Original Article
Yonsei Med J 2025 Aug;66(8):519-528
https://doi.org/10.3349/ymj.2024.0245
Yonsei Medical Journal
YMJ
pISSN: 0513-5796 · eISSN: 1976-2437

Meeting Physical Activity Guidelines: Impact on Chronic Kidney Disease Prevalence in Diabetic Individuals

Yong Jun Lee[1], Dong-Hyuk Park[1,2], Chiho Kim[1], Dong Hoon Lee[1,3], Yong-ho Lee[4,5], Byung-Wan Lee[4,5], Joon Young Kim[6], and Justin Y. Jeon[1,2]

[1]Department of Sport Industry Studies, Yonsei University, Seoul, Korea
[2]Center for Exercise Medicine and Salutogenesis, ICONS, Yonsei University, Seoul, Korea
[3]Department of Nutrition, Harvard T.H. Chan School of Public Health, Boston, MA, USA
[4]Department of Internal Medicine, Yonsei University College of Medicine, Seoul, Korea
[5]Institute of Endocrine Research, Yonsei University College of Medicine, Seoul, Korea
[6]Department of Exercise Science, Syracuse University, Syracuse, NY, USA.

Purpose: This study aimed to examine 1) the relationship between domain-specific physical activity (PA) and the prevalence of chronic kidney disease (CKD), as well as 2) the association between meeting PA and resistance exercise (RE) guideline and CKD prevalence in individuals with diabetes.

Materials and Methods: The study analyzed data from the 2019–2021 Korea National Health and Nutrition Examination Survey, a cross-sectional study that included 22559 participants. From this group, 2381 adults with diabetes were selected. CKD was defined as an estimated glomerular filtration rate <60 mL/min/1.73m^2, a urinary albumin-to-creatinine ratio ≥30 mg/g, or a physician's diagnosis. Logistic regression models were used to assess the association between compliance with the WHO's PA guidelines and CKD prevalence, with further stratification according to known CKD risk factors.

Results: Individuals with diabetes who met the PA guidelines through leisure physical activity (LPA) and RE were significantly inversely associated with the odds of CKD [odds ratio (OR): 0.55, 95% confidence interval (CI) 0.34–0.89]. This inverse association was pronounced in individuals with lower body mass index (OR: 0.31, 95% CI 0.15–0.65). However, individuals who met the recommended amount of PA through work-related physical activity and RE guideline were not significantly associated with the odds of CKD (OR: 1.46, 95% CI 0.44–4.82).

Conclusion: Meeting PA and RE guidelines are associated with reduced prevalence of CKD in individuals with diabetes. These findings underscore the potential benefits of LPA and RE in the prevention of CKD in individuals with diabetes.

Key Words: Chronic kidney disease, diabetes mellitus, physical activity, resistance training

INTRODUCTION

Globally, diabetes is a major challenge, and its prevalence is expected to increase from 537 million in 2021 to 783 million by 2045.[1] Prolonged diabetes is accompanied by various complications, including microvascular ones such as retinopathy, neuropathy, and nephropathy.[2] Among these, diabetic nephropathy is caused by glomerular vascular damage due to diabetes, which can damage the kidneys and lead to chronic kidney disease (CKD).[3]

A combination of both diabetes and hypertension, or each condition alone, is responsible for over 80% of end-stage renal

Received: August 21, 2024 **Revised:** February 24, 2025
Accepted: February 26, 2025 **Published online:** June 4, 2025
Corresponding author: Justin Y. Jeon, PhD, Department of Sport Industry Studies and Center for Exercise Medicine and Salutogenesis, Yonsei University, 50 Yonsei-ro, Seodaemun-gu, Seoul 03722, Korea.
E-mail: jjeon@yonsei.ac.kr

This study was presented at ACSM 2024 in Boston, Massachusetts (May 28–31, 2024).
• The authors have no potential conflicts of interest to disclose.

disease (ESRD) cases. Therefore, an annual assessment of the urinary albumin-to-creatinine ratio (ACR) and estimated glomerular filtration rate (eGFR) is recommended for individuals with type 1 diabetes who have a disease duration of 5 years or more, and for all individuals with type 2 diabetes, regardless of treatment status.[4] The prevalence of renal disease is 42.3% in individuals with type 2 diabetes and 9.4% in those without diabetes. Individuals with CKD and diabetes have a 30-fold higher risk of all-cause mortality[5] and a 10-fold higher risk of mortality within 10 years compared to individuals without CKD and diabetes.[6] Additionally, when individuals with CKD and diabetes progresses to end-stage renal failure, the medical cost per patient is approximately 49520 USD, resulting in significant healthcare expenses.[7] As such, the prevention and management of CKD in individuals with diabetes are crucial, not only at the individual level but also from a societal perspective.

Two critical components of the WHO's PA recommendations are as follows: 1) engaging in a minimum of 150 minutes per week of moderate-intensity physical activity (MPA) or 75 minutes of vigorous-intensity physical activity (VPA); and 2) performing resistance exercise (RE) at least twice per week.[8] Lifestyle modifications, including PA, have been shown to prevent renal function deterioration,[9] while MPA, VPA, and RE can help reduce vascular complications and mortality in individuals with diabetes.[10,11] However, studies examining the association between domain-specific PA and health outcomes have reported mixed results. While leisure physical activity (LPA) is consistently associated with positive health outcomes, the impact of work-related physical activity (WPA) on all-cause mortality, cardiopulmonary mortality, and cancer mortality remains inconsistent.[12-14] This highlights the need for further investigation into the effects of domain-specific PA on health.

Despite the well-established benefits of PA and RE,[15] research on specific domains of PA, such as WPA, LPA, and transportation physical activity (TPA) in individuals with diabetes, is limited.[16,17] Furthermore, no studies have explored the combined effects of PA and RE within these domains on the prevalence of CKD in this population.[18,19]

Therefore, we aimed to examine the relationship between domain-specific PA and the prevalence of CKD, as well as to investigate the association between RE and CKD prevalence in individuals with diabetes. We hypothesized that: 1) LPA is more strongly associated with CKD prevalence compared to non-LPA, and 2) meeting the PA guidelines through LPA and engaging in RE at least 2 days per week are associated with a lower prevalence of CKD.

