that can perpetuate a detrimental cycle [34]. Our analysis revealed that older adults with diabetes are prescribed approximately 1.8 times more medications than those without diabetes, with this trend showing a consistent increase over time. These findings highlight the need for regular evaluation of prescribing appropriateness, deprescribing unnecessary medications, and implementing personalized treatment strategies to optimize medication management. Additionally, the importance of an integrated and systematic approach to managing complex chronic conditions in older adults cannot be overstated.

Additionally, initial medication adherence is one of the key elements in diabetes management, but only about two-thirds of patients achieve adherence rates of 80% or higher, indicating a need to identify and address risk factors that contribute to poor adherence. This study determined that among older adults with diabetes, factors associated with low medication adherence within the first year of diagnosis include the presence of severe comorbidities such as ESKD, fracture, dementia, and myocardial infarction, as well as characteristics like insulin use. Initiating insulin therapy in newly diagnosed older adults with diabetes can lead to low adherence and suboptimal management due to the complexity of administration and management, as well as fear or aversion to injections [35]. To address these challenges, standardized education programs, specialized training to enhance healthcare providers' educational skills, certification for education, expanded financial support for insulin and supplies, and increased insurance coverage for continuous glucose monitoring could be beneficial. In addition, considering that two behavioral/educational interventions and three pharmacist interventions among 12 intervention studies improved both medication adherence and related health outcomes in older adults [36], the development of patient-centered, multidisciplinary interventions is needed in the future.

Comorbidities and mortality risk in older adults with diabetes

The pattern of comorbidities in the older adult population has changed in the past decade. With population aging and increased life expectancy, the prevalence of age-related conditions such as dementia, heart failure, and CKD appears to be rising. Among older adults with diabetes, the prevalence of major conditions such as hypertension and dyslipidemia remains high, exceeding 75%, while the prevalence of dementia, cancer, heart failure, and atrial fibrillation is also above 5%. These findings underscore the need for appropriate screening and management strategies to ensure effective prevention of and care for these comorbidities. In Korea, the comorbidity with the highest risk of mortality among older adults with diabetes is ESKD, followed by dementia and cancer. Diabetes itself is the most common cause of ESKD, and older adults with ESKD are at higher risk of complications such as cardiovascular disease and infection, as well as having a poor prognosis due to the burden of dialysis treatment and decreased quality of life [37-40]. Dementia also contributes to low treatment adherence by means of cognitive impairment and communica-

tion difficulties [41,42]. Notably, while it is crucial to strengthen the management of various comorbidities associated with diabetes for optimal treatment, limited healthcare resources necessitate prioritization. Focusing medical resources on managing comorbidities with high prevalence and significant mortality risk may be a necessary strategy.

Strengths and limitations

This study's strength lies in its use of a large-scale nationwide dataset to investigate various aspects of older adults with diabetes. However, the study also has several limitations. First, due to constraints in the data, different datasets were used depending on the topic, which may have influenced interpretation of the results. Second, the use of operational definitions for certain variables introduces a potential for misclassification bias. Third, some parameters that are key for diabetes management, such as diabetes duration and HbA1c, were not included in the analysis. Lastly, this work did not include detailed analyses reflecting the heterogeneous characteristics of older adults with diabetes, which could limit the findings.

In conclusion, effective strategies to address diabetes in older patients are urgently needed due to the rapidly growing older population. Comprehensive management of metabolic indicators such as blood glucose, blood pressure, dyslipidemia, obesity, and frailty, along with physical activity, is essential for older adults with diabetes. Furthermore, improvements in prescribing guidelines are needed that account for the unique characteristics of older adults, particularly in managing polypharmacy. To improve adherence to antidiabetic medication in older adults, the development of patient-centered, multidisciplinary interventions is needed. Continuous monitoring and personalized management of age-related comorbidities frequently associated with diabetes in older adults are also crucial. Lastly, individualized approaches that consider the heterogeneous nature of diabetes in older patients may serve as effective management strategies. To realize these advancements, future research should focus on developing high-quality older cohorts and older-adults-specific intervention studies to establish evidence-based management for older adults with diabetes.

SUPPLEMENTARY MATERIALS

Supplementary materials related to this article can be found online at https://doi.org/10.4093/dmj.2024.0836.

CONFLICTS OF INTEREST

Seung-Hyun Ko has been the executive editor of the *Diabetes & Metabolism* Journal since 2022. Sung Hee Choi has been an associate editor of the *Diabetes & Metabolism Journal* since 2022. They were not involved in the review process of this article. Otherwise, there was no conflict of interest.

AUTHOR CONTRIBUTIONS

Conception or design: all authors.
Acquisition, analysis, or interpretation of data: K.K., B.K., K.L., K.H., J.S.Y.
Drafting the work or revising: K.K., K.H., J.S.Y.
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Supplementary Table 1. Details of the data sources, study population, and variables used in the tables

