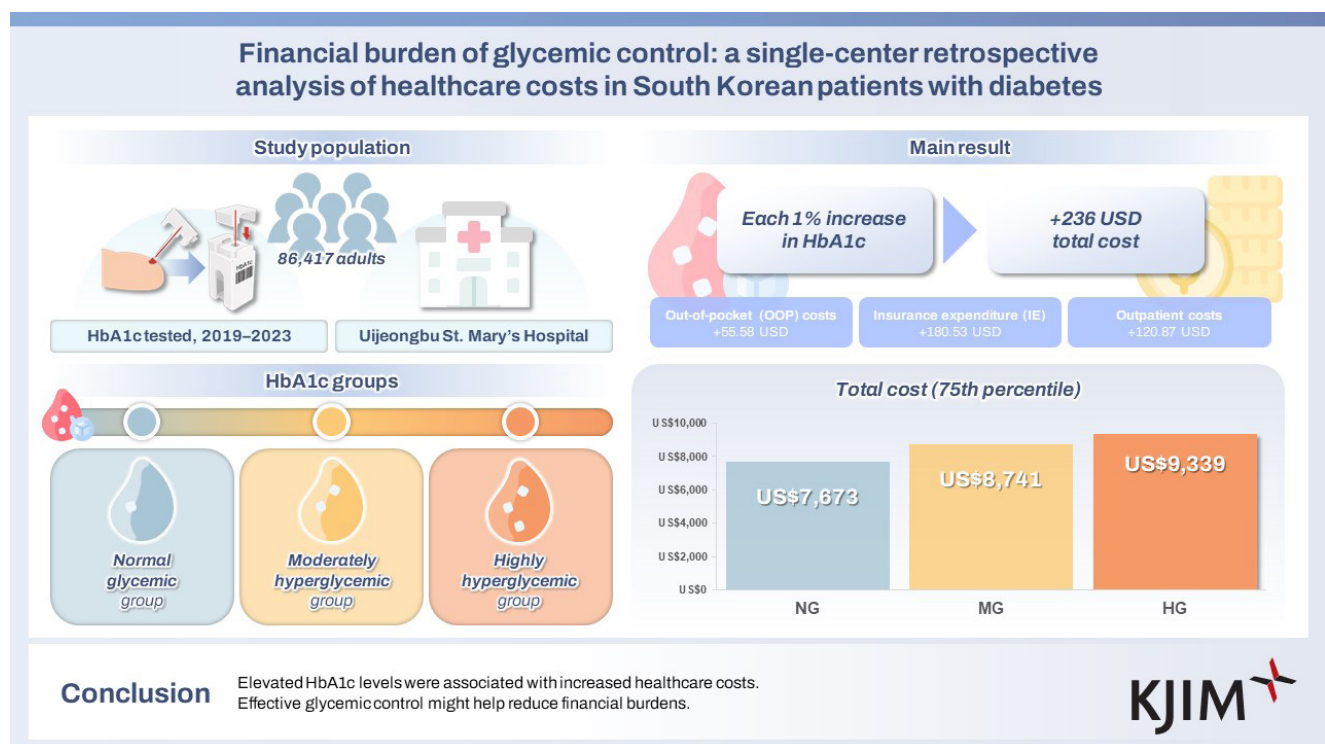


Financial burden of glycemic control: a single-center retrospective study of diabetes costs in South Korean patients

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Background/Aims: The impact of glycemic control on healthcare costs is a critical research area. In this study, we aimed to evaluate the relationship between hemoglobin A1c (HbA1c) levels and healthcare costs, including out-of-pocket (OOP) expenses and insurance expenditures (IEs), over 5 years (2019–2023).

Methods: This retrospective cohort study was conducted using data from Uijeongbu St. Mary's Hospital of patients who underwent HbA1c testing between January 1, 2019 and December 31, 2023. Patients were categorized as normal glycemic group (NG, HbA1c < 6.5%), moderately hyperglycemic group (MG, 6.5–8%), and highly hyperglycemic group (HG, ≥ 8%).

Univariate linear regression was used for evaluating associations between HbA1c levels and healthcare costs.

Results: Of 86,417 patients, 61,961, 15,065, and 9,391 were NG, MG, and HG, respectively. The HG group had the highest 75th percentile cost at 9,339 USD, compared with 7,673 and 8,741 USD in the NG and MG groups, respectively. Each 1% increase in HbA1c level was associated with an additional 236.11 USD in total costs, including 55.58 and 180.53 USD in OOP expenses and IEs, respectively. Patients with worsened glycemic control had the highest total healthcare costs (up to 12,742 USD), whereas those with improved glycemic control showed consistently lower total and inpatient costs. Higher costs were also observed among patients with diabetes, chronic kidney disease, serious disease exemption status (particularly those with poorly controlled diabetes), and those receiving medical aid.

Conclusions: Elevated HbA1c levels were associated with increased healthcare costs. Effective glycemic control might help reduce financial burdens.

Keywords: Health expenditures; Glycated hemoglobin; Financial stress; Glycemic control; Health care costs

INTRODUCTION

The global prevalence of diabetes mellitus (DM) is steadily increasing, presenting a growing public health concern [1]. According to the International Diabetes Federation, in 2021, one in ten adults worldwide had diabetes, accounting for 11.5% of the global health expenditure, estimated at 966 billion USD [2]. According to one study, the global cost of diabetes is expected to reach approximately 2.25 trillion USD annually by 2030, owing to direct healthcare expenses and indirect costs, such as absenteeism and societal impacts [3]. Similarly, the prevalence of diabetes was 13.0% among US adults in 2018, which is projected to increase to 17.9% by 2060 [4].

South Korea is no exception, with increasing prevalence and costs reflecting these global trends [5,6]. The prevalence of diabetes was 12.5% among Korean adults aged ≥ 19 years in 2022 [7], and total medical costs have continued to increase. Several studies have addressed the financial burden of diabetes. For instance, in a study using the Korean national claims database, the diabetes-related economic burden in Korea in 2019 was USD 18,293 million, with an average per capita cost of USD 4,090 [8]. A 2017 study reported similar results, while another study linked diabetes drug expenditure with cardiovascular risk [9,10]. However, although studies have quantified the financial burden of diabetes, many did not include comprehensive laboratory data, such as hemoglobin A1c (HbA1c) levels, which are crucial for understanding the relationship between glycemic control and healthcare costs. International research has

demonstrated that poor glycemic control is associated with higher medical expenditures [11-13] and that improving glycemic control reduces costs [14,15]. However, comprehensive data specific to South Korea remains scarce.

The therapeutic landscape of diabetes management is evolving. The introduction of novel hypoglycemic agents should effectively lower HbA1c levels and confer cardiovascular benefits [16,17]. Novel agents are expected to be cost-effective and provide cardiovascular benefits. Nonetheless, understanding the economic impact of improved glycemic control is essential for improving the cost-effectiveness of diabetes care strategies [18].

Therefore, in this study, we aimed to evaluate the relationship between medical costs and HbA1c levels and assess the potential cost savings associated with better glycemic control in South Korea. Specifically, the study focused on documenting the medical cost increases associated with a 1% increase in HbA1c and determining how much cost saving might be realized by a 1% reduction in HbA1c. This research was conducted to improve our understanding about the economic impact of diabetes management in South Korea and clarify the potential implications for healthcare policy, clinical practice, and the utilization of novel therapeutic agents.

METHODS

Data source and extraction

Patient data were extracted from the records at Uijeongbu St. Mary's Hospital between January 1, 2019 and December

31, 2023. The extraction focused on patients who underwent HbA1c testing and had healthcare cost data available during the study period. Among the 88,008 eligible patients, those aged < 18 years ($n = 1,552$) and clinical trial participants ($n = 39$) were excluded. Therefore, the final analysis included data of 86,417 patients. This study was designed as a cross-sectional analysis in which healthcare costs were summarized in relation to patient baseline HbA1c levels.

Age, sex, height, weight, and body mass index (BMI) data at the time of HbA1c testing were collected. In addition, information on oral hypoglycemic agents (OHAs) and insulin prescribed before and after HbA1c testing was collected. Hypoglycemic agents included metformin, dipeptidyl peptidase 4 (DPP4) inhibitors, sodium glucose co-transporter-2 (SGLT2) inhibitors, sulfonylureas, and thiazolidinedione (TZD). During the study period, patients with DM were identified using ICD-10 codes E10–E14. Patients were classified as having DM if they had at least one ICD-10 code for diabetes and were prescribed anti-diabetic medications during the study period.

