

Original Contribution

Physical Activity and Body Mass Index and Their Associations With the Development of Type 2 Diabetes in Korean Men

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The authors examined the independent and combined associations of physical activity and obesity with incident type 2 diabetes among 675,496 Korean men from the database of the National Health Insurance Corporation. During an average follow-up of 7.5 years (1996–2005), 52,995 men developed type 2 diabetes. Men with overweight, obese I, and obese II classifications had 1.47, 2.05, and 3.69 times higher risk of type 2 diabetes, respectively, compared with normal weight men, and men with low, medium, and high activity had 5%, 10%, and 9% lower risk of type 2 diabetes, respectively, compared with inactive men after adjustment for confounders and physical activity or body mass index for each other. Overweight and obesity were detrimental within all activity categories, and meeting the activity recommendations (medium and high activity) was beneficial at all body mass index levels. Meeting the activity recommendations appeared to attenuate some negative effects of overweight or obesity, and the increased risk of type 2 diabetes due to inactivity was lower in normal weight men. Both preventing overweight or obesity and increasing physical activity are important to reduce the global epidemic of type 2 diabetes, regardless of body weight and activity levels.

body mass index; cohort studies; diabetes mellitus; exercise; health behavior; lifestyle; motor activity

Abbreviations: BMI, body mass index; NHIC, National Health Insurance Corporation; WHO, World Health Organization.

The world prevalence of type 2 diabetes has substantially increased and is likely to continue to rise, particularly in developing countries including China, India, and other Asian countries that account for 60% of the world's diabetic population (1, 2). The rates and trends of type 2 diabetes vary widely between populations and regions, reflecting socioeconomic, environmental, and genetic differences (2, 3). Current evidence suggests that regular physical activity decreases and that obesity increases the risk of type 2 diabetes (1, 4–14). However, adherence to the recommended level of physical activity is low based on objectively measured physical activity (15), and the prevalence of obesity has increased worldwide (16).

Although the independent association between physical activity or obesity and type 2 diabetes has been well established, the relative and combined contributions of these risk factors to the risk of type 2 diabetes are continuously debated (8, 10, 12, 14, 17, 18). Some studies indicated that obesity rather than physical activity is more important (12, 14);

others, however, report that both factors are equally important (7, 8). One of the possible reasons for the inconsistency among studies may be due to different measurements and cutoffs for physical activity categorization. Recently, the World Health Organization (WHO) and several countries have released comparable physical activity guidelines, recommending ≥ 150 minutes/week of moderate-intensity aerobic activity or its equivalent for substantial health benefits including lower risk of type 2 diabetes (19–22). For additional and more extensive benefits, individuals are encouraged to increase their activity to 300 minutes/week of moderate-intensity activity or its equivalent. However, it is not clear whether there are additional benefits from engaging in activity in excess of the 150 minutes/week or whether there are significant benefits from participating in less than 150 minutes/week of moderate-intensity activity in type 2 diabetes prevention.

Most previous epidemiologic studies on the combined effects of physical activity and obesity on type 2 diabetes

were conducted in Western populations (7, 8, 12, 14), especially in women (7, 12, 14), but few studies are available in Asian populations. The WHO proposed different overweight and obesity cutoffs of body mass index (BMI; weight (kg)/height (m)²) of 23.0 and 25.0, respectively, in Asians because Asians have a higher body fat percentage for a given BMI than Caucasians (23, 24). However, there has been little investigation into using these cutoffs on incident type 2 diabetes for Asians.

Studying the combined effects of physical activity and obesity on type 2 diabetes is important to develop effective prevention strategies and health policies from clinical and public health perspectives, given the diverse combinations of physical activity and obesity in adult populations. The purpose of this study was to address the following 4 questions: 1) whether the risk of developing type 2 diabetes differs across different levels of physical activity and BMI after controlling for each by the other; 2) whether the effects of physical activity on developing type 2 diabetes differ across different levels of BMI; 3) whether the effect of overweight or obesity on developing type 2 diabetes differs across different levels of physical activity; and 4) whether meeting the physical activity recommendations attenuates the negative effect of overweight or obesity on developing type 2 diabetes, using the recommended cutoffs for physical activity classification (20, 22) and the WHO BMI cutoffs in Asians (23) in a large population-based cohort of Korean men.