Data sources and study population	
Table 1. Weighted prevalence of diabetes according to diabetes duration among adults aged 65 years and older, KNHANES 2011 to 2022	
Data source	KNHANES
Study population	We used data from the 5th (2011–2012), 6th (2013–2015), 7th (2016–2018), 8th (2019–2021), and 9th (2022) cycles of the KNHANES.
Table 2. Combined comorbidity and lifestyle behaviors among adults aged 65 years and older, KNHANES 2019 to 2022	
Data source	KNHANES
Study population	We used data from the 8th (2019–2021) and 9th phases (2022) of the KNHANES
Supplementary Table 2. Trends in physical activity levels among adults with diabetes aged 65 years and older, 60% sample cohort from NHID 2009 to 2017	
Data source	60% Sample cohort from NHID
Study population	Among a 60% sample cohort of adults aged 65 years and older with diabetes, extracted from the NHID between January 2009 and December 2017, we analyzed data from patients who underwent health checkups in the corresponding years.
Supplementary Table 3. Trends of antidiabetic medications use among adults with diabetes aged 65 years and older, 60% sample cohort from NHID 2012 to 2022	
Data source	60% Sample cohort from NHID
Study population	We used a 60% sample cohort of adults aged 65 years and older with diabetes, extracted from the NHID between January 2012 and December 2022.
Supplementary Table 4. Trends in prescribed medication use and polypharmacy among older adults with and without type 2 diabetes mellitus, NHIS-NSC 2009 to 2019	
Data source	National Health Insurance Service-National Sample Cohort (NHIS-NSC)
Study population	From the NHIS-NSC, which includes one million people (approximately 2% of the total population), we analyzed data from adults aged 65 years and older between 2009 and 2019.
Supplementary Table 5. Adherence to antidiabetic medications within 1 year after diagnosis of diabetes among adults aged 65 years and older, NHID 2015 to 2016	
Data source	NHID
Study population	From the NHID, we identified 2,616,828 individuals with diabetes who underwent health checkups through the NHIS between January 1, 2015 and December 31, 2016. We excluded subjects who were younger than 65 years (n=1,699,522), those with missing key variables (n=19,948), those with a diabetes duration of more than 1 year (n=849,082), and those who died within 1 year after the health checkup (n=14,928). This resulted in a total of 33,348 newly diagnosed older adults with diabetes.
Supplementary Table 6. Continuing insulin use 1 year after diagnosis of diabetes among adults aged 65 years and older, NHID 2015 to 2016	
Data source	NHID
Study population	From the NHID, we identified 2,616,828 individuals with diabetes who underwent health checkups through the NHIS between January 1, 2015 and December 31, 2016. We excluded subjects who were younger than 65 years (n=1,699,522), those with missing key variables (n=19,948), those with a diabetes duration of more than 1 year (n=849,082), and those who died within 1 year after the health checkup (n=14,928). This resulted in a total of 33,348 newly diagnosed older adults with diabetes.
Supplementary Table 7. Trends of comorbidities and mortality among adults with diabetes aged 65 years and older, 60% sample cohort from NHID 2012 to 2022	
Data source	60% Sample cohort from NHID
Study population	We used a 60% sample cohort of adults aged 65 years and older with diabetes, extracted from the NHID between January 2012 and December 2022.
Supplementary Table 8. Factors associated with 3-year mortality among adults with diabetes aged 65 years and older, NHID 2015 to 2016	
Data source	NHID
Study population	From the NHID, we identified 2,616,828 diabetes patients who underwent health checkups through the NHIS between January 1, 2015 and December 31, 2016. We excluded patients younger than 65 years (n=1,699,522) and those with missing key variables (n=47,309), leaving 869,997 patients. We then used a 70% sample of these 869,997 patients, resulting in a final sample of 608,998 patients.

(*Continued to the next page*)

Supplementary Table 1. Continued

Variables and remarks in Supplementary Table 2	
Physical activity	Physical activity levels were assessed using an NHIS self-management questionnaire, a modified version of the International Physical Activity Questionnaire. The questionnaire about physical activity was composed of three questions about the frequency (days per week) of light, moderate, and vigorous physical activity during a recent week: the frequency of (1) light intensity physical activity for more than 30 minutes (e.g., walking at a slow pace), (2) moderate-intensity physical activity for more than 30 minutes (e.g., brisk walking or slow cycling), and (3) vigorous intensity physical activity for more than 20 minutes (e.g., running, jogging, or bicycling >15 km/hr) [1]. For quantitative estimation, we calculated each participant's weekly physical activity volume as the METs, expressed as MET-min/week. We assigned 3, 5, and 8 METs for light physical activity, moderate physical activity, and vigorous physical activity, respectively [2]. Using the minimum time consumed for each physical activity category, we calculated the overall volume of weekly physical activity (MET-min/week) as follows: (3 METs×30 min×a)+(5 METs×30 min×b)+(8 METs×20 min×c), where a, b, and c are the frequencies of light physical activity, moderate physical activity, and vigorous physical activity respectively [3]. Finally, MET-min/week was stratified into four groups: 0, 0 to <500, 500 to <1,500, and ≥1,500 MET-min/week.
Variables and remarks in Supplementary Tables 5, 6, 7, and 8	
Income	Classified as 'Not Medical Aid' or 'Medical Aid' (subjects who received medical benefits according to the Medical Care Assistance Act)
Smoking	Classified as 'non-smoker,' 'ex-smoker,' or 'current smoker'
Drinking	Classified as 'none,' 'mild to moderate consumption (<30 g of alcohol/day),' or 'heavy consumption (≥30 g of alcohol/day)'
Regular exercise	Classified as 'no' or 'yes' (high-intensity activities ≥3 times a week, or moderate-intensity activities ≥5 times a week)
Insulin	Classified as 'no' or 'yes' (at least one prescription of insulin per year)
Number of antidiabetic medications	Number of prescriptions for each antidiabetic medication class
Severe hypoglycemia	Classified as 'no' or 'yes' (any claims for ICD-10 codes [E1163, E1463, E160, E161, or E162] from emergency room)
Diabetic retinopathy	Classified as 'no' or 'yes' (ICD-10 code [H36.0] among subjects with type 2 diabetes mellitus)
Hypertension	Classified as 'no' or 'yes' (at least one claim per year under ICD-10 codes [I10–I13 or I15] and at least one claim per year for the prescription of antihypertensive agents)
Dyslipidemia	Classified as 'no,' 'yes without statin,' or 'yes with statin' (at least one claim per year under ICD-10 code [E78] and at least one claim per year for the prescription of a lipid-lowering agent with or without at least one claim per year for the prescription of statins)
Myocardial infarction	Classified as 'no' or 'yes' (ICD-10 codes [I21 or I22] that were claimed during hospitalization)
Stroke	Classified as 'no' or 'yes' (ICD-10 code [I63 or I64] with claims for brain magnetic resonance imaging or computerized tomography during hospitalization)
Kidney function	Classified as 'normal,' 'CKD,' or 'ESKD' CKD: eGFR <60 mL/min/1.73 m^2, except ESKD ESKD: ICD-10 codes (N18 or N19) and registration codes for renal replacement therapy (V001, V003, V005)
Depression	Classified as 'no' or 'yes' (ICD-10 codes [F32 or F33])
Dementia	Classified as 'no' or 'yes' (prescription of anti-dementia medications [rivastigmine, galantamine, memantine, or donepezil] along with ICD-10 codes [F00, F01, F02, F03, G30, or G31])
Parkinson's disease	Classified as 'no' or 'yes' (ICD-10 code [G20] and a registration code [V124])
Cancer	Classified as 'no' or 'yes' (ICD-10 'C' codes from outpatient and inpatient claims, and a registration code for cancer [V193])
COPD	Classified as 'no' or 'yes' (ICD-10 codes [J43–J44 except J43.0], and ≥2 outpatient visits or ≥1 hospitalization claims)
Chronic liver disease	Classified as 'no' or 'yes' (ICD-10 codes [B18, K70, K71.3-71.5, K71.7, K72.1, K72.7, K72.9, K73, K74, or K76] at least two times)
Disabilities	Classified as 'no' or 'yes' Disability was identified using data from the Korean National Disability Registration System, linked to the NHID. Disability registration required a medical examination by a qualified specialist in the relevant field, followed by a medical advisory meeting to review the degree of disability based on the submitted documents [4].
One-person household (living alone)	Classified as 'no' or 'yes' (based on the number of family members registered in the NHID)
Pneumonia	Classified as 'no' or 'yes' (ICD-10 codes [J12–18])