According to the Korean insurance system, “severe refractory disease” refers to a condition that is treatable but not curable, requiring continuous management. Treatment discontinuation often results in death or serious disability. Owing to the substantial clinical and economic burden of these conditions, patients receive reduced out-of-pocket (OOP) expenses under a special reimbursement policy. In this study, this was defined as having a severe disease exemption (SDE) status, which included diagnoses of cancer (ICD-10: C00–C97), major cardiovascular disease—defined as myocardial infarction (I21–I22) or stroke (I60–I64)—rare diseases, or chronic kidney disease (CKD; N18), based on corresponding disease codes.

In South Korea, healthcare is primarily managed by the National Health Insurance (NHI) system, which provides near-universal coverage [19]. Premiums are income-based, promoting equitable access to healthcare services. In cases of financial hardship, the government offers medical aid, a public assistance program that fully covers essential medical expenses. In this study, patients were categorized according to insurance status as follows: NHI-covered, medical aid beneficiaries, uninsured, recipients of Industrial Accident Compensation Insurance, and those with unknown status.

To calculate medical costs, annual hospitalization and outpatient costs were extracted from the date of the first HbA1c measurement. All cost variables represent annual

healthcare expenditures, calculated by aggregating inpatient and outpatient costs over 1 year following the index HbA1c measurement for each patient. OOP expenses were calculated for each category. Total costs were defined as the sum of hospitalization and outpatient costs (total cost = inpatient cost + outpatient cost). The insurance expenditure (IE) was calculated by deducting personal contributions (OOP expenses) from the total cost. The costs were initially recorded in KRW and converted to USD using the average annual exchange rate in 2023 (1 USD = 1,300 KRW). To account for changes in the value of medical expenditures over time, all cost variables were adjusted to 2023 values using annual Consumer Price Index data from Statistics Korea (2019: +0.4%, 2020: +0.5%, 2021: +2.5%, 2022: +5.1%, 2023: +3.6%) [20].

Statistical analysis

Statistical analysis was performed using R (version 4.2.2; R Foundation for Statistical Computing, Vienna, Austria). Descriptive statistics were used for summarizing baseline characteristics of the study population. Continuous variables are presented as means $\pm$ standard deviations for normally distributed data and medians (interquartile ranges) for skewed data. Categorical variables are summarized as frequencies and percentages.

Patients were categorized into three groups based on their baseline HbA1c levels:

- 1) HbA1c < 6.5% (normal glycemic group, NG)
- 2) HbA1c $\geq$ 6.5 to < 8% (moderately hyperglycemic group, MG)
- 3) HbA1c $\geq$ 8% (highly hyperglycemic group, HG)

The NG group was defined based on HbA1c levels alone, representing no healthy control population but rather a heterogeneous clinical population receiving care for various medical conditions.

In addition to the primary cross-sectional analyses based on the index HbA1c measurement, analyses of glycemic control dynamics were performed as a descriptive secondary analysis using two HbA1c measurements within 12 months. The earliest recorded HbA1c value during the study period was defined as the baseline measurement. To assess longitudinal changes in glycemic control, the second HbA1c value was calculated as the average of all HbA1c measurements obtained within 12 months following the baseline test. Analyses of glycemic control dynamics excluded patients without a second HbA1c measurement within 12

months of baseline ($n = 11,741$). The patients were reclassified as follows:

- 1) Stable glycemic control: patients remained in the same glycemic category at baseline and follow-up. Regarding descriptive and comparative analyses, this group was further stratified according to baseline HbA1c level into low-stable (NG $\rightarrow$ NG), mid-stable (MG $\rightarrow$ MG), and high-persistent (HG $\rightarrow$ HG).
- 2) Improved glycemic control: patients transitioned to a lower glycemic category (for instance, HG $\rightarrow$ MG, HG $\rightarrow$ NG, MG $\rightarrow$ NG).
- 3) Worsened glycemic control: patients transitioned to a higher glycemic category (for instance, NG $\rightarrow$ MG, NG $\rightarrow$ HG, MG $\rightarrow$ HG).

Analysis of variance was used for comparing means across HbA1c groups for continuous variables; chi-square tests were used for assessing differences in categorical variables. Considering continuous variables (such as age and costs), normality was assessed using the Shapiro–Wilk test; when normality assumptions were not met, non-parametric tests were applied.

A linear regression model was used for evaluating associations between HbA1c levels and healthcare costs (total costs, inpatient costs, outpatient costs, OOP costs, and IE) as continuous outcomes. Initial analyses were performed using univariate linear regression to provide a direct assessment of the relationship between HbA1c level and each cost variable. To account for potential confounding, multivariate linear regression models were additionally fitted, adjusting for age, sex, BMI, CKD, cancer, SDE status, and insurance class. Given that the cost variables exhibited right-skewed distributions, supplementary sensitivity analyses were performed using generalized linear models (GLMs) with a gamma distribution and log link. GLM coefficients were exponentiated to obtain percent changes in cost per 1% increase in HbA1c. Regression analysis results are presented as beta coefficients (B), standard errors (SE), and p values for each independent variable. Statistical significance was set at $p < 0.05$.

Ethics

This study adhered to the ethical principles outlined in the Declaration of Helsinki and was approved by the Institutional Review Board of Uijeongbu St. Mary's Hospital (UC23ZA-SI0129). Owing to the retrospective cohort design, the study posed no risk of physical or psychological harm to the participants. Therefore, the requirement for informed consent

was waived.

RESULTS

Baseline characteristics and costs by HbA1c level

A total of 86,417 study participants were categorized into three groups based on baseline HbA1c levels: 61,961, 15,065, and 9,391 individuals in the NG, MG, and HG groups, respectively (Table 1). The average HbA1c was 5.6 ± 0.4 in the NG, 7.1 ± 0.4 in MG, and 9.8 ± 1.7 in HG groups. The mean age was 58.6 years in the NG, 65.1 in MG, and 60.7 in HG groups. Men accounted for 52.2%, 56.1%, and 58.9% of the participants in the NG, MG, and HG groups, respectively.

BMI averaged 24.3 kg/m^2 in the NG, 25.1 kg/m^2 in MG, and 24.9 kg/m^2 in HG groups. Diabetes was present in 17.8% of the participants in the NG, 75.2% in MG, and 90.5% in HG groups. The mean number of OHAs administered per patient was 0.1 in the NG, 1.0 in MG, and 1.6 in HG groups. Metformin was used in 4.6% of the participants in the NG, 42.9% in MG, and 61.2% in HG groups. DPP4 inhibitors were used in 3.5%, 29.2%, and 47.2% of NG, MG, and HG patients, respectively. Similarly, SGLT2 inhibitors were administered to 0.8% of the participants in the NG, 9.5% in MG, and 16.0% in HG groups. Insulin use increased across the groups: 6.8% in the NG, 26.8% in the MG, and 56.0% in the HG. CKD was observed in 25.3%, 30.3%, and 31.5% of the participants in the NG, MG, and HG groups, respectively. The prevalence rates of cancer were 6.6%, 9.6%, and 8.8% in the NG, MG, and HG groups, respectively. NG (19.8%), MG (25.1%), and HG (23.5%) were classified as having an SDE status.

The distribution of insurance coverage was similar across the HbA1c groups: 89.2% in the NG, 90.5% in the MG, and 89.7% in the HG were covered by NHI, and 6.8% in the NG, 8.0% in the MG, and 8.7% in the HG received medical aid.

The HG group had the highest median total cost; the 75th percentile had a median total cost of 9,339 USD, compared with 7,673 USD in the NG and 8,741 USD in the MG groups ($p < 0.001$). Inpatient costs followed a similar pattern: the 75th percentile cost in the HG group was 6,677 USD, while the NG and MG had lower costs (5,899 USD and 6,278 USD, respectively). Outpatient costs were also higher in the