MATERIALS AND METHODS

Study sample

This is an observational cohort study of individuals who were selected from the database of the National Health Insurance Corporation (NHIC). All participants were insured by the NHIC and had routine biennial medical examinations performed by the NHIC. The cohort consists of government employees, teachers, and their dependents. Our current analyses included South Korean men aged ≥ 18 years who received 1 baseline medical examination in 1996 or 1997 and at least 1 follow-up examination during 1998–2005 with a minimum of 2 years of follow-up. The NHIC population and study design have been described elsewhere (25).

Among 850,625 participants, we excluded men with heart disease ($n = 62,801$), stroke ($n = 9,130$), or cancer ($n = 294$) prior to baseline examination. For the analysis of incident type 2 diabetes, we also excluded men with diabetes ($n = 89,926$) before the start of follow-up. In addition, underweight men with BMI of < 18.5 ($n = 12,978$) were further excluded. These exclusion criteria were used to minimize potential bias due to preexisting disease on body weight, physical activity, and its associations with incident type 2 diabetes. Our final sample included 675,496 healthy adult men. We could not include women because of the limited number of cases of incident diabetes. This study was reviewed and approved by the Seoul National University Institutional Review Board.

Physical activity and BMI measurement

Physical activity was assessed on the 1996 or 1997 medical history questionnaire by self-reported leisure-time exercise that

causes sweating, which is at least equivalent to moderate-intensity physical activity. Activity categories were created on the basis of responses to questions about the exercise frequency ("How many times per week do you exercise that causes sweating?") and duration ("How long do you exercise?"). To calculate the total volume of activity, we multiplied exercise frequency by the duration, resulting in total minutes per week of physical activity, which is the principal metric used in the WHO and several national physical activity guidelines (19–22). Participants were classified into 4 activity categories: inactive (0 minutes/week), low (1–149 minutes/week), medium (150–299 minutes/week), and high (≥ 300 minutes/week). For example, if someone participates in exercise on 4 days/week for 40 minutes/session, then his/her total volume of activity is 160 minutes/week and is classified into the "medium" category. The recommended level of physical activity was defined as ≥ 150 minutes/week of moderate-intensity aerobic activity based on the guidelines. Body weight and height were measured in light clothing at the baseline examination, and BMI was calculated as kg/m². Participants were classified into "normal weight" (BMI, 18.5–22.9), "overweight" (BMI, 23.0–24.9), "obese I" (BMI, 25.0–29.9), and "obese II" (BMI, ≥ 30.0) according to the WHO BMI cutoffs for adult Asians (23, 24).

Clinical examination

Medical examinations were conducted in a standardized way by medical staff at local hospitals throughout South Korea. All hospitals participating in the NHIC examinations have quality control procedures directed by the Korean Association of Laboratory Quality Control. The examinations included body weight, height, fasting glucose analysis, blood pressure measurement, physical examination, and detailed medical history questionnaires. Fasting glucose analysis was performed after an overnight fast. Resting blood pressure was measured by standard auscultatory methods or automatic manometer in the seated position by a registered nurse or a blood pressure technician. Medical information on heart disease, stroke, cancer, diabetes, and hypertension, as well as lifestyle factors such as smoking status, alcohol intake, physical activity, and parental diabetes, was obtained from the medical history questionnaire. Hypertension was defined as systolic/diastolic blood pressure $\geq 140/90$ mm Hg or physician-diagnosed hypertension. The completed questionnaires were reviewed and entered into a database by trained staff following the NHIC standard data collection procedures.

Type 2 diabetes assessment

Type 2 diabetes was defined as fasting glucose of ≥ 126 mg/dL or physician-diagnosed diabetes. This definition was used for both excluding men with diabetes at baseline and determining type 2 diabetes incidence during the follow-up. Follow-up time was calculated from the baseline examination in either 1996 or 1997 to the first event of type 2 diabetes for men who developed type 2 diabetes or the last examination through 2005 for men who did not develop type 2 diabetes.