MATERIALS AND METHODS

Data collection

The Korea National Health and Nutrition Examination Study (KNHANES) data were collected using self-reported questionnaires or interviews with research staff.[20] Demographic, socioeconomic, and PA data were collected using self-reported questionnaires.[20] Anthropometric measurements, including height, weight, and waist circumference, as well as cardiometabolic risk factors including blood pressure, lipids, fasting glucose (FG), and hemoglobin A1c (HbA1c), were measured. Blood pressure was measured three times after a 5-minute rest, and the average value of the second and third measurements was used. For blood tests, an Serum Separator Tube (8 mL) for chemistry analysis and an Ethylene Diamine Tetra Acetic Acid tube (2 mL) for hematology were collected after a minimum 8-hour fast. For urine tests, 30 mL of the first morning urine was collected for analysis. A family history of diabetes was recorded, and participants were asked about their smoking status (current, past, or never) and frequency of alcohol consumption during the past year (less or more than once a month). Income was categorized into quartiles based on Korean currency: 1 million won or less, 100–200 million won, 200–300 million won, and more than 300 million won. The highest academic degree attained (elementary school, middle school, high school, or college graduate or higher) was also surveyed. Information on diabetes, hypertension, and cardiovascular diseases was collected using a computer-assisted personal interviewing method.

Study participants

We used a large representative dataset from the KNHANES, conducted between 2019 and 2021. The reason we used data from 2019–2021 is that datasets from other years do not include information on serum albumin. Of the 22559 participants included in the surveys, 2381 individuals with diabetes were included in the final analysis. We excluded participants who were younger than 18 years, had a fasting time of less than 7 hours (n=1721), were not diagnosed with diabetes (n=14271), had no data on the ACR (n=109), and had no information on PA (n=209). All participants provided informed consent, and the study was approved by the Research Ethics Review Committee of the Korea Disease Control and Prevention Agency (2018-01-03-C-A, 2018-01-03-2C-A, 2018-01-03-5C-A).

Diabetes

Diabetes was defined as meeting any of the following criteria: 1) self-reported physician diagnosis of diabetes, 2) current treatment with oral hypoglycemic agents or insulin, or 3) fasting blood glucose level ≥126 mg/dL or HbA1c ≥6.5%.[21] Blood samples were collected after a minimum 8-hour fast at the mobile examination center and analyzed by expert nurses and clinical pathologists.[20] HbA1c values were calculated using the IFCC-NGSP master equation, expressed as mmol/mol.[22]

Hypertension

Hypertension was identified based on 1) self-reported physi-

https://doi.org/10.3349/ymj.2024.0245

cian diagnosis, or 2) systolic blood pressure ≥140 mm Hg or diastolic blood pressure ≥90 mm Hg.[20] Blood pressure measurements were taken by expert nurses and clinical pathologists after participants rested for 5 minutes in a seated position.

Chronic kidney disease

CKD was defined as meeting any of the following criteria: 1) self-reported physician diagnosis, 2) ACR ≥30 mg/g, or 3) eGFR <60 mL/min/1.73 m^2.[23] The eGFR was calculated using the re-expressed four-variable Modification of Diet in Renal Disease study equation for standardized serum creatinine (mg/dL): eGFR=142×min (standardized serum creatinine/K, 1)$^{\alpha}$×max (standardized serum creatinine/K, 1)$^{-1.200}$×0.9938^{age}×1012 [if female].[24] In the context of females, α and K are substituted with -0.241 and 0.7, respectively, whereas for males, they are replaced with -0.302 and 0.9, where α and K are -0.241 and 0.7 for females and -0.302 and 0.9 for males, respectively. Serum creatinine was measured from fasting blood samples, and urinary creatinine and albumin levels were assessed from the first morning urine sample. Undiagnosed CKD was defined as the presence of ACR ≥30 mg/g or eGFR <60 mL/min/1.73 m^2 in participants with diabetes who had not received a formal CKD diagnosis from a physician.

Physical activity

In the KNHANES, PA was measured using the Global Physical Activity Questionnaire (GPAQ),[20,25] which was translated into Korean, and its validity and reliability were verified, the outcomes of which were underscored by Spearman correlation coefficients of 0.61 (p<0.01) and 0.34 (p<0.01) for validity and reliability, respectively.[26] The survey consisted of 16 questions, which collected information on PA participation in three different domains, as well as sedentary behavior. These domains were WPA, TPA, and LPA.

The GPAQ classifies WPA and LPA into two categories: MPA and VPA. VPA was defined as activities that elicit significant breathlessness or a fast heartbeat for more than 10 minutes, whereas MPA was defined as activities that result in slight breathlessness or a fast heartbeat for more than 10 minutes.

Regarding the domains of PA, WPA was defined as the level of PA performed during work hours, encompassing both paid and unpaid work as well as household chores. LPA focused on sports, exercise, and other recreational activities. Finally, the TPA captured PA lasting 10 minutes or more during transportation between different locations (e.g., commuting to work, shopping, and attending religious services). The WPA and LPA consisted of 12 questions, with six questions for each domain. Three questions were on TPA and one question was on sedentary behavior. Total PA was calculated by summing all domain-specific PA. In addition to the GPAQ, participation in RE, an assessment of the number of days of participation in RE per week, was also surveyed. The frequency of RE per week means engaging in RE such as push-ups, sit-ups, using dumbbells or barbells, or utilizing a pull-up bar.

Statistical analysis

Descriptive analyses were used to present participant characteristics, and independent t-tests and chi-squared tests were used to compare continuous and categorical variables, respectively. Multivariate-adjusted logistic regression analysis was employed to estimate odds ratios (ORs) and corresponding 95% confidence intervals (CIs) to investigate the relationship between domain-specific PA and CKD, as well as RE and CKD. The models were progressively adjusted for potential confounders: Model 1 was adjusted for age and sex; Model 2 included additional adjustments for income, education, body mass index (BMI), and family history of diabetes mellitus; and Model 3 incorporated blood markers such as FG, HbA1c, triglycerides (TG), and total cholesterol (TC).

For descriptive analysis, domain-specific PA was delineated in minutes per week. In the primary analysis, metabolic equivalent of task (MET)-minutes/week were utilized after the allocation of MET values (4 METs for MPA and 8 METs for VPA) to integrate the intensity of PA. To follow the current PA recommendation guidelines, total and domain-specific PA, such as WPA, LPA, and TPA, were categorized into three groups (1–599 METs-min/week, ≥600 METs-min/week, and 0 METs-min/week).

Finally, we conducted a stratified analysis to explore whether the association between compliance with LPA recommendations and the prevalence of CKD differed based on sociodemographic and risk factors. All statistical analyses were performed using the IBM SPSS Statistics version 27.0 (IBM Corp., Armonk, NY, USA).