(*Continued to the next page*)

Supplementary Table 1. Continued

Variables and remarks in Supplementary Tables 5, 6, 7, and 8	
Heart failure	Classified as 'no' or 'yes' (ICD-10 code [I50] from claims during hospitalization)
Fracture	Classified as 'no' or 'yes' (vertebral [S22.0, S22.1, S32.0, M48.4, and M48.5] or hip [S72.0 and S72.1] or upper arm [S42.0, S42.2, and S42.3] or forearm [S52.5 and S52.6], or lower leg [S82.3, S82.5, and S82.6])
Atrial fibrillation	ICD-10 code (I48) that were claimed at least once during hospitalization or twice in outpatient visits.
Proliferative diabetic retinopathy	Procedure codes S5160 or S5161 for pan-retinal photocoagulation in patients already diagnosed with diabetic retinopathy (ICD-10 code H360) within 1 year.
Death	Ascertained from the National Death Registry

KNHANES, Korea National Health and Nutrition Examination Survey; NHID, National Health Information Database; NHIS-NSC, National Health Insurance Service-National Sample Cohort; NHIS, National Health Insurance System; MET, metabolic equivalent of task; ICD-10, International Classification of Diseases, 10th revision; CKD, chronic kidney disease; ESKD, end-stage kidney disease; eGFR, estimated glomerular filtration rate; COPD, chronic obstructive pulmonary disease.

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Supplementary Table 2. Trends in physical activity levels among adults with diabetes aged 65 years and older, 60% sample cohort from NHID 2009 to 2017

Year	2009	2010	2011	2012	2013	2014	2015	2016	2017
No. of patients aged ≥65 years	127,876	144,508	156,590	173,841	188,188	210,762	227,330	247,990	269,101
MET-min/week									
0	40,221 (31.5)	43,315 (30.0)	46,318 (29.6)	50,851 (29.3)	54,738 (29.1)	58,193 (27.6)	60,819 (26.8)	63,660 (25.7)	66,508 (24.7)
0 to <500	31,741 (24.8)	35,709 (24.7)	38,566 (24.6)	43,227 (24.9)	46,776 (24.9)	54,506 (25.9)	58,094 (25.6)	65,291 (26.3)	70,435 (26.2)
500 to <1,500	45,558 (35.6)	54,182 (37.5)	59,484 (38.0)	65,906 (37.9)	71,699 (38.1)	81,523 (38.7)	90,490 (39.8)	99,701 (40.2)	110,716 (41.1)
≥1,500	10,356 (8.1)	11,302 (7.8)	12,222 (7.8)	13,857 (8.0)	14,975 (8.0)	16,540 (7.9)	17,927 (7.9)	19,338 (7.8)	21,442 (8.0)
No. of patients aged 65–74 years	101,863	113,572	119,715	130,925	138,905	152,195	159,612	173,541	181,868
MET-min/week									
0	30,008 (29.5)	31,825 (28.0)	32,677 (27.3)	35,021 (26.8)	36,650 (26.4)	37,773 (24.8)	38,121 (23.9)	39,527 (22. 8)	39,252 (21.6)
0 to <500	25,029 (24.6)	27,819 (24.5)	29,148 (24.4)	32,367 (24.7)	34,007 (24.5)	38,769 (25.5)	40,294 (25.2)	45,296 (26.1)	47,107 (25.9)
500 to <1,500	37,908 (37.2)	44,287 (39.0)	47,652 (39.8)	52,105 (39.8)	56,099 (40.4)	62,351 (41.0)	67,341 (42.2)	73,624 (42.4)	79,309 (43.6)
≥1,500	8,918 (8.8)	9,641 (8.5)	10,238 (8.6)	11,432 (8.7)	12,149 (8.8)	13,302 (8.7)	13,856 (8.7)	15,094 (8.7)	16,200 (8.9)
No. of patients aged ≥75 years	26,013	30,936	36,875	42,916	49,283	58,567	67,718	74,449	87,233
MET-min/week									
0	10,213 (39.3)	11,490 (37.1)	13,641 (37.0)	15,830 (36.9)	18,088 (36.7)	20,420 (34.9)	22,698 (33.5)	24,133 (32.4)	27,256 (31.3)
0 to <500	6,712 (25.8)	7,890 (25.5)	9,418 (25.5)	10,860 (25.3)	12,769 (25.9)	15,737 (26.9)	17,800 (26.3)	19,995 (26.9)	23,328 (26.7)
500 to <1,500	7,650 (29.4)	9,895 (32.0)	11,832 (32.1)	13,801 (32.2)	15,600 (31.7)	19,172 (32.7)	23,149 (34.2)	26,077 (35.0)	31,407 (36.0)
≥1,500	1,438 (5.5)	1,661 (5.4)	1,984 (5.4)	2,425 (5.7)	2,826 (5.7)	3,238 (5.5)	4,071 (6.0)	4,244 (5.7)	5,242 (6.0)

Values are presented as number (%).
NHID, National Health Information Database; MET, metabolic equivalent of task.