Table 1. Baseline Characteristics by Type 2 Diabetes Status at Follow-up in Men, the National Health Insurance Corporation Study, South Korea, 1996–2005

	All (n = 675,496)		No Type 2 Diabetes (n = 622,501)		Type 2 Diabetes (n = 52,995)		P Value ^a
	%	Mean (SD)	%	Mean (SD)	%	Mean (SD)	
Age, years		39.4 (10.7)		39.0 (10.7)		43.6 (10.4)	<0.001
Body mass index ^b		23.6 (2.5)		23.5 (2.5)		24.7 (2.7)	<0.001
18.5–22.9	43.2		44.7		26.5		
23.0–24.9	29.0		29.0		29.5		
25.0–29.9	26.6		25.3		40.9		
≥30.0	1.2		1.0		3.1		<0.001
Physical activity, minutes/week							
0	41.3		41.2		42.6		
1–149	40.6		40.7		39.7		
150–299	11.3		11.3		11.1		
≥300	6.8		6.8		6.6		<0.001
Smoking status							
Never	29.2		29.6		25.1		
Former	13.3		13.2		13.7		
Current	57.5		57.2		62.2		<0.001
Alcohol intake, days/week							
None	25.0		25.2		23.6		
<1	24.3		24.6		20.4		
1–2	33.2		33.2		32.9		
≥3	17.5		17.0		23.1		<0.001
Systolic blood pressure, mm Hg		122.2 (14.2)		121.8 (14.0)		126.9 (15.9)	<0.001
Diastolic blood pressure, mm Hg		79.0 (10.3)		78.7 (10.2)		82.1 (11.1)	<0.001
Hypertension	27.4		26.3		40.5		
Fasting glucose, mg/dL		88.9 (12.3)		88.3 (11.9)		96.6 (14.0)	<0.001
Parental diabetes	5.3		5.0		8.2		<0.001
Average follow-up, years ^c		7.5 (2.0–9.8)		7.6 (2.0–9.8)		5.9 (2.0–9.8)	<0.001

Abbreviation: SD, standard deviation.

^a P values were obtained by using chi-square tests for categorical variables and the t test for continuous variables.^b Body mass index: weight (kg)/height (m)².^c Mean (range).

Statistical analyses

Baseline differences between men who developed type 2 diabetes and men who did not develop type 2 diabetes during follow-up were examined by using the chi-square test for categorical variables and the t test for continuous variables. Cox proportional hazard models were used to estimate the hazard ratios and 95% confidence intervals of incident type 2 diabetes across categories of BMI and physical activity. Tests for linear trends across exposure categories for both physical activity and BMI used in this study were calculated by using general linear models. Cox regression models were adjusted for age (years), smoking status (never, former, or current), alcohol intake (none, <1, 1–2, ≥3 days/week), hypertension, parental diabetes, baseline glucose levels, and physical activity (0, 1–149, 150–299, or ≥300 minutes/week) for BMI or BMI for physical activity. The proportional hazards assumption

was examined and satisfied by comparing the log-log survival plots grouped on exposure categories. No significant multiplicative interaction was observed between physical activity and BMI on type 2 diabetes, by using an interaction term in the Cox model ($P = 0.26$). We tested additive interaction using relative excess risk due to interaction. All statistical tests were 2 sided, and $P < 0.05$ was accepted to indicate statistical significance with SAS, version 9.2, software (SAS Institute, Inc., Cary, North Carolina).