Table 1. Baseline characteristics of the study population by HbA1c level

Variable	Total (n = 86,417)	NG ^{a)} (A1c < 6.5) (n = 61,961)	MG (6.5 ≤ A1c < 8) (n = 15,065)	HG (8 ≤ A1c) (n = 9,391)	p value
A1c (%)	6.3 ± 1.5	5.6 ± 0.4	7.1 ± 0.4	9.8 ± 1.7	< 0.001
Age (yr)	60.0 ± 16.7	58.6 ± 17.6	65.1 ± 12.9	60.7 ± 14.4	< 0.001
Male sex	46,322 (53.6)	32,350 (52.2)	8,445 (56.1)	5,527 (58.9)	< 0.001
BMI (kg/m ²)	24.5 ± 4.1	24.3 ± 4.0	25.1 ± 4.1	24.9 ± 4.3	< 0.001
DM	30,880 (35.7)	11,048 (17.8)	11,330 (75.2)	8,502 (90.5)	< 0.001
Number of OHA	0.4 ± 0.9	0.1 ± 0.4	1.0 ± 1.1	1.6 ± 1.2	< 0.001
Metformin	15,070 (17.4)	2,861 (4.6)	6,465 (42.9)	5,744 (61.2)	< 0.001
DPP4 inhibitor	11,005 (12.7)	2,169 (3.5)	4,406 (29.2)	4,430 (47.2)	< 0.001
SGLT2 inhibitor	3,461 (4.0)	520 (0.8)	1,434 (9.5)	1,507 (16.0)	< 0.001
SU	6,452 (7.5)	749 (1.2)	2,358 (15.7)	3,345 (35.6)	< 0.001
TZD	971 (1.1)	175 (0.3)	384 (2.5)	412 (4.4)	< 0.001
Insulin usage	13,482 (15.6)	4,190 (6.8)	4,032 (26.8)	5,260 (56.0)	< 0.001
Cancer	6,341 (7.3)	4,072 (6.6)	1,445 (9.6)	824 (8.8)	< 0.001
SDE	18,240 (21.1)	12,242 (19.8)	3,787 (25.1)	2,211 (23.5)	< 0.001
CKD	23,224 (26.9)	15,700 (25.3)	4,569 (30.3)	2,955 (31.5)	< 0.001
Insurance					< 0.001
NHI	77,325 (89.5)	55,274 (89.2)	13,628 (90.5)	8,423 (89.7)	
Uninsured	1,392 (1.6)	1,129 (1.8)	149 (1.0)	114 (1.2)	
Medical aid	6,214 (7.2)	4,186 (6.8)	1,210 (8.0)	818 (8.7)	
IACI	1,407 (1.6)	1,304 (2.1)	68 (0.5)	35 (0.4)	
Unknown	79 (0.1)	68 (0.1)	10 (0.1)	1 (0.0)	

Values are presented as mean ± standard deviation or number (%).

HbA1c, hemoglobin A1c; NG, normal glycemic group; MG, moderately hyperglycemic group; HG, highly hyperglycemic group; BMI, body mass index; DM, diabetes mellitus; OHA, oral hypoglycemic agent; DPP4, dipeptidyl peptidase 4; SGLT2, sodium glucose co-transporter-2; SU, sulfonylurea; TZD, thiazolidinedione; SDE, severe disease exemption; CKD, chronic kidney disease; NHI, National Health Insurance; IACI, Industrial Accident Compensation Insurance.

^{a)}The NG group represents a heterogeneous clinical population rather than healthy controls.

HG group, with a 75th percentile value of 2,651 USD, compared with 1,849 USD in the NG and 2,388 USD in the MG ($p < 0.001$) (Fig. 1).

Regression analysis of HbA1c level versus cost relationships

Total healthcare costs were higher by an estimated 236.11 USD (SE: 28.72) per 1% increase in HbA1c level. The corresponding regression equation was as follows: total cost = 5,399.73 + 236.11 × HbA1c, with an F-value of 67.59. For inpatient costs, each 1% increase in HbA1c level was associated with a 67.37 USD higher cost (SE: 22.11); the regression equation was inpatient cost = 4,525.69 + 67.37 × HbA1c, with an F-value of 9.28. In regard to outpatient costs, a 1% increase in HbA1c level was associated with a

120.87 USD higher cost (SE: 12.81); the regression equation was outpatient cost = 1,146.08 + 120.87 × HbA1c (F-value: 89.05). OOP costs were higher by 55.58 USD (SE: 7.29) per 1% increase in HbA1c level; the regression equation was OOP cost = 1,394.76 + 55.58 × HbA1c (F-value 58.10). Finally, IEs were higher by 180.53 USD (SE: 24.51) per 1% increase in HbA1c level; the regression equation was IE = 4,004.97 + 180.53 × HbA1c (F-value: 54.26) (Table 2).

In multivariate linear regression models adjusted for age, sex, BMI, CKD, cancer, SDE status, and insurance class, higher HbA1c levels were associated with significantly higher outpatient and OOP costs, whereas the associations with total cost, inpatient cost, and IE were not significant (Table 3).

Full regression coefficients for all covariates across the five cost domains are presented in Supplementary Table 1. CKD,

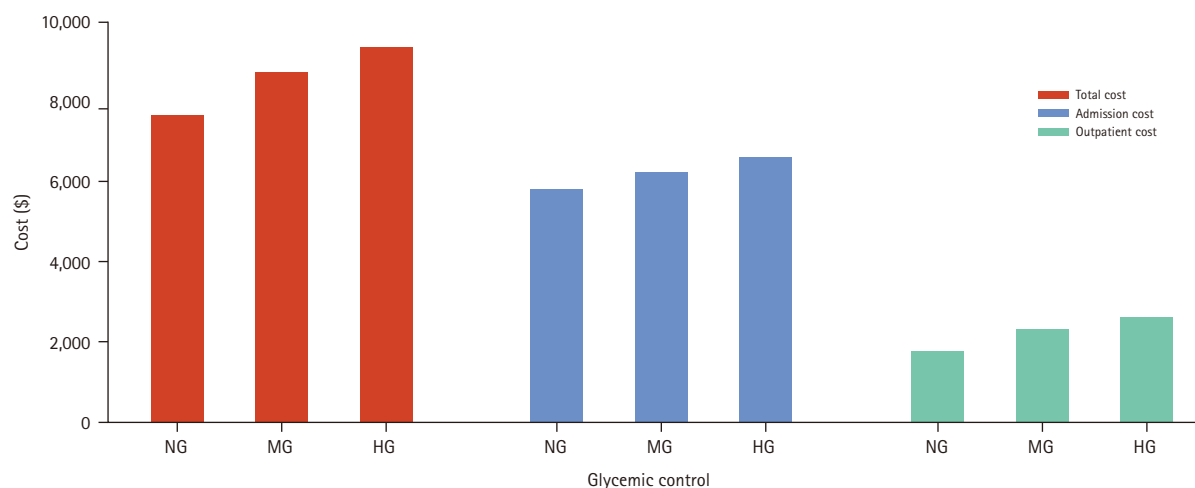


Figure 1. Total, admission, and outpatient costs for the glycemic control groups. The figure illustrates the 75th percentiles of total, admission (inpatient), and outpatient costs for the NG (HbA1c < 6.5%), MG (HbA1c 6.5–7.9%), and HG (HbA1c ≥ 8%) groups. Patients in the HG group incurred the highest total costs (9,339 USD), inpatient costs (6,677 USD), and outpatient costs (2,651 USD) ($p < 0.001$). The NG group represents patients with HbA1c < 6.5% and does not constitute a healthy control population. NG, normal glycemic group; MG, moderately hyperglycemic group; HG, highly hyperglycemic group; HbA1c, hemoglobin A1c.

Table 2. Results of regression analysis of healthcare costs by HbA1c level

Cost category	B	Standard error	t	p value	F	Regression equation
Total cost	236.11	28.72	8.222	< 0.001	67.59	$5,399.73 + 236.11 \times \text{HbA1c}$
Inpatient cost	67.37	22.11	3.046	< 0.001	9.28	$4,525.69 + 67.37 \times \text{HbA1c}$
Outpatient cost	120.87	12.81	9.436	< 0.001	89.05	$1,146.08 + 120.87 \times \text{HbA1c}$
Out-of-pocket cost	55.58	7.29	7.622	< 0.001	58.10	$1,394.76 + 55.58 \times \text{HbA1c}$
Insurance expenditure	180.53	24.51	7.366	< 0.001	54.26	$4,004.97 + 180.53 \times \text{HbA1c}$

HbA1c, hemoglobin A1c.

Table 3. Adjusted linear regression estimates of the association between HbA1c and healthcare cost categories

Cost category	B	Standard error	t	p value
Total cost	80.38	54.28	1.481	0.139
Inpatient cost	-9.05	41.60	-0.216	0.829
Outpatient cost	73.75	25.42	2.901	0.004
Out-of-pocket cost	50.82	15.34	3.317	0.001
Insurance expenditure	29.50	46.57	0.633	0.526

HbA1c, hemoglobin A1c.

The models were adjusted for age, sex, body mass index, chronic kidney disease, cancer, serious disease exemption status, and insurance status.

cancer, and SDE status were consistently the strongest predictors of higher healthcare expenditures.

In regard to the sensitivity analyses using gamma log-link GLMs, the direction of the associations remained consistent. In Gamma log-link GLMs, each 1% higher HbA1c level was associated with an approximately 6.0% increase in outpa-

tient costs and 1.7% increase in OOP costs, whereas no significant association was observed for total, inpatient, or IE (Supplementary Table 2).

Annual costs by A1c levels

The annual total, inpatient, and outpatient costs were ana-

lyzed for all three HbA1c groups from 2019 to 2023 (Fig. 2).