RESULTS

Baseline characteristics

Table 1 presents the characteristics of participants with and without CKD. Among 2381 participants diagnosed with diabetes, 647 had CKD while 1734 did not. Those with CKD had a higher prevalence of hypertension, lower income, and lower education level compared to those without CKD. Individuals with CKD also exhibited higher levels of FG, HbA1c, TC, TG, and lower high density lipoprotein concentrations. Total PA levels were lower in individuals with CKD. Regarding domain-specific PA, significant differences were noted in moderate LPA and total PA, with the non-CKD group showing higher levels of LPA and TPA compared to the CKD group.

Association between domain-specific PA and prevalence of CKD in individuals with diabetes

In the multivariate-adjusted model (Model 3), we observed a significant inverse relationship between LPA and the prevalence of CKD in individuals with diabetes, with OR of 0.69

Table 1. Characteristics of Participants

	Total (n=2381)	Non-CKD (n=1734)	CKD (n=647)	*p*
Age (yr)	63.5±12.0	62.4±11.9	66.5±11.8	0.001‡
BMI				0.705
<25 kg/m^2	1111 (46.7)	805 (46.4)	306 (47.3)	
≥25 kg/m^2	1270 (53.3)	929 (53.6)	341 (52.7)	
Sex				0.040*
Men	1243 (52.2)	887 (51.2)	356 (55.0)	
Women	1138 (47.8)	847 (48.8)	291 (45.0)	
Family history of DM				0.001‡
Yes	1292 (54.3)	941 (54.3)	351 (54.3)	
No	958 (40.2)	717 (41.3)	241 (37.2)	
Missing	131 (5.5)	76 (4.4)	55 (8.5)	
Hypertension				0.001‡
Normal	921 (38.7)	745 (43.0)	176 (27.2)	
Hypertension	1449 (60.9)	983 (56.7)	466 (72.0)	
Missing	11 (0.5)	6 (0.3)	5 (0.8)	
Smoking				0.422
Never	1240 (52.1)	909 (52.4)	331 (51.2)	
Current	453 (19.0)	319 (18.4)	134 (20.7)	
Past	684 (28.7)	504 (29.1)	180 (27.8)	
Missing	4 (0.2)	2 (0.1)	2 (0.3)	
Alcohol consumption				0.959
<Once/1 month	1335 (56.1)	971 (56.0)	364 (56.3)	
≥Once/1 month	1043 (43.8)	761 (43.9)	282 (43.6)	
Missing	3 (0.1)	2 (0.1)	1 (0.2)	
Income				0.001‡
Quantile 1	722 (30.3)	461 (26.6)	261 (40.3)	
Quantile 2	647 (27.2)	480 (27.7)	167 (25.8)	
Quantile 3	526 (22.1)	406 (23.4)	120 (18.5)	
Quantile 4	480 (20.2)	382 (22.0)	98 (15.1)	
Missing	6 (0.3)	5 (0.3)	1 (0.2)	
Education				0.001‡
Elementary school	822 (34.5)	548 (31.6)	274 (42.3)	
Middle school	372 (15.6)	269 (15.5)	103 (15.9)	
High school	674 (28.3)	514 (29.6)	160 (24.7)	
Complemented university	507 (21.3)	400 (23.1)	107 (16.5)	
Missing	6 (0.3)	3 (0.2)	3 (0.5)	
Blood markers				
Glucose, mg/dL	135.18±37.52	132.52±33.91	142.29±45.07	0.001‡
HbA1c, mmol/mol (%)	54.71±13.67 (7.2±1.3)	53.36±12.33 (7.0±1.1)	58.33±16.21 (7.5±1.5)	0.001‡
<6.5	596 (25.0)	443 (25.5)	153 (23.6)	
≥6.5	1785 (75.0)	1291 (74.5)	494 (76.4)	
Insulin, ulU/mL	11.6±10.7	11.6±10.5	11.4±11.3	0.721
TC, mg/dL	173.3±43.7	174.6±42.7	169.8±45.9	0.017
HDL, mg/dL	47.0±11.4	47.5±11.1	45.7±11.8	0.001‡
TG, mg/dL	155.7±123.8	149.9±105.8	171.5±161.6	0.002
GOT, IU/L	28.3±16.8	28.0±15.1	29.3±20.7	0.150
GPT, IU/L	29.1±26.2	29.4±23.6	28.6±32.2	0.513
Blood pressure, mm Hg				
SBP	126.5±15.9	124.7±15.0	131.0±17.4	0.001‡
DBP	75.0±10.0	75.2±9.5	74.6±11.3	0.221
Total PA				<0.001‡
0 METs-min/week	1020 (42.8)	703 (40.5)	317 (49.0)	
1–599 METs-min/week	501 (21.0)	376 (21.7)	125 (19.3)	
≥600 METs-min/week	860 (36.1)	655 (37.8)	205 (31.7)	
At work				0.294
0 METs-min/week	2257 (94.8)	1641 (94.6)	616 (95.2)	
1–599 METs-min/week	46 (1.9)	38 (2.2)	8 (1.2)	
≥600 METs-min/week	78 (3.3)	55 (3.2)	23 (3.6)	
Leisure-time				<0.001‡
0 METs-min/week	1912 (80.3)	1354 (78.1)	558 (86.2)	
1–599 METs-min/week	192 (8.1)	155 (8.9)	37 (5.7)	
≥600 METs-min/week	277 (11.6)	225 (13.0)	52 (8.0)	
Transport				0.084
0 METs-min/week	1274 (53.5)	904 (52.1)	370 (57.2)	
1–599 METs-min/week	505 (21.2)	376 (21.7)	129 (19.9)	
≥600 METs-min/week	602 (25.3)	454 (26.2)	148 (22.9)	
Sedentary time (min/day)	528.3±227.7	522.5±226.2	543.9±230.9	0.044*

CKD, chronic kidney disease; SBP, systolic blood pressure; DBP, diastolic blood pressure; PA, physical activity; MET, metabolic equivalent of task; BMI, body mass index; DM, diabetes mellitus; HbA1c, hemoglobin A1c; TC, total cholesterol; HDL, high density lipoprotein; TG, triglycerides; GOT, glutamic oxaloacetic transaminase; GPT, glutamic pyruvic transaminase.
Data are presented as mean±standard deviation or n (%).
*p<0.05; ‡p<0.001.