RESULTS

During an average follow-up of 7.5 years from 1996 or 1997 through 2005, 52,995 men developed type 2 diabetes among 675,496 men. The incidence rate was 10.5 per 1,000 person-years. Men who developed type 2 diabetes were more likely to

Table 2. Hazard Ratios (95% Confidence Intervals) of Incident Type 2 Diabetes by Body Mass Index and Physical Activity in Men, the National Health Insurance Corporation Study, South Korea, 1996–2005

	No. of Participants	No. of Cases	Model 1 ^a		Model 2 ^b	
			HR	95% CI	HR	95% CI
Body mass index^c						
18.5–22.9	292,145	14,048	1.00	Reference group	1.00	Reference group
23.0–24.9	196,112	15,635	1.46	1.43, 1.50	1.47	1.43, 1.50
25.0–29.9	179,455	21,650	2.04	2.00, 2.09	2.05	2.01, 2.09
≥30.0	7,784	1,662	3.68	3.49, 3.87	3.69	3.50, 3.88
$P_{\text{linear trend}}$				<0.001		<0.001
Physical activity, minutes/week						
0	279,003	22,575	1.00	Reference group	1.00	Reference group
1–149	274,248	21,036	0.98	0.96, 0.999	0.95	0.93, 0.97
150–299	76,032	5,884	0.94	0.91, 0.96	0.90	0.87, 0.93
≥300	46,213	3,500	0.94	0.91, 0.97	0.91	0.88, 0.94
$P_{\text{linear trend}}$				<0.001		<0.001

Abbreviations: CI, confidence interval; HR, hazard ratio.

^a The Cox regression model was adjusted for age, smoking status, alcohol intake, hypertension, parental diabetes, and baseline glucose.^b Further adjusted for physical activity for body mass index or body mass index for physical activity.^c Body mass index: weight (kg)/height (m)².

be older, to be obese, to smoke and drink more alcohol, and to have higher blood pressure, fasting glucose, and parental diabetes at baseline (Table 1). However, physical activity levels between the 2 groups appeared fairly comparable.

Table 2 shows the independent associations of BMI or physical activity with incident type 2 diabetes. Compared with men of normal weight, men with overweight, obese I, and obese II had 1.46, 2.04, and 3.68 times higher risk of developing type 2 diabetes, respectively, after adjustment for possible confounders (model 1). In contrast, compared with inactive men, men with low, medium, and high activity levels had 2%, 6%, and 6% lower risk of developing type 2 diabetes, respectively, after adjustment for baseline confounders (model 1). When we additionally adjusted for physical activity for BMI or BMI for physical activity (model 2), the observed associations remained significant, suggesting mutually independent associations

of physical activity and BMI with incident type 2 diabetes. We also observed significant linear trends across both BMI and physical activity levels for developing type 2 diabetes (both P for linear trends < 0.001). However, the hazard ratios in medium (150–299 minutes/week) and high (≥ 300 minutes/week) activity levels were similar, indicating no further benefits for type 2 diabetes prevention beyond the minimum activity recommendations (150 minutes/week).

We further examined the independent associations of BMI or physical activity with type 2 diabetes using stratified analyses, after combining the 2 highest categories of physical activity (≥ 150 minutes/week) based on the consistent hazard ratios shown in Table 2. In the physical activity-stratified analyses (Table 3), BMI was associated with type 2 diabetes within all 3 activity categories (all P for linear trends < 0.001). In the BMI-stratified analyses (Table 4), men who met the activity

Table 3. Hazard Ratios (95% Confidence Intervals) of Incident Type 2 Diabetes by Body Mass Index in Physical Activity-stratified Analyses in Men, the National Health Insurance Corporation Study, South Korea, 1996–2005^a

Body Mass Index ^b	Physical Activity, minutes/week								
	Inactive (0)			Insufficient (1–149)			Recommended (≥ 150)		
	% of Participants	HR	95% CI	% of Participants	HR	95% CI	% of Participants	HR	95% CI
18.5–22.9	19.0	1.00	Reference group	17.1	1.00	Reference group	7.1	1.00	Reference group
23.0–24.9	11.6	1.50	1.45, 1.55	11.9	1.47	1.41, 1.52	5.6	1.39	1.32, 1.47
25.0–29.9	10.3	2.06	2.00, 2.13	11.1	2.08	2.01, 2.15	5.2	1.95	1.85, 2.05
≥30.0	0.4	3.76	3.47, 4.07	0.5	3.79	3.50, 4.10	0.2	3.33	2.95, 3.77
$P_{\text{linear trend}}$			<0.001			<0.001			<0.001

Abbreviations: CI, confidence interval; HR, hazard ratio.