Supplementary Table 3. Trends of antidiabetic medications use among adults with diabetes aged 65 years and older, 60% sample cohort from NHID 2012 to 2022

Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
No. of patients aged ≥65 years	698,866	745,837	804,676	853,260	909,762	986,562	1,054,918	1,145,181	1,240,705	1,339,971	1,441,688
Insulin, %[a]	10.3	9.8	9.3	9.1	9.1	9.1	9.0	8.9	9.1	8.8	8.7
Metformin, %	80.8	82.3	83.2	83.8	84.1	84.3	84.5	85.0	85.3	85.4	85.2
SU, %	63.9	60.1	56.4	52.8	49.5	46.8	44.5	42.5	41.0	39.4	38.0
Meglitinides, %	3.2	2.5	2.0	1.5	1.1	0.8	0.7	0.5	0.4	0.4	0.2
TZD, %	6.3	6.1	7.9	9.1	9.8	10.2	10.6	10.9	11.0	10.9	10.8
AGI, %	15.5	11.3	8.6	6.5	4.8	3.7	2.8	2.3	1.9	1.5	1.1
DPP4i, %	24.6	33.7	40.6	48.5	55.1	59.1	61.9	63.5	64.7	65.0	64.5
SGLT2i, %	0.0	0.0	0.4	1.2	2.3	3.6	4.4	5.9	7.3	9.2	11.5
No. of oral antidiabetic medications, %											
1	28.4	28.2	27.8	26.8	25.8	25.3	24.9	24.9	24.5	24.5	24.7
2	42.1	40.9	39.7	39.0	38.8	38.7	38.8	38.7	38.9	39.0	39.0
3	20.8	23.0	24.3	26.2	27.5	28.3	28.8	29.0	29.4	29.4	29.2
4	4.3	3.9	4.2	4.5	4.7	4.6	4.6	4.8	4.7	4.6	4.7
≥5	0.4	0.3	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5

NHID, National Health Information Database; SU, sulfonylurea; TZD, thiazolidinedione; AGI, alpha-glucosidase inhibitor; DPP4i, dipeptidyl peptidase-4 inhibitor; SGLT2i, sodium-glucose cotransporter-2 inhibitor.
[a]Insulin use was recognized if being prescribed at least three times a year.

Supplementary Table 4. Trends in prescribed medication use and polypharmacy among older adults with and without type 2 diabetes mellitus, NHIS-NSC 2009 to 2019

Variable	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Older adults without diabetes											
Number	93,179	95,061	97,264	101,331	105,066	108,689	112,079	114,796	119,455	123,015	127,444
No. of prescribed medications											
Mean±SD	4.2±4.5	4.3±4.6	4.4±4.5	4.5±4.6	4.5±4.6	4.6±4.7	4.6±4.6	4.7± 4.7	4.7±4.7	4.8±4.8	5.1±4.9
Median (IQR)	3 (0–6)	3 (0–67)	3 (0–67)	3 (1–67)	3 (1–67)	3 (1–67)	3 (1–67)	4 (1–67)	4 (1–67)	4 (1–67)	4 (1–68)
Maximum	43	41	47	50	60	53	49	50	50	50	55
0	28,102 (30.2)	26,478 (27.9)	25,562 (26.3)	25,261 (24.9)	25,124 (23.9)	25,274 (23.3)	25,372 (22.6)	24,657 (21.5)	24,888 (20.8)	24,567 (20.0)	23,514 (18.5)
1 to <5	29,558 (31.7)	31,086 (32.7)	32,791 (33.7)	34,777 (34.3)	36,589 (34.8)	38,239 (35.2)	40,534 (36.2)	41,468 (36.1)	43,831 (36.7)	45,036 (36.6)	45,410 (35.6)
5 to <10	24,109 (25.9)	25,424 (26.7)	26,359 (27.1)	28,011 (27.6)	29,103 (27.7)	30,086 (27.7)	30,793 (27.5)	32,302 (28.1)	33,621 (28.2)	34,885 (28.4)	37,403 (29.4)
10 to <20	10,613 (11.4)	11,215 (11.8)	11,678 (12.0)	12,292 (12.1)	13,165 (12.5)	13,920 (12.8)	14,196 (12.7)	15,043 (13.1)	15,759 (13.2)	16,993 (13.8)	19,270 (15.1)
≥20	797 (0.9)	858 (0.9)	874 (0.9)	990 (1.0)	1,085 (1.0)	1,170 (1.1)	1,184 (1.1)	1,326 (1.2)	1,356 (1.1)	1,534 (1.3)	18,47 (1.5)
Older adults with diabetes											
Number	19,645	21,236	23,068	24,851	26,603	28,209	29,967	31,584	34,340	36,652	39,646
No. of prescribed medications											
Mean±SD	8.9±5.4	8.9±5.3	8.9±5.4	8.9±5.4	9.0±5.4	9.0±5.4	9.0±5.4	9.1±5.4	9.1±5.4	9.2±5.5	9.4±5.5
Median (IQR)	8 (5–612)	8 (5–612)	8 (5–612)	8 (5–612)	8 (5–612)	8 (5–612)	8 (5–612)	8 (5–612)	8 (5–612)	8 (5–612)	8 (5–612)
Maximum	55	75	85	83	72	64	61	69	63	64	57
0	390 (2.0)	394 (1.9)	394 (1.7)	384 (1.6)	379 (1.4)	409 (1.5)	404 (1.4)	391 (1.2)	384 (1.1)	443 (1.2)	353 (0.9)
1 to <5	3,674 (18.7)	3,798 (17.9)	4,062 (17.6)	4,448 (17.9)	4,722 (17.8)	5,006 (17.8)	5,320 (17.8)	5,435 (17.2)	5,938 (17.3)	6,236 (17.0)	6,347 (16.0)
5 to <10	8,069 (41.1)	8,956 (42.2)	9,857 (42.7)	10,664 (42.9)	11,375 (42.8)	11,936 (42.3)	12,677 (42.3)	13,335 (42.2)	14,580 (42.5)	15,282 (41.7)	16,518 (41.7)
10 to <20	6,634 (33.8)	7,177 (33.8)	7,729 (33.5)	8,264 (33.3)	8,874 (33.4)	9,563 (33.9)	10,178 (34.0)	10,860 (34.4)	11,767 (34.3)	12,815 (35.0)	14,248 (35.9)
≥20	878 (4.5)	911 (4.3)	1,026 (4.5)	1,091 (4.4)	1,253 (4.7)	1,295(4.6)	1,388 (4.6)	1,563 (5.0)	1,671 (4.9)	1,876 (5.1)	2,180 (5.5)

Values are presented as number (%) unless otherwise indicated.
NHIS-NSC, National Health Insurance Service-National Sample Cohort; SD, standard deviation; IQR, interquartile range.