(95% CI 0.49–0.96) (Table 2). Furthermore, we found a significant association between RE and CKD in individuals with diabetes, with OR of 0.68 (95% CI 0.53–0.88). However, there were no statistically significant associations between WPA and the prevalence of CKD, with OR of 1.46 (95% CI 0.87–2.47). TPA also showed a similar pattern, with OR of 0.83 (95% CI 0.66–1.05) (Table 2). Furthermore, we observed similar results in the relationship between LPA and prevalence of undiagnosed CKD in individuals with diabetes (OR: 0.68, 95% CI 0.48–0.97). However, no significant association was found between WPA and undiagnosed CKD (OR: 1.33, 95% CI 0.77–2.30) (Supplementary Table 1, only online).

In the additional analysis presented in Supplementary Tables 2-4 (only online), we confirmed independent relationships between each domain-specific PA and CKD. For these analyses, WPA was adjusted for LPA and TPA, LPA was adjusted for WPA and TPA, and TPA was adjusted for WPA and LPA. The results revealed that LPA had an independent inverse relationship with CKD (OR: 0.70, 95% CI 0.50–0.99), whereas WPA (OR: 1.53, 95% CI 0.90–2.59) and TPA (OR: 0.85, 95% CI 0.67–1.07) did not show significant independent associations.

https://doi.org/10.3349/ymj.2024.0245

Table 2. Association between Total PA, RE, Domain-Specific PA, and Prevalence of CKD

	Total		Model 1	Model 2	Model 3
	n	CKD	OR (95% CI)	OR (95% CI)	OR (95% CI)
WPA					
0 METs-min/week	2257	616	Reference		
1–599 METs-min/week	46	8	0.65 (0.30–1.42)	0.64 (0.29–1.41)	0.54 (0.24–1.20)
≥600 METs-min/week	78	23	1.35 (0.81–2.25)	1.36 (0.83–2.26)	1.46 (0.87–2.47)
LPA					
0 METs-min/week	1912	558	Reference		
1–599 METs-min/week	192	37	0.63 (0.43–0.92)*	0.64 (0.44–0.93)*	0.60 (0.41–0.89)*
≥600 METs-min/week	277	52	0.61 (0.44–0.84)*	0.61 (0.44–0.84)*	0.69 (0.49–0.96)*
TPA					
0 METs-min/week	1274	370	Reference		
1–599 METs-min/week	505	129	0.87 (0.69–1.11)	0.87 (0.68–1.10)	0.87 (0.68–1.11)
≥600 METs-min/week	602	148	0.84 (0.67–1.05)	0.85 (0.68–1.06)	0.83 (0.66–1.05)
Total PA					
0 METs-min/week	1020	317	Reference		
1–599 METs-min/week	501	125	0.78 (0.61–1.00)	0.79 (0.61–1.01)	0.78 (0.61–1.01)
≥600 METs-min/week	860	205	0.76 (0.62–0.94)*	0.77 (0.63–0.95)*	0.79 (0.64–0.99)*
RE					
<2 days/week	1921	547	Reference		
≥2 days/week	460	100	0.66 (0.52–0.85)†	0.65 (0.50–0.83)†	0.68 (0.53–0.88)*

PA, physical activity; RE, resistance exercise; CKD, chronic kidney disease; OR, odds ratio; CI, confidence interval; WPA, work-related physical activity; MET, metabolic equivalent of task; LPA, leisure physical activity; TPA, transportation physical activity; BMI, body mass index; DM, diabetes mellitus; FG, fasting glucose; HbA1c, hemoglobin A1c; TG, triglycerides; TC, total cholesterol.
OR (95% CI) of CKD according to domain-specific PA. Model 1: adjusted for age and sex, Model 2: adjusted for Model 1+ BMI, DM family history, income, education, hypertension, Model 3: adjusted for Model 2+FG, HbA1c, TG, and TC.
*p<0.05; †p<0.01.

Relationship between meeting the WHO's PA recommendations, including RE, and the prevalence of CKD by domain-specific PA

We conducted further analyses to investigate the association between domain-specific PA and RE with the prevalence of CKD in individuals with diabetes. Table 3 presents the results of a multiple regression analysis that examines how the prevalence of CKD varies based on compliance with recommendations for RE and PA. In Model 3, when analyzed by domain, the OR for CKD in individuals with diabetes who fulfill the criteria for both LPA and RE was OR of 0.55 (95% CI 0.34–0.89). Furthermore, in the case of TPA, there was also a significant inverse relationship between the prevalence of CKD and meeting the recommended amount of PA as TPA, along with meeting the requirements for RE, with OR of 0.61 (95% CI 0.39–0.95). In the case of WPA, a non-statistically significant relationship was observed, with OR of 1.46 (95% CI 0.44–4.82) (Table 3).

We analyzed the relationship between undiagnosed CKD and domain-specific PA, including RE. A significant association was found between undiagnosed CKD and LPA, including RE, with OR of 0.51 (95% CI 0.32–0.82), while WPA including RE showed no significance, with OR of 1.29 (95% CI 0.40–4.17). The association between LPA, including RE, and undiagnosed CKD remained significant after adjusting for various covariates but attenuated upon further adjustment for metabolic factors, with OR of 0.66 (95% CI 0.40–1.07) (Supplementary Table 5, only online).

The analysis of the independent relationship between CKD and adherence to the WHO's PA guidelines across different domains revealed that WPA (OR: 1.76, 95% CI 0.53–5.89) (Supplementary Table 6, only online) and TPA (OR: 0.65, 95% CI 0.41–1.02) were not significantly associated independently (Supplementary Table 7, only online), whereas LPA showed an independent inverse relationship with CKD (OR: 0.56, 95% CI: 0.35–0.91) (Supplementary Table 8, only online).

Table 4 presents potential effect modifiers that impact the association between different levels of PA compliance (only RE, only PA, or both) and the prevalence of CKD. The association between LPA and CKD prevalence was more evident among participants with low BMI (<25 kg/m^2) and normal Hb1Ac (<6.5%). In the group with low BMI and in those with normal HbA1c levels, an inverse association was observed between LPA and RE, with OR of 0.31 (95% CI 0.15–0.65) and OR of 0.32 (95% CI 0.11–0.94), respectively (both p<0.001, p=0.026). No interactions were found with other factors (Table 4).