^a The Cox regression model was adjusted for age, smoking status, alcohol intake, hypertension, parental diabetes, and baseline glucose.^b Body mass index: weight (kg)/height (m)².

Table 4. Hazard Ratios (95% Confidence Intervals) of Incident Type 2 Diabetes by Physical Activity in Body Mass Index-stratified Analyses in Men, the National Health Insurance Corporation Study, South Korea, 1996–2005^a

Physical Activity, minutes/week	Normal Weight (18.5–22.9)						Overweight (23.0–24.9)						Body Mass Index ^b					
	% of Participants	HR	95% CI	% of Participants	HR	95% CI	% of Participants	HR	95% CI	% of Participants	HR	95% CI	% of Participants	HR	95% CI	% of Participants	HR	95% CI
0	19.0	1.00	Reference group	11.6	1.00	Reference group	10.3	1.00	Reference group	0.4	1.00	Reference group	0.4	1.00	Reference group	0.4	1.00	Reference group
1–149	17.1	0.97	0.93, 1.00	11.9	0.94	0.90, 0.97	11.1	0.97	0.94, 0.995	0.5	0.96	0.86, 1.06						
≥150	7.1	0.94	0.90, 0.99	5.6	0.89	0.85, 0.93	5.2	0.91	0.88, 0.95	0.2	0.87	0.75, 0.99						
<i>P</i> _{linear trend}		0.006		<0.001													0.045	

Abbreviations: CI, confidence interval; HR, hazard ratio.

^a The Cox regression model was adjusted for age, smoking status, alcohol intake, hypertension, parental diabetes, and baseline glucose.

^b Body mass index: weight (kg)/height (m)².

recommendations had 6%–13% lower risk of type 2 diabetes within all BMI levels (all *P* for linear trends < 0.05).

In the joint analysis (Table 5), overweight and obesity were associated with higher risk of type 2 diabetes regardless of physical activity levels, and inactivity was also associated with higher risk of type 2 diabetes at all BMI levels, compared with the reference group, meeting the activity recommendations and normal weight. Within the overweight and obese categories, men who met the activity recommendations appeared to show somewhat lower risk of type 2 diabetes compared with inactive men, suggesting that engaging in the recommended level of physical activity is likely to attenuate some of the negative effects of overweight or obesity on developing type 2 diabetes. In addition, the increased risk of developing type 2 diabetes associated with inactivity was lower in normal weight men. We also observed a positive interaction on an additive scale, calculated as 3.93 (obese II and inactive) – 1.06 (normal weight and inactive) – 3.33 (obese II and active) + 1 = 0.54 from Table 5 (18), suggesting that there is 0.54 relative excess risk due to the additive interaction. Therefore, prevention of either inactivity or obesity reduces not only the risk of type 2 diabetes caused by one of the risk factors but also the risk caused by the interaction of these 2 factors. We found 7.6% of men lost to follow-up. They were 5.6 years older with 0.2 kg/m² lower BMI and 10 minutes/week more activity compared with men with follow-up (all *P* < 0.001).

DISCUSSION

We found a significant positive association of BMI and a significant negative association of physical activity with incident type 2 diabetes in this large cohort study of Korean men. These associations were observed after controlling physical activity or BMI for each other, suggesting mutually independent associations between BMI or physical activity and type 2 diabetes. The stratified analyses indicated that overweight and obesity were detrimental within all 3 physical activity categories, and meeting the physical activity recommendations was beneficial at all levels of BMI. In the joint analysis, meeting the activity recommendations appeared to attenuate some negative effects of overweight or obesity on incident type 2 diabetes. Also, the increased risk of type 2 diabetes due to inactivity was reduced in the normal weight group.