In 2019, the NG group had the highest 75th percentile total cost of 2,703 USD compared with 1,970 USD in the MG and 2,309 USD in the HG groups. By 2023, these costs increased; the 75th percentile reached 5,485 USD in the HG, 5,594 USD in the MG, and 4,677 USD in the NG groups. Over the years, the MG and HG groups had higher total costs at the 75th percentile than did the NG group, except in 2019.

The inpatient costs at the 75th percentile followed a similar pattern. In 2019, the inpatient cost in the HG group was 1,210 USD, compared with 2,035 USD in the NG and 1,010 USD in the MG groups. By 2023, the 75th percentile inpatient cost increased to 4,693 USD in the HG group, 4,843 USD in the MG, and 3,982 USD in the NG groups. The 75th percentile values increased the most between 2020 and 2021, particularly in the HG and MG groups.

Outpatient costs also increased steadily over the 5-year study period, although they were generally lower than inpatient costs. In 2019, the 75th percentile outpatient costs in the HG, NG, and MG groups were USD 967, 632, and 779, respectively, and by 2023, the corresponding values were USD 796, 732, and 796, respectively. Outpatient costs were consistently higher in the HG and MG than in the NG group during the study period.

Annual OOP and IE costs by HbA1c level

During the study period, the highest 75th percentile for IE was observed in the HG group at 6,416 USD, followed by the MG group at 6,030 USD and the NG group at 5,193 USD. The 75th percentile for OOP mirrored this trend: HG = 2,582 USD, MG = 2,388 USD, and NG = 2,138 USD. Both the IE and OOP costs increased across all groups from 2019 to 2023; however, the HG group often exhibited the highest annual increases in OOP and IE costs.

In the inpatient setting, the 75th percentile of annual IE costs was the highest in the HG group, followed by the MG and NG groups (HG: 5,039 USD; MG: 4,711; NG: 4,372 USD). The HG group also encountered the highest inpatient OOP costs at the 75th percentile (1,422 USD). Steady increases in inpatient costs were observed throughout the study period. In 2023, the HG and MG incurred higher OOP costs than the NG group.

The annual outpatient IE costs showed a distinct pattern, with the 75th percentile remaining highest in the HG group. In this group, the 75th percentile outpatient IE cost was 481

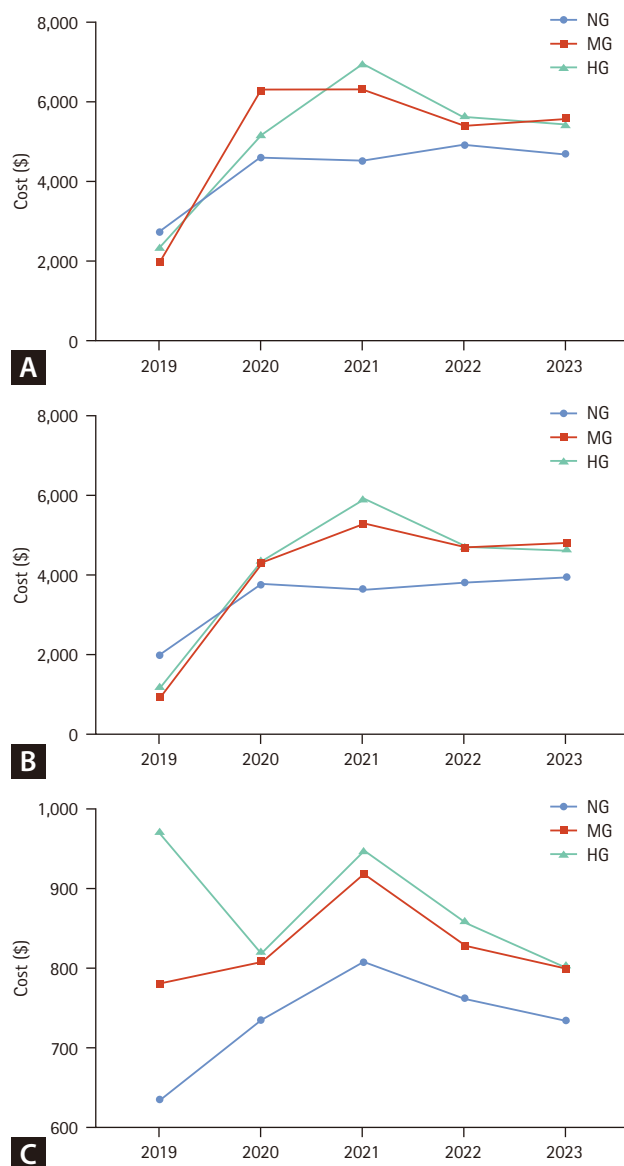


Figure 2. Annual total, inpatient, and outpatient costs by glycemic control group (2019–2023). The figure illustrates the 75th percentiles of annual total, inpatient, and outpatient costs across the NG (HbA1c < 6.5%), MG (HbA1c 6.5–7.9%), and HG (HbA1c ≥ 8%) groups from 2019 to 2023. (A) Total costs increased consistently over time, and the MG and HG groups exhibited higher costs than the NG group, except in 2019. By 2023, total costs in the MG, HG, and NG groups were 5,594, 5,485, and 4,677 USD, respectively. (B) Inpatient costs followed a similar trend; that is, they increased sharply between 2020 and 2021, particularly in the MG and HG groups. In 2023, inpatient costs peaked in the MG, HG, and NG groups at 4,843, 4,693, and 3,982 USD. (C) Outpatient costs were consistently lower but increased steadily across all groups. By 2023, outpatient costs reached 796 USD in the HG and MG groups and 732 USD in the NG group. The NG group represents patients with HbA1c < 6.5% and does not constitute a healthy control population. NG, normal glycemic group; MG, moderately hyperglycemic group; HG, highly hyperglycemic group; HbA1c, hemoglobin A1c.

USD in 2019 and 384 USD in 2023. Furthermore, the proportion of OOP costs in the total outpatient costs appeared to be higher than that of the total inpatient costs (Fig. 3).

Costs by diabetes, CKD, and SDE status

Using the subgroup analysis, patients with DM, CKD, or SDE incurred significantly higher costs than did their non-DM, non-CKD, and non-SDE counterparts. In patients with DM, the NG group incurred the highest costs, whereas in pa-