Table 3. Relationship between Meeting the WHO's PA Recommendations, Including RE, and the Prevalence of CKD by Domain-Specific PA

	Total		Model 1	Model 2	Model 3
	n	CKD	OR (95% CI)	OR (95% CI)	OR (95% CI)
WPA+RE					
Not meet	1858	528	Reference	Reference	Reference
Meets only RE recommendations	445	96	0.64 (0.50–0.83)†	0.63 (0.49–0.83)†	0.67 (0.52–0.88)†
Meets only PA recommendations	63	19	1.27 (0.73–2.24)	1.27 (0.73–2.23)	1.35 (0.76–2.42)
Meets both recommendations	15	4	1.13 (0.35–3.65)	1.17 (0.36–3.79)	1.46 (0.44–4.82)
LPA+RE					
Not meet	1786	518	Reference	Reference	Reference
Meets only RE recommendations	318	77	0.71 (0.54–0.95)*	0.71 (0.54–0.95)*	0.73 (0.54–0.97)*
Meets only PA recommendations	135	29	0.76 (0.50–1.18)	0.77 (0.50–1.19)	0.84 (0.54–1.30)
Meets both recommendations	142	23	0.47 (0.29–0.74)†	0.46 (0.29–0.74)†	0.55 (0.34–0.89)*
TPA+RE					
Not meet	1469	428	Reference	Reference	Reference
Meets only RE recommendations	310	71	0.66 (0.50–0.89)†	0.66 (0.49–0.88)†	0.69 (0.51–0.93)†
Meets only PA recommendations	452	119	0.90 (0.71–1.15)	0.91 (0.72–1.16)	0.89 (0.69–1.14)
Meets both recommendations	150	29	0.57 (0.37–0.87)†	0.58 (0.37–0.89)*	0.61 (0.39–0.95)*
Total PA+RE					
Not meet	1316	390	Reference	Reference	Reference
Meets only RE recommendations	205	52	0.72 (0.51–1.02)	0.71 (0.51–1.01)	0.72 (0.50–1.02)
Meets only PA recommendations	605	157	0.90 (0.72–1.13)	0.91 (0.73–1.14)	0.91 (0.73–1.15)
Meets both recommendations	255	48	0.55 (0.39–0.78)†	0.55 (0.39–0.78)†	0.62 (0.43–0.88)†

PA, physical activity; RE: resistance exercise; CKD, chronic kidney disease; OR, odds ratio; CI, confidence interval; WPA, work-related physical activity; LPA, leisure physical activity; TPA, transportation physical activity; BMI, body mass index; DM, diabetes mellitus; HbA1c, hemoglobin A1c; FG, fasting glucose; TG, triglycerides; TC, total cholesterol.
OR (95% CI) of CKD according to domain-specific PA and RE. Model 1: adjusted for age and sex, Model 2: adjusted for Model 1+BMI, DM family history, income, education, hypertension, Model 3: adjusted for Model 2+FG, HbA1c, TG, and TC, WHO's PA guideline is defined as 150 minutes per week of moderate PA or 75 minutes per week of vigorous PA and at least 2 days per week of RE.
*p<0.05; †p<0.01.

DISCUSSION

Our findings demonstrated that meeting the WHO's PA recommendations, including RE, was associated with lower prevalence of CKD in individuals with diabetes, particularly in individuals with low BMI and normal HbA1c level. In addition, our study demonstrated that not all PA had equal association with CKD. We found that WPA was not associated with prevalence of CKD, whereas LPA was inversely associated with the prevalence of CKD in individuals with diabetes.

Previous research has demonstrated the benefits of the WHO's PA recommendations for risk of CKD in individuals with diabetes.[27] Meeting the recommendation to engage in at least 600 METs-min/week of total PA was associated with a 29% reduction in CKD risk among individuals with diabetes.[27] A study investigating the relationship of weekly PA to the risk of CKD, ESRD, and adverse kidney-related outcomes such as eGFR revealed that sedentary individuals with diabetes were more likely to develop ESRD, exhibit a lower eGFR, and have higher serum creatinine levels compared to physically active individuals with diabetes.[28] These findings are consistent with our results on the association between total PA and the prevalence of CKD. On the other hand, studies that have examined the relationship between domain-specific PA and CKD have reported different results compared to our study. A study conducted on adults in the United States found that different types of PA, including work, leisure, and transportation, are linked to a lower risk of CKD. People who engaged in at least 300 METs-min of WPA or LPA per week had a lower CKD prevalence compared to those who did not (OR of 0.88, 95% CI 0.80–0.97 and OR of 0.68, 95% CI 0.60–0.76, respectively).[18] Another study reported that working while standing is more beneficial for CKD prevention than sitting is (OR of 0.88, 95% CI 0.86–0.96), whereas leisure and transportation PAs were not associated with CKD (OR of 1.07, 95% CI 0.96–1.20 and OR of 1.08 95% CI 0.97–1.21, respectively).[19]

The two previous studies that have examined the relationship between domain-specific PA and CKD have shown conflicting results compared to ours. However, our observation of Korean adults with diabetes, using a large population-based dataset, adds novel information to the sparse literature by demonstrating 1) a significant relationship between the prevalence of CKD and LPA combined with RE and 2) no meaningful relationship between the prevalence of CKD and PAs related to work or transportation.

Our study provides new insights by disaggregating PA at work, whereas previous studies have only differentiated between standing and sedentary work in the workplace. In our

https://doi.org/10.3349/ymj.2024.0245

Table 4. Stratified Analyses on the Association between LPA with RE and Prevalence of CKD by Potential Effect Modifiers