These findings are consistent with those of previous epidemiologic studies, in which higher levels of physical activity were associated with lower risk of type 2 diabetes, whereas overweight or obesity is associated with higher risk of type 2 diabetes (4, 8, 12, 14). We also found a consistent inverse association between physical activity and type 2 diabetes across different levels of obesity (7, 11). A number of studies show that being active compensates for, although does not eliminate, the adverse effect of being overweight or obese on the risk of type 2 diabetes (5, 6, 12, 14). In addition, several randomized clinical trials have suggested that a healthier lifestyle including physical activity and diet modification is beneficial in reducing the risk of developing diabetes (9, 13). Diabetes prevention trials from China (26) and India (27) have similar results. However, these multiple lifestyle interventions, mostly combined with

Table 5. Hazard Ratios (95% Confidence Intervals) of Incident Type 2 Diabetes by Combined Categories of Body Mass Index and Physical Activity in Men, the National Health Insurance Corporation Study, South Korea, 1996–2005^a

Body Mass Index ^b	Physical Activity, minutes/week								
	Recommended (≥ 150)			Insufficient (1–149)			Inactive (0)		
	% of Participants	HR	95% CI	% of Participants	HR	95% CI	% of Participants	HR	95% CI
18.5–22.9	7.1	1.00	Reference group	17.1	1.00	0.96, 1.05	19.0	1.06	1.01, 1.11
23.0–24.9	5.6	1.40	1.32, 1.48	11.9	1.47	1.40, 1.54	11.6	1.57	1.50, 1.65
25.0–29.9	5.2	1.95	1.85, 2.05	11.1	2.09	2.00, 2.19	10.3	2.17	2.07, 2.27
≥ 30.0	0.2	3.33	2.95, 3.76	0.5	3.83	3.52, 4.17	0.4	3.93	3.60, 4.28

Abbreviations: CI, confidence interval; HR, hazard ratio.

^a The Cox regression model was adjusted for age, smoking status, alcohol intake, hypertension, parental diabetes, and baseline glucose.^b Body mass index: weight (kg)/height (m)².

healthy diet and exercise, did not demonstrate the independent effect of physical activity or obesity on type 2 diabetes. Also, these trials involved only high risk participants with impaired glucose tolerance, whereas our study included both healthy and high risk participants. We observed a positive association of BMI and a negative association of physical activity with type 2 diabetes, regardless of baseline glucose levels (Table 6). Current evidence on the relative contributions of physical activity and obesity to the risk of type 2 diabetes largely came from epidemiologic studies in Western populations. This study now adds to the body of knowledge and the understanding of the complicated independent and combined associations of obesity and physical activity with type 2 diabetes in an Asian population, using the recommended cutoffs for classification of physical activity and BMI (20, 22, 23).

Although we found that both overweight or obesity and physical activity are independent predictors of type 2 diabetes, the magnitude of the association with overweight or obesity was stronger than for physical activity, given the recommended categories used in this study, which is consistent with some earlier studies (12, 14). One possible explanation may be related to using self-reported activity rather than objectively measured activity such as cardiorespiratory fitness. This may lead to underestimation of the effects of physical activity. In fact, we recently found that measured cardiorespiratory fitness predicts mortality better than self-reported physical activity (28). Also, when measured cardiorespiratory fitness was used instead of self-reported activity, both cardiorespiratory fitness and BMI were equally important in type 2 diabetes prevention in men (10). A recent study found that the risk of type 2 diabetes

Table 6. Hazard Ratios (95% Confidence Intervals) of Incident Type 2 Diabetes Across Body Mass Index and Physical Activity Categories by Baseline Glucose Levels in Men, the National Health Insurance Corporation Study, South Korea, 1996–2005^a

	Normal Fasting Glucose (<100 mg/dL) (n = 544,822)		Impaired Fasting Glucose (100–125 mg/dL) (n = 130,674)	
	HR	95% CI	HR	95% CI
Body mass index ^b				
18.5–22.9	1.00	Reference group	1.00	Reference group
23.0–24.9	1.43	1.39, 1.47	1.57	1.52, 1.63
25.0–29.9	2.09	2.04, 2.15	2.12	2.04, 2.19
≥ 30	4.04	3.77, 4.34	3.56	3.31, 3.84
P _{linear trend}		<0.001		<0.001
Physical activity, minutes/week				
0	1.00	Reference group	1.00	Reference group
1–149	0.93	0.91, 0.96	0.99	0.96, 1.02
150–299	0.86	0.83, 0.90	0.95	0.91, 0.99
≥ 300	0.92	0.88, 0.96	0.90	0.85, 0.95
P _{linear trend}		<0.001		<0.001

Abbreviations: CI, confidence interval; HR, hazard ratio.