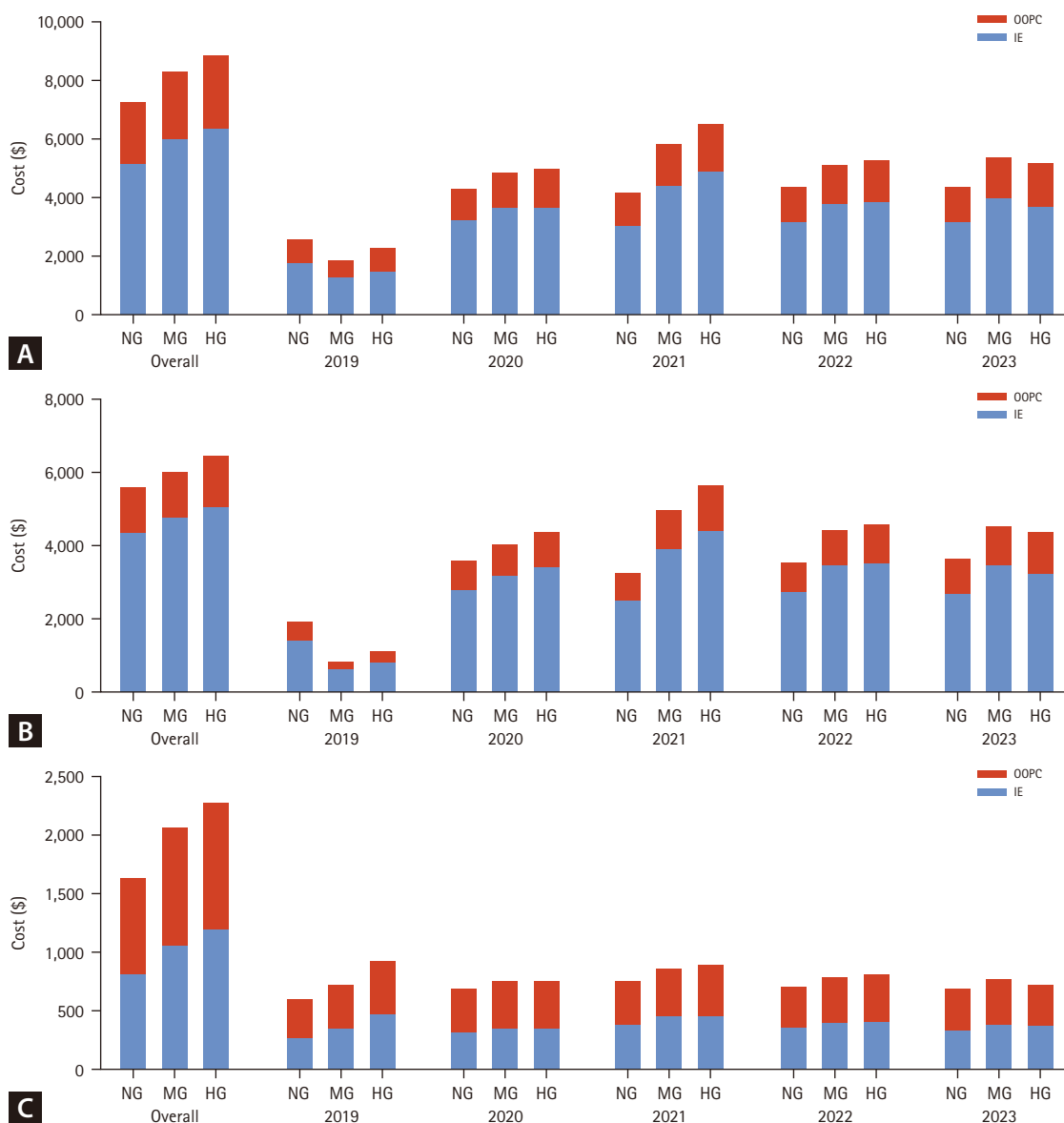


Figure 3. Annual OOPC and IE costs by glycemic control group (2019–2023). The figure shows the 75th percentile of OOPC and IE costs in the NG (HbA1c < 6.5%), MG (HbA1c 6.5–7.9%), and HG (HbA1c ≥ 8%) groups over the years 2019 to 2023. (A) Overall costs: the HG group consistently exhibited the highest total IE (6,416 USD) and OOPC (2,582 USD) costs. IE and OOPCs increased steadily across all groups over the study period. (B) Inpatient costs: the 75th percentile inpatient IE cost was highest in the HG group (HG, 5,039 USD; MG, 4,711 USD; NG, 4,372 USD). Inpatient OOPCs were also highest in the HG group (1,422 USD), and costs rose steadily over the years, especially in the HG and MG groups. (C) Outpatient costs: the 75th percentile outpatient IE costs were consistently highest in the HG group (481 USD in 2019 and 384 USD in 2023). The OOPC-to-total outpatient cost ratio was higher than that observed for inpatient costs. The NG group represents patients with HbA1c < 6.5% and does not constitute a healthy control population. NG, normal glycemic group; MG, moderately hyperglycemic group; HG, highly hyperglycemic group; HbA1c, hemoglobin A1c; OOPC, out-of-pocket cost; IE, insurance expenditure.

tients with CKD and SDE, the costs increased progressively with HbA1c levels (Fig. 4). The detailed costs for the subgroups and numbers for each group are summarized in the legend of Figure 4 and Supplementary Table 3.

Costs by insurance class

In patients covered by NHI, the total costs at the 75th percentile increased from NG to HG (NG, 6,948 USD; MG, 7,916 USD; HG, 8,726 USD). This increase was reflected in the IE, which accounted for most of the costs (NG, 4,751 USD; MG, 5,455 USD; HG, 6,022 USD). However, the OOP costs increased only modestly (NG, 2,197 USD; MG, 2,461 USD; HG, 2,704 USD). Patients who received medical aid

incurred the highest total costs. The 75th percentile of total costs was similar in the MG and HG groups (MG, 13,987 USD; HG, 13,848 USD) but lower in the NG group (NG, 11,966 USD). Despite the higher total costs, OOP cost remained low for medical aid recipients (NG, 1,205 USD; MG, 1,382 USD; HG, 1,367 USD), but IE costs were much higher (NG, 10,761 USD; MG, 12,605 USD; HG, 12,481 USD). In patients without insurance coverage, the total costs at the 75th percentile were notably lower than those of medical aid recipients (NG, 6,837 USD; MG, 4,989 USD; HG, 5,371 USD). However, OOP cost accounted for a substantial proportion of the total costs and remained high (NG, 2,311 USD; MG, 2,668 USD; HG, 2,725 USD). The IE costs were

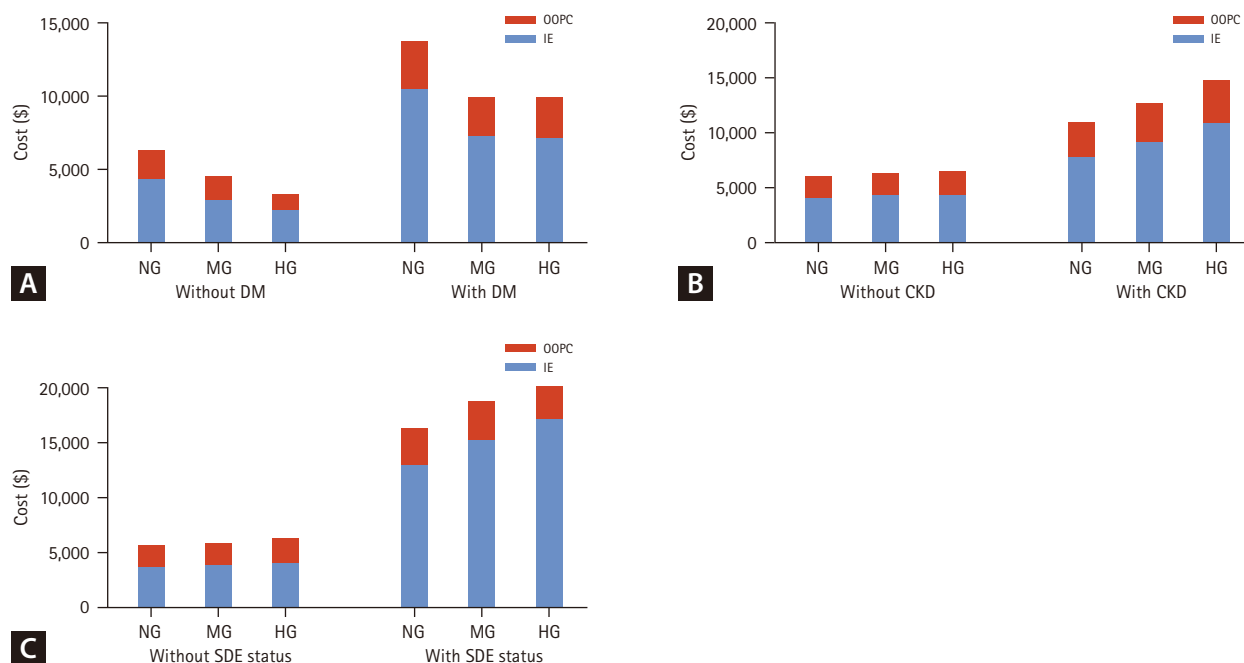


Figure 4. Subgroup analysis of healthcare costs by glycemic status in patients with DM, CKD, or SDE status. The figure presents the 75th percentile of total healthcare costs, OOPC, and IE across the NG (HbA1c < 6.5%), MG (6.5–7.9%), and HG (HbA1c ≥ 8.0%) groups, stratified by the presence or absence of DM, CKD, or SDE status. (A) DM subgroup. Among patients without DM (NG, n = 50,913; MG, n = 3,735; HG, n = 889), total healthcare costs at the 75th percentile were highest in the NG group (6,549 USD), followed by the MG (4,467 USD) and HG (3,430 USD) groups. In contrast, patients with DM (NG, n = 11,048; MG, n = 11,330; HG, n = 8,502) incurred substantially higher costs, with total costs reaching 14,204 USD (NG), 10,272 USD (MG), and 10,126 USD (HG). OOPC and IE showed similar patterns, indicating a markedly higher financial burden among patients with DM. (B) CKD subgroup. Among patients without CKD (NG, n = 46,261; MG, n = 10,496; HG, n = 6,436), total costs were relatively stable across glycemic categories (6,389 USD, 6,769 USD, and 6,764 USD, respectively). In patients with CKD (NG, n = 15,700; MG, n = 4,569; HG, n = 2,955), total costs increased progressively with worsening glycemic control, reaching 11,620 USD (NG), 13,408 USD (MG), and 15,204 USD (HG). OOPC and IE were consistently higher in patients with CKD than in those without CKD. (C) SDE status subgroup. Among patients with SDE status (NG, n = 12,242; MG, n = 3,787; HG, n = 2,211), total healthcare costs were the highest observed across all subgroups (16,871 USD, 19,154 USD, and 21,213 USD, respectively). In contrast, patients without SDE status (NG, n = 49,719; MG, n = 11,278; HG, n = 7,180) incurred substantially lower costs (5,958 USD, 6,233 USD, and 6,680 USD, respectively). All costs are presented in 2023 U.S. dollars adjusted for inflation using the Consumer Price Index. The NG group represents patients with HbA1c < 6.5% and does not constitute a healthy control population. NG, normal glycemic group; MG, moderately hyperglycemic group; HG, highly hyperglycemic group; HbA1c, hemoglobin A1c; OOPC, out-of-pocket cost; IE, insurance expenditure; DM, diabetes mellitus; CKD, chronic kidney disease; SDE, serious disease exemption.

relatively low and showed intergroup variability (NG, 4,526 USD; MG, 2,321 USD; HG, 2,646 USD) (Fig. 5).