Supplementary Table 5. Adherence to antidiabetic medications within 1 year after diagnosis of diabetes among adults aged 65 years and older, NHID 2015 to 2016

Variable	Number	Subjects with medication possession ratio ≥80%	Univariable OR (95% CI)	Multivariable OR (95% CI)
Age	33,348	22,608 (67.8)	0.98 (0.97–0.98)	0.99 (0.98–0.99)
Sex				
Men	15,889	10,365 (65.2)	1 (ref.)	1 (ref.)
Women	17,459	12,243 (70.1)	1.25 (1.20–1.31)	1.13 (1.06–1.21)
Income				
Not Medical Aid	32,536	22,058 (67.8)	1 (ref.)	1 (ref.)
Medical Aid	812	550 (67.7)	1.00 (0.86–1.16)	1.00 (0.86–1.17)
Smoking				
Non-smoker	23,251	15,962 (68.7)	1 (ref.)	1 (ref.)
Ex-smoker	7,063	4,746 (67.2)	0.94 (0.88–0.99)	1.06 (0.99–1.14)
Current smoker	3,034	1,900 (62.6)	0.77 (0.71–0.83)	0.88 (0.81–0.97)
Drinking				
Non	26,318	17,975 (68.3)	1 (ref.)	1 (ref.)
Mild to moderate	5,988	3,994 (66.7)	0.93 (0.88–0.99)	0.90 (0.84–0.96)
Heavy	1,042	639 (61.3)	0.74 (0.65–0.84)	0.76 (0.66–0.87)
Regular exercise				
No	26,307	17,748 (67.5)	1 (ref.)	1 (ref.)
Yes	7,041	4,860 (69.0)	1.08 (1.02–1.14)	1.05 (0.99–1.11)
BMI, kg/m^2				
<18.5	599	295 (49.3)	0.60 (0.50–0.70)	0.82 (0.69–0.98)
18.5 to <23.0	7,778	4,821 (62.0)	1 (ref.)	1 (ref.)
23.0 to <25.0	8,435	5,682 (67.4)	1.27 (1.19–1.35)	1.10 (1.03–1.19)
25.0 to <30.0	14,119	10,026 (71.0)	1.50 (1.42–1.59)	1.17 (1.08–1.27)
≥ 30.0	2,417	1,784 (73.8)	1.73 (1.56–1.91)	1.19 (1.04–1.37)
Waist circumference (male/female), cm				
<80/<75	4,033	2,412 (59.8)	0.68 (0.63–0.73)	0.87 (0.80–0.96)
<85/<80	5,766	3,713 (64.4)	0.82 (0.77–0.88)	0.91 (0.84–0.98)
<90/<85	8,239	5,662 (68.7)	1 (ref.)	1 (ref.)
<95/<90	7,122	4,952 (69.5)	1.04 (0.97–1.11)	0.97 (0.91–1.05)
<100/<95	4,597	3,250 (70.7)	1.10 (1.02–1.19)	0.99 (0.90–1.08)
≥100/≥95	3,591	2,619 (72.9)	1.23 (1.12–1.34)	1.06 (0.95–1.18)
Insulin				
No	29,581	20,695 (70.0)	1 (ref.)	1 (ref.)
Yes	3,767	1,913 (50.8)	0.44 (0.41–0.47)	0.48 (0.45–0.52)
Number of antidiabetic medications ≥3				
No	29,927	19,941 (66.6)	1 (ref.)	1 (ref.)
Yes	3,421	2,667 (78.0)	1.77 (1.63–1.93)	2.13 (1.95–2.33)
Severe hypoglycemia				
No	33,254	22,561 (67.8)	1 (ref.)	1 (ref.)
Yes	94	47 (50.0)	0.47 (0.32–0.71)	0.70 (0.44–1.05)

(*Continued to the next page*)

Supplementary Table 5. Continued

Variable	Number	Subjects with medication possession ratio ≥80%	Univariable OR (95% CI)	Multivariable OR (95% CI)
Diabetic retinopathy				
No	33,268	22,546 (67.8)	1 (ref.)	1 (ref.)
Yes	80	62 (77.5)	1.64 (0.97–2.77)	1.68 (0.98–2.90)
Hypertension				
No	7,142	4,203 (58.9)	1 (ref.)	1 (ref.)
Yes	26,206	18,405 (70.2)	1.65 (1.56–1.74)	1.61 (1.52–1.71)
Dyslipidemia				
No	10,970	6,677 (60.9)	1 (ref.)	1 (ref.)
Yes without statin	1,351	820 (60.7)	0.99 (0.88–1.12)	0.94 (0.83–1.06)
Yes with statin	21,027	15,111 (71.9)	1.64 (1.56–1.72)	1.48 (1.40–1.55)
Myocardial infarction				
No	32,080	21,819 (68.0)	1 (ref.)	1 (ref.)
Yes	1,268	789 (62.2)	0.78 (0.69–0.87)	0.84 (0.74–0.95)
Stroke				
No	29,277	19,978 (68.2)	1 (ref.)	1 (ref.)
Yes	4,071	2,630 (64.6)	0.85 (0.79–0.91)	0.91 (0.85–0.99)
Kidney function				
Normal	28,713	19,527 (68.0)	1 (ref.)	1 (ref.)
CKD	4,568	3,052 (66.8)	0.95 (0.89–1.01)	0.97 (0.90–1.04)
ESKD	67	29 (43.3)	0.36 (0.22–0.58)	0.64 (0.38–1.07)
Depression				
No	26,044	17,890 (68.7)	1 (ref.)	1 (ref.)
Yes	7,304	4,718 (64.6)	0.83 (0.79–0.88)	0.89 (0.84–0.95)
Dementia				
No	31,946	21,811 (68.3)	1 (ref.)	1 (ref.)
Yes	1,402	797 (56.9)	0.61 (0.55–0.68)	0.79 (0.70–0.89)
Parkinson's disease				
No	33,166	22,506 (67.9)	1 (ref.)	1 (ref.)
Yes	182	102 (56.0)	0.60 (0.45–0.81)	0.77 (0.57–1.05)
Cancer				
No	31,385	21,400 (68.2)	1 (ref.)	1 (ref.)
Yes	1,963	1,208 (61.5)	0.75 (0.68–0.82)	0.90 (0.82–1.00)
COPD				
No	23,690	16,410 (69.3)	1 (ref.)	1 (ref.)
Yes	9,658	6,198 (64.2)	0.80 (0.76–0.84)	0.91 (0.86–0.96)
Chronic liver disease				
No	26,166	17,950 (68.6)	1 (ref.)	1 (ref.)
Yes	7,182	4,658 (64.9)	0.85 (0.80–0.89)	0.91 (0.86–0.97)
Disabilities				
No	28,445	19,364 (68.1)	1 (ref.)	1 (ref.)
Yes	4,903	3,244 (66.2)	0.92 (0.86–0.98)	1.00 (0.93–1.07)