CKD	n (%)	Not meet Reference	Meets only RE recommendations OR (95% CI)	Meets only PA recommendations OR (95% CI)	Meets both recommendation OR (95% CI)	*p* for interaction
Age						0.354
<65 years	1162/240 (20.6)	1	0.69 (0.42–1.14)	0.87 (0.48–1.61)	0.78 (0.41–1.49)	
≥65 years	1219/407 (33.3)	1	0.75 (0.52–1.08)	0.94 (0.49–1.84)	0.43 (0.20–0.88)*	
BMI						0.001†
<25 kg/m^2	1111/306 (27.5)	1	0.58 (0.38–0.89)*	0.50 (0.25–1.03)	0.31 (0.15–0.65)†	
≥25 kg/m^2	1270/341 (26.8)	1	0.90 (0.60–1.35)	1.33 (0.75–2.36)	1.11 (0.58–2.13)	
Sex						0.664
Men	1243/356 (28.6)	1	0.77 (0.54–1.10)	0.89 (0.50–1.58)	0.55 (0.32–0.94)*	
Women	1138/291 (25.5)	1	0.70 (0.42–1.17)	0.86 (0.42–1.75)	0.83 (0.27–2.53)	
Hypertension						0.626
Normal	921/176 (19.1)	1	0.88 (0.52–1.47)	0.81 (0.38–1.74)	0.87 (0.42–1.81)	
Hypertension	1449/466 (32.1)	1	0.71 (0.49–1.03)	1.00 (0.56–1.78)	0.45 (0.23–0.87)*	
Smoking						0.599
Never	1240/331 (26.6)	1	0.84 (0.53–1.32)	1.03 (0.55–1.93)	0.90 (0.38–2.14)	
Current	453/134 (29.5)	1	0.72 (0.34–1.51)	1.14 (0.46–2.81)	0.92 (0.36–2.36)	
Past	684/180 (26.3)	1	0.72 (0.45–1.14)	0.61 (0.24–1.53)	0.38 (0.18–0.82)*	
Alcohol consumption						0.830
<Once /1 month	1335/364 (27.2)	1	0.66 (0.44–1.01)	0.87 (0.45–1.68)	0.98 (0.50–1.92)	
≥Once/1 month	1043/282 (27.0)	1	0.80 (0.53–1.20)	0.87 (0.49–1.59)	0.37 (0.18–0.75)†	
Income						0.107
Quantile 1	722/261 (36.1)	1	0.77 (0.46–1.29)	0.80 (0.29–2.21)	0.51 (0.19–1.42)	
Quantile 2	647/167 (25.8)	1	0.70 (0.39–1.25)	1.50 (0.90–3.21)	0.66 (0.26–1.68)	
Quantile 3	526/120 (22.8)	1	0.96 (0.53–1.74)	0.56 (0.18–1.70)	0.80 (0.30–2.11)	
Quantile 4	480/98 (20.4)	1	0.67 (0.30–1.46)	0.82 (0.34–2.01)	0.47 (0.17–1.27)	
Education						0.627
Elementary school	822/274 (33.3)	1	0.61 (0.36–1.04)	0.72 (0.28–1.87)	0.46 (0.13–1.67)	
Middle school	372/103 (27.6)	1	0.99 (0.49–1.99)	1.24 (0.38–3.99)	0.35 (0.07–1.72)	
High school	674/160 (23.7)	1	0.75 (0.43–1.33)	1.08 (0.49–2.39)	0.77 (0.35–1.69)	
Over school	507/107 (21.1)	1	0.72 (0.38–1.36)	0.66 (0.29–1.53)	0.56 (0.24–1.30)	
HbA1c						0.026*
<6.5%	596/153 (25.6)	1	0.67 (0.38–1.18)	0.19 (0.04–0.83)*	0.32 (0.11–0.94)*	
≥6.5%	1785/494 (27.6)	1	0.74 (0.53–1.05)	1.19 (0.73–1.92)	0.69 (0.40–1.19)	

LPA, leisure physical activity; RE, resistance exercise; CKD, chronic kidney disease; OR, odds ratio; CI, confidence interval; BMI, body mass index; HbA1c, hemoglobin A1c; DM, diabetes mellitus; FG, fasting glucose; TG, triglycerides; TC, total cholesterol.
ORs (95% CI) of CKD based on domain-specific PA and RE, categorized by potential modifiers of CKD. Adjusted for age and sex, BMI, DM family history, income, education, hypertension, FG, HbA1c, TG, and TC. WHO's PA guideline is defined as 150 minutes per week of moderate PA or 75 minutes per week of vigorous PA and at least 2 days per week of RE.
*p<0.05; †p<0.01.

study, we defined WPA as encompassing a wide range of tasks that individuals perform for their livelihood, including both paid and unpaid labor, domestic work, food and crop harvesting, fishing or hunting for subsistence, and job-seeking activities.[20] Consequently, we found that the differences in the relationship between WPA and LPA with the prevalence of CKD may also be attributed to psychological factors. While the underlying physiological mechanisms of PA may be similar across different domains, the psychological impact of LPA should be considered,[29] as most LPAs include sports and recreational activities with stress-relieving components.[20] In conclusion, it can be inferred that the greater effectiveness of LPA over WPA may be due to the potential psychological effects associated with LPA.

The association between RE and CKD in this study can be understood through the mechanisms involved in glucose utilization within the cells during RE. The combination of RE and aerobic exercise (AE) is excellent in reducing the duration of hyperglycemia, which is a risk factor for CKD.[30,31] Understanding these mechanisms can elucidate the detailed implications of our results. According to a previous study, HbA1c levels in individuals with diabetes were evaluated after a 6-month ex-

ercise intervention, including RE, AE, and a combination of both. The combination exercise group showed the greatest decrease in HbA1c.[30] A meta-analysis provided evidence that combining AE with RE can improve blood glucose control, as measured by HbA1c, in individuals with diabetes, compared to the effects of AE alone.[31] In this study, engaging in RE twice a week and achieving an LPA of over 600 METs/week were significantly associated with a lower prevalence of CKD. These findings provide evidence supporting the ideal form of PA for preventing CKD in individuals with diabetes.

We found that the relationship between meeting PA guidelines and the prevalence of CKD differs by BMI. In the low-BMI group, LPA and RE were associated with lower prevalence of CKD, which could be inferred from the significant impact of obesity on CKD.[32] In fact, in context of studies that contradict our findings, it was observed that the ACR and eGFR did not improve in individuals with type 2 diabetes after exercise intervention. A study on individuals with diabetic obesity and CKD implemented a regimen of aerobic and strength training three times per week for 12 weeks, followed by a home-based exercise program for 42 weeks. The study found no significant differences in eGFR or ACR compared to those in the control group.[33] Another study examining a 24-week lifestyle intervention that incorporated AE and RE in individuals with CKD did not demonstrate any significant variations in eGFR or urine Albumin-Creatinine Ratio.[34] However, the participants in that study were obese, and their BMI remained high (> 25 kg/m^2) even after the intervention.

We also discovered that LPA and RE were significantly linked to a lower prevalence of CKD in the normal HbA1c group. Increased blood sugar levels result in the generation of reactive oxygen species, thereby inducing heightened oxidative stress[35] and contributing to diminished renal function.[36] Taken together, our data suggest that it is important for improvements to extend beyond merely engaging in PA and include substantial changes such as actual weight loss and decreased HbA1c.

The strengths of this study are as follows: 1) it demonstrated variations in the prevalence of CKD and its associations across different domains of PA, observing differences in the prevalence of CKD within each domain; 2) beyond just examining domain-specific PA, it also analyzed the relationship between prevalence of CKD and RE when combined with LPA, providing evidence that the combination of RE and LPA is most effective in preventing CKD in individuals with diabetes; and 3) this study focused on Asians, particularly at a heightened risk of kidney disease due to diabetes[37] and analyzed a large-scale sample from South Korea.