Supplementary Table 4 presents the distribution of key health conditions across the insurance groups. Medical aid beneficiaries had a higher prevalence of severe health conditions than patients with NHI or no insurance coverage. Specifically, 30.1% of medical aid patients were diagnosed with DM, compared with 27.7% of patients with NHI, and only 5.8% of those without insurance. Similarly, CKD was most common among medical aid recipients (35.9%), followed by NHI (26.8%) and uninsured patients (10.4%). The prevalence of cancer was 7.2% for patients receiving medical aid or NHI, but only 2.8% for uninsured patients. SDE status was more prevalent among medical aid patients (30.3%) than among NHI (20.8%) and uninsured (9.6%) patients. All intergroup differences were statistically significant ($p < 0.001$).

Comparison of healthcare costs by glycemic control dynamics

Total healthcare costs were the highest in the worsened group (12,742 USD), followed by the high-persistent group (11,444 USD), whereas the low- and mid-stable groups in-

curred lower costs (9,971 and 8,680 USD). Inpatient costs showed a similar pattern, with the worsened group exhibiting substantially higher admission-related expenditures than all other groups (8,780 USD). Conversely, outpatient costs were the highest in the high-persistent group (3,861 USD). The improved group consistently showed lower total and inpatient costs than the worsened group. Outpatient costs in the improved group were 3,525 USD (Fig. 6).

DISCUSSION

This study evaluated the association between glycemic status and healthcare costs in South Korea using a large single-center dataset of 86,417 individuals over 5 years. Higher HbA1c levels were consistently associated with greater healthcare expenditures, particularly total and inpatient costs. Using unadjusted analyses, each 1% increase in HbA1c level was associated with an additional 236.11 USD in total healthcare costs, with similar associations found in inpatient, outpatient, OOP, and IEs. In multivariate models accounting for major clinical and insurance-related factors, higher HbA1c

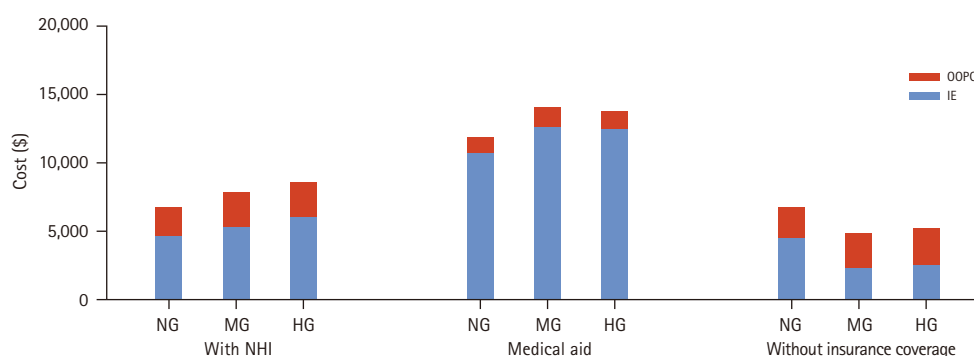


Figure 5. Healthcare costs by insurance class and glycemic status (75th percentile values). This figure presents the 75th percentile of total healthcare costs, OOPC, and IE according to glycemic status—NG (HbA1c < 6.5%), MG (6.5–7.9%), and HG ($\geq 8.0\%$)—stratified by insurance class. NHI: among patients covered by the NHI (NG, $n = 55,274$; MG, $n = 13,628$; HG, $n = 8,423$), total healthcare costs increased with worsening glycemic status (NG, 6,948 USD; MG, 7,916 USD; HG, 8,726 USD). This increase was primarily driven by IE (NG, 4,751 USD; MG, 5,455 USD; HG, 6,022 USD), whereas OOPC increased modestly (NG, 2,197 USD; MG, 2,461 USD; HG, 2,704 USD). Medical aid: medical aid beneficiaries (NG, $n = 4,186$; MG, $n = 1,210$; HG, $n = 818$) incurred the highest overall total healthcare costs, with similarly high costs in the MG (13,987 USD) and HG (13,848 USD) groups compared with the NG group (11,966 USD). Despite these high total costs, OOPC remained low across all glycemic categories (NG 1,205 USD, MG 1,381 USD, and HG 1,367 USD), as expenditures were predominantly covered by IE (NG 10,761 USD, MG 12,605 USD, and HG 12,481 USD). Without insurance coverage: among patients without insurance coverage (NG, $n = 2,501$; MG, $n = 227$; HG, $n = 150$), the total healthcare costs were lower than those observed in medical aid recipients (NG, 6,837 USD; MG, 4,989 USD; HG, 5,371 USD). In this group, OOPC accounted for a substantial proportion of the total costs (NG 2,311 USD, MG 2,668 USD, HG 2,725 USD), while IE costs were relatively small and variable (NG 4,526 USD, MG 2,321 USD, HG 2,645 USD). All cost values are presented in 2023 USD, adjusted for inflation using the Consumer Price Index. The NG group represents patients with HbA1c < 6.5% and does not constitute a healthy control population. NG, normal glycemic group; MG, moderately hyperglycemic group; HG, highly hyperglycemic group; HbA1c, hemoglobin A1c; OOPC, out-of-pocket cost; IE, insurance expenditure; NHI, National Health Insurance.

remained significantly associated with increased outpatient and OOP expenditures, whereas total and inpatient costs were largely attributable to comorbidities such as CKD, cancer, and SDE status. Sensitivity analyses using gamma log-link GLMs showed consistent patterns, with higher HbA1c levels being associated with greater outpatient utilization and patient-borne costs. Together, these findings suggest that poor glycemic control is linked with a higher ambulatory care burden and greater financial exposure of patients, underscoring the economic relevance of sustained glycemic management in routine clinical practice. Further multicenter or population-based studies are warranted to clarify causal pathways and quantify potential cost reductions associated with improved glycemic control.

Furthermore, subgroup analysis highlighted the disproportionate financial burden borne by patients with DM, CKD, and SDE, particularly among those in the highly hyperglycemic group. Importantly, patients with worsening glycemic control incurred higher total and inpatient costs than did those who maintained or improved their glycemic control. These results underscore the critical importance of glycemic management for mitigating the economic burden of diabetes and highlight the potential cost-saving benefits

of improving glycemic control in South Korean healthcare settings.

The study also showed that total healthcare costs significantly increased with increasing HbA1c levels. The 75th percentile total cost reached 9,339 USD in the HG group ($\text{HbA1c} \geq 8\%$) compared with 7,673 and 8,741 USD in the NG and MG groups, respectively; for every 1% increase in HbA1c, total cost rose by 236.11 USD. Similarly, Boye et al. [12] reported significantly higher costs for an HbA1c level of $\geq 7\%$ in the US, with an annual total cost of 16,460 USD versus 13,704 USD for an HbA1c level of $< 7\%$. Although absolute costs in our study were lower than those in the US due to differences in healthcare systems, the positive relationship between costs and poorer glycemic control was consistent. Furthermore, Oh et al. [8], using Korean NHI data, reported annual direct medical costs of approximately 2,941 USD in patients with diabetes, which is consistent with our findings. Kim et al. [21] estimated the annual per capita costs for diabetes to be 1,939 USD in a prospective Korean cohort study, with higher costs among those with complications. When adjusted for inflation, these results were compared with ours and reaffirmed the significant economic burden posed by diabetes. In a Spanish population-based