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Supplementary Table 5. Continued

Variable	Number	Subjects with medication possession ratio ≥80%	Univariable OR (95% CI)	Multivariable OR (95% CI)
One-person household (living alone)				
No	30,630	20,794 (67.9)	1 (ref.)	1 (ref.)
Yes	2,718	1,814 (66.7)	0.95 (0.87–1.03)	0.92 (0.84–1.00)
Pneumonia				
No	31,659	21,771 (68.8)	1 (ref.)	1 (ref.)
Yes	1,689	837 (49.6)	0.45 (0.40–0.49)	0.64 (0.58–0.71)
Heart failure				
No	29,762	20,338 (68.3)	1 (ref.)	1 (ref.)
Yes	3,586	2,270 (63.3)	0.80 (0.74–0.86)	0.86 (0.80–0.93)
Fracture				
No	30,899	21,112 (68.3)	1 (ref.)	1 (ref.)
Yes	2,449	1,496 (61.1)	0.73 (0.67–0.79)	0.77 (0.71–0.85)

Values are presented as number (%). Multivariable logistic regression models were used to calculate multivariable ORs with 95% CI after adjustment for all variables in table, except for the variable being examined.
NHID, National Health Information Database; OR, odds ratio; CI, confidence interval; BMI, body mass index; CKD, chronic kidney disease; ESKD, end-stage kidney disease; COPD, chronic obstructive pulmonary disease.

Supplementary Table 6. Continuing insulin use 1 year after diagnosis of diabetes among adults aged 65 years and older, NHID 2015 to 2016

Variable	Number	Continuing insulin use	Univariable OR (95% CI)	Multivariable OR (95% CI)
Age	33,348	369 (1.1)	0.97 (0.95–0.99)	0.96 (0.94–0.98)
Sex				
Men	15,889	223 (1.4)	1 (ref.)	1 (ref.)
Women	17,459	146 (0.8)	0.59 (0.48–0.73)	0.76 (0.57–1.01)
Income				
Not Medical Aid	32,536	357 (1.1)	1 (ref.)	1 (ref.)
Medical Aid	812	12 (1.5)	1.35 (0.76–2.42)	1.21 (0.66–2.19)
Smoking				
Non-smoker	23,251	221 (1.0)	1 (ref.)	1 (ref.)
Ex-smoker	7,063	85 (1.2)	1.27 (0.99–1.63)	0.99 (0.73–1.34)
Current smoker	3,034	63 (2.1)	2.21 (1.67–2.93)	1.76 (1.25–2.47)
Drinking				
Non	26,318	299 (1.1)	1 (ref.)	1 (ref.)
Mild to moderate	5,988	62 (1.0)	0.91 (0.69–1.20)	0.86 (0.63–1.16)
Heavy	1,042	8 (0.8)	0.67 (0.33–1.36)	0.53 (0.25–1.09)
Regular exercise				
No	26,307	294 (1.1)	1 (ref.)	1 (ref.)
Yes	7,041	75 (1.1)	0.95 (0.74–1.23)	0.94 (0.72–1.23)
BMI, kg/m				
<18.5	599	20 (3.3)	2.24 (1.39–3.63)	1.66 (0.98–2.82)
18.5 to <23.0	7,778	118 (1.5)	1 (ref.)	1 (ref.)
23.0 to <25.0	8,435	87 (1.0)	0.68 (0.51–0.89)	0.77 (0.56–1.06)
25.0 to <30.0	14,119	129 (0.9)	0.60 (0.47–0.77)	0.79 (0.55–1.13)
≥30.0	2,417	15 (0.6)	0.41 (0.24–0.70)	0.56 (0.28–1.11)
Waist circumference (male/female), cm				
<80/<75	4,033	72 (1.8)	1.79 (1.30–2.46)	1.27 (0.86–1.87)
<85/<80	5,766	75 (1.3)	1.30 (0.95–1.77)	1.13 (0.81–1.58)
<90/<85	8,239	83 (1.0)	1 (ref.)	1 (ref.)
<95/<90	7,122	71 (1.0)	0.99 (0.72–1.36)	1.08 (0.77–1.51)
<100/<95	4,597	36 (0.8)	0.78 (0.52–1.15)	0.88 (0.57–1.34)
≥100/≥95	3,591	32 (0.9)	0.88 (0.59–1.33)	1.12 (0.68–1.85)
Insulin				
No	29,581	165 (0.6)	1 (ref.)	1 (ref.)
Yes	3,767	204 (5.4)	10.21 (8.29–12.57)	8.36 (6.68–10.48)
Number of antidiabetic medications ≥3				
No	29,927	268 (0.9)	1 (ref.)	1 (ref.)
Yes	3,421	101 (3.0)	3.37 (2.67–4.25)	2.08 (1.63–2.65)
Severe hypoglycemia				
No	33,254	365 (1.1)	1 (ref.)	1 (ref.)
Yes	94	4 (4.3)	4.01 (1.46– 10.96)	1.35 (0.47–3.85)
Diabetic retinopathy				
No	33,268	363 (1.1)	1 (ref.)	1 (ref.)
Yes	80	6 (7.5)	7.35 (3.18– 17.00)	3.40 (1.37–8.43)

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Supplementary Table 6. Continued