Our study had certain limitations that should be considered during interpretation of the results. First, the KNHANES did not differentiate between type 1 and type 2 diabetes. However, the prevalence of type 1 diabetes in Korea is very low (approximately 0.02%),[38] making it unlikely that our findings were significantly influenced by type 1 diabetes. Second, PA was assessed using self-reported questionnaires rather than objective measures, such as accelerometers. As with all self-reported measures, measurement errors in our PA questionnaire, particularly for non-LPAs, such as work and transport, may have introduced bias towards the null. Nevertheless, our questionnaire (GPAQ) has been previously validated and offers the advantage of assessing domain-specific PA, which was the primary focus of our study. Moreover, the questionnaire has been widely employed in more than 50 countries to assess domain-specific PAs, enabling the comparison of PA trends across nations. A study was conducted to assess the reliability of the Korean-translated GPAQ. The results showed high reliability for LPA (κ=0.60–0.67) and moderate reliability for WPA (κ=0.30–0.38).[26] Third, since RE can be included in the assessment of LPA, it is possible that LPA may have been overestimated. However, in the KNHANES, these two items were assessed separately as distinct questions.[20,26] This separate assessment ensures that the LPA is evaluated independently without the risk of overestimation due to the inclusion of RE. Finally, our study used a cross-sectional design, making it difficult to establish a causal relationship between domain-specific PA and prevalence of CKD in individuals with diabetes. This is because PA may be limited due to CKD. However, we conducted the same analysis targeting undiagnosed CKD patients who were unaware of their diagnosis, and the results were similar.

In conclusion, meeting the WHO-recommended PA levels through LPA and engaging in RE at least twice a week were significantly associated with a lower prevalence of CKD in individuals with diabetes. These findings suggest that various types of PA may impact CKD development differently in individuals with diabetes, emphasizing the importance of incorporating RE. However, caution is warranted when generalizing these findings to all individuals with diabetes, as this study focused specifically on Korean patients. Additionally, longitudinal cohort studies are needed to further investigate racial disparities and differences based on obesity status in individuals with diabetes.

ACKNOWLEDGEMENTS

This work was supported by the Yonsei Signature Research Cluster Project (2024-22-0009), the Ministry of Education of the Republic of Korea and the National Research Foundation of Korea(NRF-2024S1A5C3A02043449), a grant of the Information and Communications Promotion Fund through the National IT Industry Promotion Agency (NIPA), funded by the Ministry of Science and ICT (MSIT), Republic of Korea.

AUTHOR CONTRIBUTIONS

Conceptualization: Yong Jun Lee, Chiho Kim, Dong Hoon Lee, and Justin Y. Jeon. Data curation: Yong Jun Lee, Chiho Kim, Dong-Hyuk Park, and Justin Y. Jeon. Formal analysis: Yong Jun Lee, Chiho Kim, Dong-Hyuk Park, and Justin Y. Jeon. Funding acquisition: Justin Y. Jeon. Investigation: all authors. Methodology: all authors. Project ad-

https://doi.org/10.3349/ymj.2024.0245

ministration: Dong-Hyuk Park. Supervision: Justin Y. Jeon. Validation: Joon Young Kim, Yong-ho Lee, Byung-Wan Lee, and Justin Y. Jeon. Writing—original draft: Yong Jun Lee and Chiho Kim. Writing—review & editing: all authors. Approval of final manuscript: all authors.

ORCID iDs

Yong Jun Lee https://orcid.org/0009-0007-4436-6097
Dong-Hyuk Park https://orcid.org/0000-0002-2545-3132
Chiho Kim https://orcid.org/0009-0008-1852-6429
Dong Hoon Lee https://orcid.org/0000-0003-1329-4637
Yong-ho Lee https://orcid.org/0000-0002-6219-4942
Byung-Wan Lee https://orcid.org/0000-0002-9899-4992
Joon Young Kim https://orcid.org/0000-0003-0448-1684
Justin Y. Jeon https://orcid.org/0000-0001-7978-4271