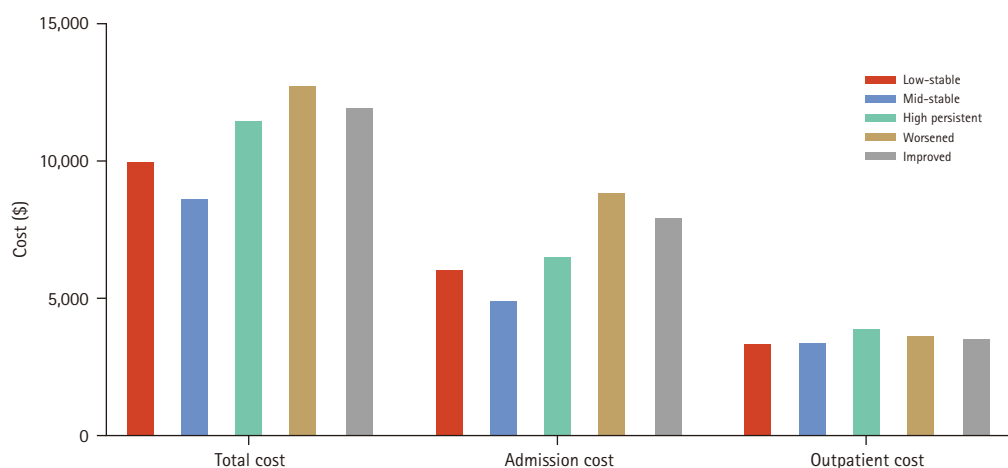


Figure 6. Comparison of healthcare costs by glycemic control dynamics. The figure compares total, inpatient, and outpatient healthcare costs across five glycemic control trajectory groups: low-stable (NG→NG, $\text{HbA1c} < 6.5\%$), mid-stable (MG→MG, $\text{HbA1c} 6.5\text{--}7.9\%$), high-persistent (HG→HG, $\text{HbA1c} \geq 8\%$), worsened, and improved glycemic control. Total costs: total healthcare costs were highest in the worsened group (12,742 USD), followed by the improved (11,975 USD) and high-persistent groups (11,444 USD). Lower total costs were observed in the low (9,971 USD) and mid-stable groups (8,680 USD). Inpatient costs: inpatient costs were greatest in the worsened group (8,780 USD), followed by the improved (7,919 USD) and high-persistent groups (6,523 USD). In contrast, the mid-stable group had the lowest inpatient costs (4,881 USD), with modestly higher costs in the low-stable group (6,074 USD). Outpatient costs: outpatient costs showed a different pattern, with the highest costs observed in the high-persistent group (3,861 USD), followed by the worsened (3,577 USD) and improved groups (3,525 USD). Outpatient costs were comparatively lower in the mid-stable (3,325 USD) and low-stable groups (3,278 USD). The NG group represents patients with $\text{HbA1c} < 6.5\%$ and does not constitute a healthy control population. NG, normal glycemic group; MG, moderately hyperglycemic group; HG, highly hyperglycemic group; HbA1c, hemoglobin A1c.

study performed by Mata-Cases et al. [22], a direct relationship was found between worsening glycemic control and increased healthcare costs; annual healthcare costs were 23% higher in patients with poor glycemic control (HbA1c 8–10%) than in those with good glycemic control (HbA1c < 7%). This finding was primarily attributed to higher hospitalization rates and costs, which aligns with our finding of elevated inpatient costs in the HG group. The additional costs likely stem from the need for intensive blood glucose management, including insulin titration and prolonged hospital stays [23]. Collectively, these findings emphasize the importance of targeted interventions to improve HbA1c levels, which could significantly reduce the societal financial burden on systems such as the NHI. Importantly, our subgroup analyses of data of patients with diabetes, CKD, or SDE demonstrated that even within these high-risk populations, higher HbA1c levels were consistently associated with greater healthcare costs. These findings suggest that the observed relationship between poor glycemic control and increased financial burden persists even after accounting for major comorbid conditions. These results should be interpreted as describing the structure of associations between glycemic control and healthcare costs rather than as identifying specific utilization-level cost drivers.

In our study, medical aid beneficiaries had significantly higher total healthcare costs than did the other insurance groups. One possible reason is that the prevalence of severe illnesses such as CKD (35.9%), SDE status (30.3%), and cancer (7.2%) was higher in this group. In previous studies, the presence of chronic disease was significantly associated with greater outpatient and inpatient service use [24,25]. These serious and chronic conditions require more frequent and intensive medical care, thereby increasing healthcare expenses [26].

Another factor may be the low OOP costs for medical aid recipients, which could lead to a higher use of healthcare services. With fewer financial barriers, both necessary treatments and potentially avoidable services may contribute to cost increases. For instance, in a Korean study that focused on patients with end-stage renal disease, the OOP costs for patients with NHI were 2.6 to 3 times higher than those for medical aid patients, despite no difference in healthcare utilization rates [27], suggesting that patients receiving medical aid must manage their severe illnesses and effectively access medical services. In addition, a recent study has found an association between low income and unhealthy

habits, resulting in multimorbidity [28]. To address this, policies should focus on improving care for severe conditions and ensuring the efficient use of resources.

Our study demonstrated that elevated HbA1c levels and worsening glycemic control over time were associated with higher healthcare costs. Notably, the Worsened group incurred the highest expenses, indicating that “failure to achieve blood glucose control” may lead to a greater financial burden. However, given that this analysis was based on a descriptive secondary assessment within a cross-sectional design, causality or long-term temporal effects cannot be inferred. Nevertheless, these patterns raise the possibility that enhanced HbA1c management might be associated with lower hospitalization rates and related costs. No previous study has directly analyzed the relationship between changes in HbA1c levels over time and healthcare costs. However, a meta-analysis reported that greater HbA1c variability was associated with an increased risk of macrovascular and microvascular complications and mortality in patients with diabetes [29]. Moreover, several studies have demonstrated that higher diabetes-related costs are significantly associated with increased cardiovascular events and mortality over 10 years, further emphasizing the importance of glycemic control in terms of reducing clinical and financial burdens [9,30]. These previous findings and our results suggest that stabilizing HbA1c levels is crucial for preventing complications and reducing associated healthcare costs. In this context, the introduction of medications with cardiovascular and renal benefits, such as SGLT2 inhibitors and GLP-1 receptor agonists, which reduce hospitalization and complication-associated costs, appears economically justified [31].

However, this study has some limitations. First, it employed a retrospective, cross-sectional, real-world design, which precluded causal inferences about the relationship between HbA1c levels and healthcare costs. Accordingly, no washout period or restriction on incident cases was applied. Although this limits causal interpretation, it enhances the generalizability of our findings to routine clinical practice. Second, the study was conducted using data from a single institution, Uijeongbu St. Mary's Hospital, which also functions as a regional trauma center. This institutional characteristic might have influenced the patient case mix and healthcare utilization patterns, thereby limiting the generalizability of the findings to other settings. Moreover, because cost data were restricted to services provided within this institution, healthcare utilization at other facilities, particularly

for diabetes-related complications, was not captured, likely leading to an underestimation of total healthcare costs. Third, discordance between HbA1c levels and diabetes diagnostic codes was observed, reflecting an inherent limitation of operational definitions in real-world administrative data [32]. Patients with well-controlled diabetes may exhibit HbA1c levels < 6.5% despite being diagnosed with diabetes, whereas some individuals with elevated HbA1c levels may not receive a diabetes code during non-endocrine hospitalizations owing to under-coding. To minimize misclassification bias, HbA1c was analyzed primarily as a continuous biological marker. In addition, the NG group in this study should not be interpreted as a healthy control population, as it included individuals undergoing HbA1c testing for diverse clinical indications. Although this heterogeneity might introduce residual confounding factors, subgroup and multivariate analyses were performed to mitigate this limitation. Fourth, although the study period spanned 5 years and included the COVID-19 pandemic, individual COVID-19 infection or hospitalization status could not be identified due to data anonymization. Nevertheless, annual cost trends were assessed; moreover, the overall association between HbA1c levels and healthcare expenditures remained consistent across the years, supporting the robustness of the findings. Finally, only direct medical costs were analyzed, and detailed cost components, such as emergency department visits, intensive care unit admissions, specialty-specific services, and diabetes-related complications, could not be separately evaluated owing to the use of aggregated cost variables. In addition, hypoglycemic events could not be reliably captured, despite previous studies showing that severe hypoglycemia is associated with increased medical costs [33]. A more granular assessment of cost drivers requires prospective or nationwide datasets with richer clinical and healthcare utilization data. Further multicenter or population-based studies are warranted to clarify the causal pathways and quantify the potential cost reductions associated with improved glycemic control. Collectively, these limitations indicate that the present findings should be interpreted as characterizing real-world associations between glycemic status and healthcare costs rather than causal effects, whereas they provide clinically relevant insights into the economic burden associated with poor glycemic control in routine real-world practice.

This study demonstrated that high HbA1c levels and worsening glycemic control were significantly associated with

increased healthcare costs, particularly inpatient expenses. Patients with stable or improved glycemic control incurred lower costs, underscoring the importance of glycemic stability for reducing financial burden. Notably, each 1% increase in the HbA1c level was associated with an average cost rise of 236 USD, providing a practical benchmark for evaluating the economic value of glycemic control interventions.

KEY MESSAGE

1. Higher HbA1c levels were consistently associated with increased healthcare costs, particularly total and inpatient expenditures.
2. Each 1% increase in HbA1c was associated an average rise of approximately USD 236 in total healthcare costs.
3. Poor and worsening glycemic control were associated with a greater ambulatory care burden and higher OOP expenses.