Variable	Number	Continuing insulin use	Univariable OR (95% CI)	Multivariable OR (95% CI)
Hypertension				
No	7,142	91 (1.3)	1 (ref.)	1 (ref.)
Yes	26,206	278 (1.1)	0.83 (0.66–1.05)	1.06 (0.82–1.37)
Dyslipidemia				
No	10,970	150 (1.4)	1 (ref.)	1 (ref.)
Yes without statin	1,351	15 (1.1)	0.81 (0.48–1.38)	0.91 (0.53–1.57)
Yes with statin	21,027	204 (1.0)	0.71 (0.57–0.87)	0.88 (0.70–1.10)
Myocardial infarction				
No	32,080	348 (1.1)	1 (ref.)	1 (ref.)
Yes	1,268	21 (1.7)	1.54 (0.99–2.39)	1.08 (0.67–1.72)
Stroke				
No	29,277	325 (1.1)	1 (ref.)	1 (ref.)
Yes	4,071	44 (1.1)	0.97 (0.71–1.34)	0.82 (0.58–1.14)
Kidney function				
Normal	28,713	300 (1.0)	1 (ref.)	1 (ref.)
CKD	4,568	69 (1.5)	1.45 (1.12–1.89)	1.36 (1.03–1.80)
ESRD	67	0 (0.0)	<0.00 (<0.00–>999.99)	<0.00 (<0.00–>999.99)
Depression				
No	26,044	283 (1.1)	1 (ref.)	1 (ref.)
Yes	7,304	86 (1.2)	1.09 (0.85–1.38)	0.99 (0.77–1.29)
Dementia				
No	31,946	354 (1.1)	1 (ref.)	1 (ref.)
Yes	1,402	15 (1.1)	0.97 (0.58–1.62)	0.78 (0.45–1.36)
Parkinson's disease				
No	33,166	364 (1.1)	1 (ref.)	1 (ref.)
Yes	182	5 (2.8)	2.55 (1.04–6.23)	2.39 (0.93–6.11)
Cancer				
No	31,385	319 (1.0)	1 (ref.)	1 (ref.)
Yes	1,963	50 (2.6)	2.55 (1.88–3.44)	1.56 (1.14–2.15)
COPD				
No	23,690	247 (1.0)	1 (ref.)	1 (ref.)
Yes	9,658	122 (1.3)	1.21 (0.98–1.51)	0.96 (0.76–1.21)
Chronic liver disease				
No	26,166	263 (1.0)	1 (ref.)	1 (ref.)
Yes	7,182	106 (1.5)	1.48 (1.18–1.85)	1.23 (0.97–1.55)
Disabilities				
No	28,445	315 (1.1)	1 (ref.)	1 (ref.)
Yes	4,903	54 (1.1)	1.00 (0.74–1.33)	0.87 (0.64–1.17)
One-person household (living alone)				
No	30,630	337 (1.1)	1 (ref.)	1 (ref.)
Yes	2,718	32 (1.2)	1.07 (0.74–1.54)	1.13 (0.78–1.64)
Pneumonia				
No	31,659	333 (1.1)	1 (ref.)	1 (ref.)
Yes	1,689	36 (2.1)	2.05 (1.45–2.90)	0.85 (0.58–1.24)

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Supplementary Table 6. Continued

Variable	Number	Continuing insulin use	Univariable OR (95% CI)	Multivariable OR (95% CI)
Heart failure				
No	29,762	316 (1.1)	1 (ref.)	1 (ref.)
Yes	3,586	53 (1.5)	1.40 (1.04–1.87)	1.04 (0.76–1.43)
Fracture				
No	30,899	331 (1.1)	1 (ref.)	1 (ref.)
Yes	2,449	38 (1.6)	1.46 (1.04–2.04)	1.41 (0.99–2.01)

Values are presented as number (%). Multivariable logistic regression models were used to calculate multivariable OR with 95% CI after adjustment for all variables in table, except for the variable being examined.
NHID, National Health Information Database; OR, odds ratio; CI, confidence interval; BMI, body mass index; CKD, chronic kidney disease; ESKD, end-stage kidney disease; COPD, chronic obstructive pulmonary disease.

Supplementary Table 7. Trends of comorbidities and mortality among adults with diabetes aged 65 years and older, 60% sample cohort from NHID 2012 to 2022