REFERENCES

1. Magliano DJ, Boyko EJ; IDF Diabetes Atlas 10th Edition Scientific Committee. IDF diabetes atlas, 10th edition. In: IDF diabetes atlas [Internet]. Brussels: International Diabetes Federation; 2021 [accessed on 2023 May 1]. Available at: https://www.ncbi.nlm.nih.gov/books/NBK581934.
2. Beckman JA, Creager MA. Vascular complications of diabetes. Circ Res 2016;118:1771-85.
3. Long AN, Dagogo-Jack S. Comorbidities of diabetes and hypertension: mechanisms and approach to target organ protection. J Clin Hypertens (Greenwich) 2011;13:244-51.
4. ElSayed NA, Aleppo G, Aroda VR, Bannuru RR, Brown FM, Bruemmer D, et al. 11. Chronic kidney disease and risk management: standards of care in diabetes-2023. Diabetes Care 2023;46(Suppl 1):S191-202.
5. Sagoo MK, Gnudi L. Diabetic nephropathy: an overview. Methods Mol Biol 2020;2067:3-7.
6. Afkarian M, Sachs MC, Kestenbaum B, Hirsch IB, Tuttle KR, Himmelfarb J, et al. Kidney disease and increased mortality risk in type 2 diabetes. J Am Soc Nephrol 2013;24:302-8.
7. Manns B, Hemmelgarn B, Tonelli M, Au F, So H, Weaver R, et al. The cost of care for people with chronic kidney disease. Can J Kidney Health Dis 2019;6:2054358119835521.
8. Bull FC, Al-Ansari SS, Biddle S, Borodulin K, Buman MP, Cardon G, et al. World Health Organization 2020 guidelines on physical activity and sedentary behaviour. Br J Sports Med 2020;54:1451-62.
9. Yamamoto-Kabasawa K, Hosojima M, Yata Y, Saito M, Tanaka N, Tanaka J, et al. Benefits of a 12-week lifestyle modification program including diet and combined aerobic and resistance exercise on albuminuria in diabetic and non-diabetic Japanese populations. Clin Exp Nephrol 2015;19:1079-89.
10. Blomster JI, Chow CK, Zoungas S, Woodward M, Patel A, Poulter NR, et al. The influence of physical activity on vascular complications and mortality in patients with type 2 diabetes mellitus. Diabetes Obes Metab 2013;15:1008-12.
11. Lee DH, Luo X, Rezende LFM, Joh HK, Keum N, Rimm EB, et al. Long-term weight training and mortality in U.S. male health professionals with and without type 2 diabetes. Diabetes Care 2023;46:138-48.
12. Wanner M, Tarnutzer S, Martin BW, Braun J, Rohrmann S, Bopp M, et al. Impact of different domains of physical activity on cause-specific mortality: a longitudinal study. Prev Med 2014;62:89-95.
13. Dinu M, Pagliai G, Macchi C, Sofi F. Active commuting and multiple health outcomes: a systematic review and meta-analysis. Sports Med 2019;49:437-52.
14. Autenrieth CS, Baumert J, Baumeister SE, Fischer B, Peters A, Döring A, et al. Association between domains of physical activity and all-cause, cardiovascular and cancer mortality. Eur J Epidemiol 2011;26:91-9.
15. Lee DH, Rezende LFM, Joh HK, Keum N, Ferrari G, Rey-Lopez JP, et al. Long-term leisure-time physical activity intensity and all-cause and cause-specific mortality: a prospective cohort of US adults. Circulation 2022;146:523-34.
16. Muddu M, Mutebi E, Ssinabulya I, Kizito S, Mulindwa F, Kiiza CM. Utility of albumin to creatinine ratio in screening for microalbuminuria among newly diagnosed diabetic patients in Uganda: a cross sectional study. Afr Health Sci 2019;19:1607-16.
17. Regassa LD, Gete YK, Mekonnen FA. Time to acute kidney injury and its predictors among newly diagnosed type 2 diabetic patients at government hospitals in Harari Region, East Ethiopia. PLoS One 2019;14:e0215967.
18. He F, Hu Z, Li Y, Zhang H. Association of domain-specific physical activity with chronic kidney disease: a cross-sectional study. Research Square [Preprint]. 2022 [accessed on 2023 August 30]. Available at: https://doi.org/10.21203/rs.3.rs-2264027/v1.
19. Yamamoto S, Inoue Y, Kuwahara K, Miki T, Nakagawa T, Honda T, et al. Leisure-time, occupational, and commuting physical activity and the risk of chronic kidney disease in a working population. Sci Rep 2021;11:12308.
20. Kweon S, Kim Y, Jang MJ, Kim Y, Kim K, Choi S, et al. Data resource profile: the Korea national health and nutrition examination survey (KNHANES). Int J Epidemiol 2014;43:69-77.
21. Genuth SM, Palmer JP, Nathan DM. Classification and diagnosis of diabetes. In: Diabetes in America [Internet]. Bethesda: National Institute of Diabetes and Digestive and Kidney Diseases (US); 2018 [accessed on 2023 September 1]. Available at: https://www.ncbi.nlm.nih.gov/books/NBK568014.
22. Consensus Committee. Consensus statement on the worldwide standardization of the hemoglobin A1C measurement: the American Diabetes Association, European Association for the Study of Diabetes, International Federation of Clinical Chemistry and Laboratory Medicine, and the International Diabetes Federation. Diabetes Care 2007;30:2399-400.
23. Li PK, Bavanandan S, Mohamed R, Szeto CC, Wong VW, Chow KM, et al. 2018 kidney disease: improving global outcomes (KDIGO) hepatitis C in chronic kidney disease guideline implementation: Asia summit conference report. Kidney Int Rep 2020;5:1129-38.
24. Levey AS, Coresh J, Greene T, Marsh J, Stevens LA, Kusek JW, et al. Expressing the modification of diet in renal disease study equation for estimating glomerular filtration rate with standardized serum creatinine values. Clin Chem 2007;53:766-72.
25. Armstrong T, Bull F. Development of the world health organization global physical activity questionnaire (GPAQ). J Public Health 2006;14:66-70.
26. Lee J, Lee C, Min J, Kang DW, Kim JY, Yang HI, et al. Development of the Korean global physical activity questionnaire: reliability and validity study. Glob Health Promot 2020;27:44-55.
27. Chen Y, Sloan FA, Yashkin AP. Adherence to diabetes guidelines for screening, physical activity and medication and onset of complications and death. J Diabetes Complications 2015;29:1228-33.
28. Böhm M, Schumacher H, Werner C, Teo KK, Lonn EM, Mahfoud F, et al. Association between exercise frequency with renal and cardiovascular outcomes in diabetic and non-diabetic individuals at high cardiovascular risk. Cardiovasc Diabetol 2022;21:12.
29. Hackett RA, Steptoe A. Psychosocial factors in diabetes and cardiovascular risk. Curr Cardiol Rep 2016;18:95.
30. Sigal RJ, Kenny GP, Boulé NG, Wells GA, Prud'homme D, Fortier M, et al. Effects of aerobic training, resistance training, or both on

glycemic control in type 2 diabetes: a randomized trial. Ann Intern Med 2007;147:357-69.
31. Snowling NJ, Hopkins WG. Effects of different modes of exercise training on glucose control and risk factors for complications in type 2 diabetic patients: a meta-analysis. Diabetes Care 2006;29:2518-27.
32. Hall JE, do Carmo JM, da Silva AA, Wang Z, Hall ME. Obesity, kidney dysfunction and hypertension: mechanistic links. Nat Rev Nephrol 2019;15:367-85.
33. Leehey DJ, Collins E, Kramer HJ, Cooper C, Butler J, McBurney C, et al. Structured exercise in obese diabetic patients with chronic kidney disease: a randomized controlled trial. Am J Nephrol 2016;44:54-62.
34. Howden EJ, Coombes JS, Strand H, Douglas B, Campbell KL, Isbel NM. Exercise training in CKD: efficacy, adherence, and safety. Am J Kidney Dis 2015;65:583-91.
35. Yu T, Jhun BS, Yoon Y. High-glucose stimulation increases reactive oxygen species production through the calcium and mitogen-activated protein kinase-mediated activation of mitochondrial fission. Antioxid Redox Signal 2011;14:425-37.
36. Baud L, Ardaillou R. Reactive oxygen species: production and role in the kidney. Am J Physiol 1986;251(5 Pt 2):F765-76.
37. Nwosu UA, Darbinian JA, Chen KK, Zeng B, Arzumanyan H, Lo JC, et al. Prevalence of albuminuria among adults with diabetes and preserved estimated glomerular filtration rate by race and ethnicity. Diabetes Care 2023;46:e78-80.
38. Song SO, Song YD, Nam JY, Park KH, Yoon JH, Son KM, et al. Epidemiology of type 1 diabetes mellitus in Korea through an investigation of the national registration project of type 1 diabetes for the reimbursement of glucometer strips with additional analyses using claims data. Diabetes Metab J 2016;40:35-45.

https://doi.org/10.3349/ymj.2024.0245