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CRedit authorship contributions

Han-Sang Baek: conceptualization, methodology, formal analysis, data
 curation, visualization, software, writing - original draft, writing - re-
 view & editing; Sungju Kim: supervision; Dong-Jun Lim: supervision;
 Chul-Min Kim: supervision; Tae Seo Sohn: supervision; Sungrae Kim:
 supervision

Conflicts of interest

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Supplementary Table 1. Multivariate linear regression coefficients for factors associated with healthcare costs

Cost category	Variable	B	Standard error	t	p value
Total cost	HbA1c	80.38	54.28	1.481	0.139
	Age	-28.21	5.44	-5.189	< 0.001
	Male	1,345.32	173.22	7.766	< 0.001
	BMI	-43.68	21.15	-2.065	0.039
	CKD	4,506.88	192.24	23.444	< 0.001
	Cancer	10,024.58	330.26	30.354	< 0.001
	SDE	5,641.13	238.97	23.606	< 0.001
	Medical aid	2,113.64	302.13	6.996	< 0.001
	Without insurance coverage	888.49	432.08	2.056	0.040
Inpatient cost	HbA1c	-9.05	41.60	-0.216	0.829
	Age	-2.09	4.20	-0.497	0.619
	Male	1,198.08	133.72	8.960	< 0.001
	BMI	-82.12	16.33	-5.029	< 0.001
	CKD	1,562.15	148.40	10.527	< 0.001
	Cancer	6,403.18	254.94	25.116	< 0.001
	SDE	1,460.87	184.47	7.919	< 0.001
	Medical aid	1,396.42	233.23	5.987	< 0.001
	Without insurance coverage	1,366.00	333.54	4.095	< 0.001
Outpatient cost	HbA1c	73.75	25.42	2.90	0.004
	Age	-28.32	2.55	-11.12	< 0.001
	Male	-164.12	81.13	-2.02	0.043
	BMI	31.47	9.91	3.18	0.001
	CKD	2,396.31	90.04	26.614	< 0.001
	Cancer	1,797.49	154.68	11.621	< 0.001
	SDE	3,495.28	111.92	31.229	< 0.001
	Medical aid	531.55	141.51	3.756	< 0.001
	Without insurance coverage	-143.77	202.37	-0.710	0.477
Out-of-pocket cost	HbA1c	50.82	15.34	3.317	0.001
	Age	-2.18	1.54	-1.417	0.156
	Male	1.93	48.95	0.039	0.969
	BMI	21.34	5.98	3.570	< 0.001
	CKD	1,322.72	54.33	24.347	< 0.001
	Cancer	1,073.37	93.33	11.501	< 0.001
	SDE	486.52	67.53	7.204	< 0.001
	Medical aid	-1,628.87	85.38	-19.078	< 0.001
	Without insurance coverage	1,198.81	122.10	9.818	< 0.001
Insurance expenditure	HbA1c	29.50	46.57	0.633	0.526
	Age	-26.03	4.66	-5.581	< 0.001
	Male	1,343.38	148.61	9.040	< 0.001
	BMI	-65.02	18.15	-3.583	< 0.001
	CKD	3,184.08	164.93	19.306	< 0.001
	Cancer	8,951.21	283.33	31.593	< 0.001
	SDE	5,154.60	205.01	25.143	< 0.001
	Medical Aid	3,742.51	259.20	14.439	< 0.001
	Without insurance coverage	-310.32	370.68	-0.837	0.403

Values are multivariate linear regression estimates reported as unstandardized coefficients (B), standard errors, t-statistics, and p values. HbA1c, hemoglobin A1c; BMI, body mass index; CKD, chronic kidney disease; SDE, serious disease exemption.

Models adjusted for age, sex, BMI, CKD, cancer, SDE, and insurance class. The categorical variable reference categories were as follows: sex, female; CKD, no CKD; cancer, no cancer; SDE, no SDE; insurance class, National Health Insurance (with class 1 = medical aid and class 2 = without insurance coverage). Continuous variables (HbA1c level, age, and BMI) were linearly modeled.

Supplementary Table 2. GLMs (gamma family with log link) for the association between HbA1c and healthcare costs

Cost category	Variable	B	Standard error	t	p value
Total cost	HbA1c	0.0053	0.0041	1.299	0.197
Inpatient cost	HbA1c	-0.0055	0.0047	-1.179	0.239
Outpatient cost	HbA1c	0.0580	0.0062	9.824	< 0.001
Out-of-pocket cost	HbA1c	0.0170	0.0044	3.862	0.000
Insurance expenditure	HbA1c	0.0011	0.0046	0.241	0.810

GLM, generalized linear models; HbA1c, hemoglobin A1c; BMI, body mass index; CKD, chronic kidney disease; SDE, serious disease exemption.

Coefficients (B) and standard errors were obtained from GLMs with gamma distribution and log link.

B estimates are on the log-cost scale; the percent change in cost per 1-percentage-point increase in HbA1c is calculated as $(e^B - 1) \times 100\%$. For example, for outpatient cost, $B \approx 0.058$ implies $\approx 6.0\%$ higher cost per +1% HbA1c; for out-of-pocket cost, $B \approx 0.017$ implies $\approx 1.7\%$ higher cost. Two-tailed tests were performed.

Models adjusted for age, sex, BMI, CKD, cancer, SDE status, and insurance class (reference: National Health Insurance; class 1 = medical aid; class 2 = without insurance coverage).

Supplementary Table 3. Healthcare costs by HbA1c category in key clinical subgroups

	Non-DM				DM			
	NG (n = 50,913)	MG (n = 3,735)	HG (n = 889)	p value	NG (n = 11,048)	MG (n = 11,330)	HG (n = 8,502)	p value
Total cost	6,549.0	4,467.0	3,430.0	< 0.001	14,204.0	10,272.0	10,126.0	< 0.001
OOP cost	1,928.0	1,443.0	1,134.0	< 0.001	3,209.0	2,708.0	2,749.0	< 0.001
IE cost	4,322.0	2,934.0	2,217.0	< 0.001	10,508.0	7,215.0	7,112.0	< 0.001
	Without CKD				With CKD			
	NG (n = 46,261)	MG (n = 10,496)	HG (n = 6,436)	p value	NG (n = 15,700)	MG (n = 4,569)	HG (n = 2,955)	p value
Total cost	6,389.0	6,769.0	6,764.0	< 0.001	11,620.0	13,408.0	15,204.0	< 0.001
OOP cost	1,785.0	1,940.0	2,031.0	< 0.001	3,185.0	3,484.0	3,945.0	< 0.001
IE cost	4,296.0	4,556.0	4,523.0	< 0.001	7,945.0	9,442.0	11,039.0	< 0.001
	With SDE status				Without SDE status			
	NG (n = 12,242)	MG (n = 3,787)	HG (n = 2,211)	p value	NG (n = 49,719)	MG (n = 11,278)	HG (n = 7,180)	p value
Total cost	16,871.0	19,154.0	21,213.0	< 0.001	5,958.0	6,233.0	6,680.0	< 0.001
OOP cost	3,308.0	3,618.0	4,111.0	< 0.001	1,872.0	2,025.0	2,173.0	< 0.001
IE cost	13,000.0	15,189.0	17,180.0	< 0.001	3,782.0	3,918.0	4,238.0	< 0.001

HbA1c, hemoglobin A1c; DM, diabetes mellitus; CKD, chronic kidney disease; SDE, serious disease exemption; NG, normal glycemic group; MG, moderately hyperglycemic group; HG, highly hyperglycemic group; OOP, out-of-pocket cost; IE, insurance expenditure. The values represent the 75th percentile of healthcare costs (USD) within each subgroup.

HbA1c categories were defined as follows: NG, HbA1c < 6.5%; MG, 6.5% ≤ HbA1c < 8.0%; HG, HbA1c ≥ 8.0%.

Healthcare costs include total OOP and IE components.

All cost values were converted to USD and adjusted to 2023 values using annual Consumer Price Index data from Statistics Korea. p values were derived from comparisons across HbA1c groups within each subgroup.

Supplementary Table 4. Distribution of health conditions by insurance group

	With NHI (n = 77,325)	Medical aid (n = 6,214)	Without insurance coverage (n = 2,878)	<i>p</i> value
DM	21,420 (27.7)	1,872 (30.1)	166 (5.8)	< 0.001
CKD	20,697 (26.8)	2,228 (35.9)	299 (10.4)	< 0.001
Cancer	5,577 (7.2)	5,577 (7.2)	80 (2.8)	< 0.001
SDE	16,080 (20.8)	1,885 (30.3)	275 (9.6)	< 0.001

Values are presented as number (%).

NHI, National Health Insurance; DM, diabetes mellitus; CKD, chronic kidney disease; SDE, severe disease exception.