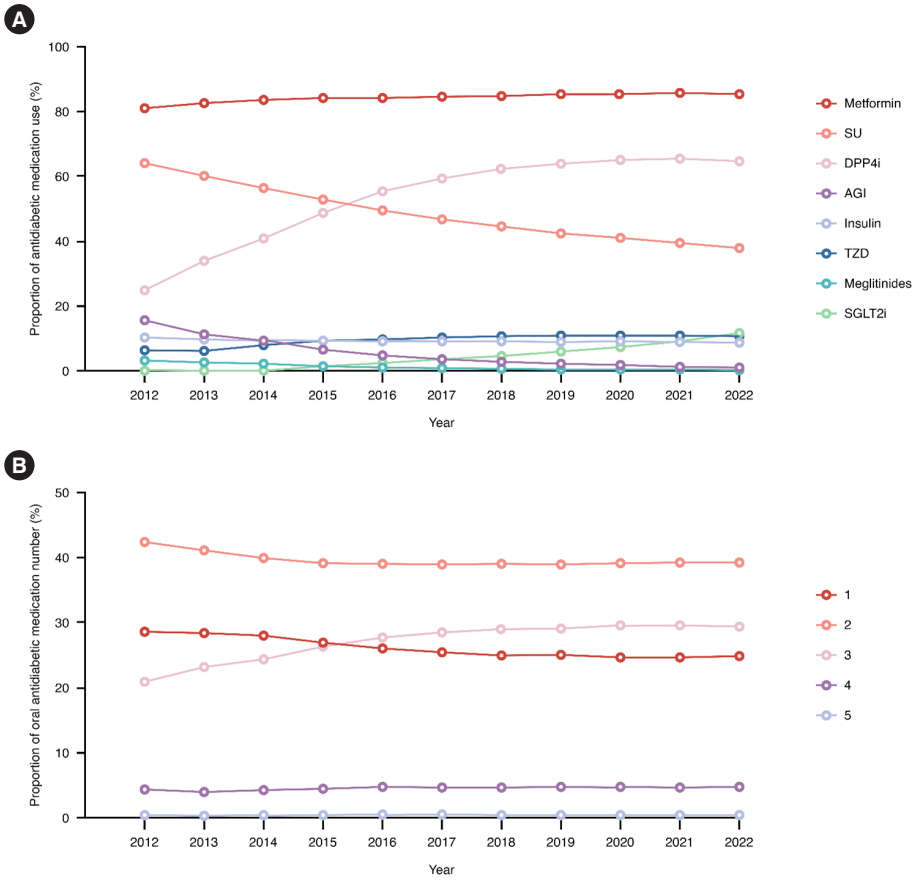
Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Number	698,866	745,837	804,676	853,260	909,762	986,562	1,054,918	1,145,181	1,240,705	1,339,971	1,441,688
Hypertension, %	79.6	79.6	79.1	78.6	78.3	77.7	77.6	77.4	77.3	77.3	77.1
Dyslipidemia, %	47.7	50.7	55.8	59.5	63.0	65.8	68.3	70.5	72.9	75.4	77.1
Dementia, %	6.4	7.1	7.8	8.4	8.9	9.3	9.9	11.0	11.1	11.3	11.4
Cancer, %	6.4	6.7	6.8	6.9	7.0	7.0	7.1	7.2	7.3	7.5	7.6
Heart failure, %	2.3	2.3	2.4	2.7	4.5	5.1	5.5	5.6	5.1	5.7	6.6
AF, %	3.5	3.7	3.9	4.2	4.4	4.6	4.9	5.2	5.4	5.6	5.8
Stroke, %	2.2	2.1	1.9	1.9	1.9	1.9	1.9	1.9	1.7	1.7	1.7
ESKD, %	1.1	1.1	1.2	1.2	1.3	1.3	1.3	1.3	1.4	1.4	1.4
MI, %	1.0	1.0	1.0	1.0	1.2	1.3	1.4	1.4	1.3	1.3	1.4
PDR, %	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6
SH, %	1.4	1.3	1.2	1.1	1.1	1.0	1.0	0.9	0.7	0.5	0.5
Death, %	3.9	3.8	3.7	3.6	3.6	3.4	3.5	3.2	3.5	3.6	4.1

Values are presented as percentage.
NHID, National Health Information Database; AF, atrial fibrillation; ESKD, end-stage kidney disease; MI, myocardial infarction; PDR, proliferative diabetic retinopathy; SH, severe hypoglycemia.

Supplementary Table 8. Factors associated with 3-year mortality among adults with diabetes aged 65 years and older, NHID 2015 to 2016

Variable	Number	Event	Duration, PY	IR, /1,000 PY	HR (95% CI)	
					Model 1	Model 2
Kidney function						
Normal	498,492	23,268	1,463,941.0	15.89	1 (ref.)	1 (ref.)
CKD	107,913	10,684	309,139.1	34.56	2.18 (2.13–2.23)	1.43 (1.39–1.46)
ESKD	2,593	568	6,964.2	81.56	5.19 (4.77–5.64)	2.54 (2.33–2.77)
Dementia						
No	580,616	29,130	1,702,598.4	17.11	1 (ref.)	1 (ref.)
Yes	28,382	5,390	77,445.9	69.60	4.10 (3.99–4.22)	1.98 (1.92–2.05)
Cancer						
No	573,701	30,350	1,680,295.8	18.06	1 (ref.)	1 (ref.)
Yes	35,297	4,170	99,748.5	41.81	2.33 (2.25–2.40)	1.85 (1.79–1.91)
Pneumonia						
No	586,109	30,631	1,717,229.1	17.84	1 (ref.)	1 (ref.)
Yes	22,889	3,889	62,815.2	61.91	3.50 (3.38–3.61)	1.57 (1.52–1.63)
Parkinson's disease						
No	604,720	33,876	1,768,066.6	19.16	1 (ref.)	1 (ref.)
Yes	4,278	644	11,977.8	53.77	2.82 (2.61–3.05)	1.40 (1.29–1.51)
Heart failure						
No	556,165	28,955	1,629,391.7	17.77	1 (ref.)	1 (ref.)
Yes	52,833	5,565	150,652.6	36.94	2.09 (2.03–2.15)	1.37 (1.33–1.42)
Disabilities						
No	512,285	26,613	1,500,732.4	17.73	1 (ref.)	1 (ref.)
Yes	96,713	7,907	279,311.9	28.31	1.60 (1.56–1.64)	1.22 (1.19–1.26)
Fracture						
No	566,044	30,821	1,656,394.2	18.61	1 (ref.)	1 (ref.)
Yes	42,954	3,699	123,650.1	29.92	1.61 (1.56–1.67)	1.23 (1.19–1.27)
Myocardial infarction						
No	589,492	32,616	1,724,244.1	18.92	1 (ref.)	1 (ref.)
Yes	19,506	1,904	55,800.2	34.12	1.81 (1.73–1.89)	1.20 (1.15–1.26)

Model 1: non-adjusted; Model 2: adjustment for all variables (age, sex, income, smoking, drinking, regular exercise, body mass index, waist circumference, insulin use, number of antidiabetic medications ≥3, severe hypoglycemia, diabetic retinopathy, hypertension, dyslipidemia, myocardial infarction, stroke, kidney function, depression, dementia, Parkinson's disease, cancer, chronic obstructive pulmonary disease, chronic liver disease, disabilities, living in a one-person household, pneumonia, heart failure, and fractures), except for the variable being examined.
NHID, National Health Information Database; PY, person-years; IR, incidence rate; HR, hazard ratio; CI, confidence interval; CKD, chronic kidney disease; ESKD, end-stage kidney disease.



Supplementary Fig. 1. (A) Trends of antidiabetic medication use. (B) Number of oral antidiabetic medications among adults with diabetes aged 65 years and older, 60% sample cohort from National Health Information Database, 2012 to 2022. Insulin use was recognized if being prescribed at least three times a year. SU, sulfonylurea; DPP4i, dipeptidyl peptidase-4 inhibitor; AGI, alpha-glucosidase inhibitor; TZD, thiazolidinedione; SGLT2i, sodium-glucose cotransporter-2 inhibitor.