^a The Cox regression model was adjusted for age, smoking status, alcohol intake, hypertension, and parental diabetes.^b Body mass index: weight (kg)/height (m)².

is significantly higher among Asians than among whites and that BMI or weight gain is particularly detrimental for Asians (3). Thus, cultural and genetic differences between populations may also affect the association between obesity and type 2 diabetes.

Physical activity guidelines recommend a minimum of 150 minutes/week of moderate-intensity aerobic activities or its equivalent for substantial health benefits, as well as the higher dose of activities (≥ 300 minutes/week) for additional benefits (20, 22). However, we observed similar, but no additional, benefits in the higher dose of activity beyond the minimum recommendations. We also observed significant benefits in type 2 diabetes prevention even in the low dose activities (1–149 minutes/week). This finding confirms that some activity is better than none in type 2 diabetes prevention. However, whether higher doses of activity beyond the basic recommendation produce more benefits for diabetes prevention is still unclear. A recent study (29) reports significant interactions between ethnicity and physical activity in relation to markers of diabetes, suggesting substantially lower levels of activity and less health benefits associated with higher physical activity in Asians than in white Europeans. The current study also showed similar results with lower levels of activity (18.1% in this study vs. 40%–50% in white men (29, 30) who met the activity recommendations) and smaller effects of activity on type 2 diabetes (10% lower risk of type 2 diabetes in this study vs. 30%–60% lower risk of type 2 diabetes in white men who met similar levels of the activity recommendations (6, 8, 11)).

It has been postulated that regular physical activity improves insulin sensitivity and glucose metabolism, whereas obesity, especially abdominal obesity, leads to insulin resistance, with these exposures being independent of one another (31, 32). The biologic mechanisms linking physical activity to insulin sensitivity may involve improved activity of more muscle glucose transporters (33). Regarding the possible mechanisms by which obesity increases insulin resistance, increased production of various adipokines from adipose tissue, elevated inflammation levels, and beta-cell dysfunction may play an important role (34). On the basis of this study, it is possible that obesity may play a more important role than physical activity in developing type 2 diabetes.

Our study has several strengths. A large population-based cohort ($n = 675,496$) with extensive period of follow-up (7.5 years) provided us with a large number of cases of diabetes ($n = 52,995$) to be able to conduct comprehensive, stratified, and joint analyses of physical activity and obesity on incident type 2 diabetes. This study used the recently suggested cutoffs for physical activity guidelines (19–22). Thus, our findings can be a useful reference to compare the effects of physical activity on type 2 diabetes in future studies. Also, the findings of the higher risk of type 2 diabetes in overweight ($\geq 23 \text{ kg/m}^2$) and obese ($\geq 25 \text{ kg/m}^2$) men at lower BMI levels using the Asian specific cutoffs (23, 24) confirm the usefulness of these definitions for Asians in relation to type 2 diabetes. Type 2 diabetes commonly remains undetected for many years (35). However, we believe that using an objective measure of fasting glucose from the frequent biannual medical examinations plus physician-diagnosed diabetes at both baseline and follow-up examinations may identify most

type 2 diabetes events and prevent misclassification of the study outcome.

One of the major limitations in this study is the use of self-reported physical activity. However, an accurate measurement of complex and multifaceted daily physical activity is still challenging in large population studies. Physical activity was measured on the basis of leisure-time exercise in this study without information on other domains such as occupation, home, or commuting. However, because this study consists of government employees or teachers, occupational physical activity may not be a major contributor to overall physical activity. Also, the homogeneity of the study population may minimize possible confounding effects by different socioeconomic strata, although it may limit the generalizability. We measured physical activity and BMI at baseline, but the levels of activity and BMI could change during the follow-up, which could affect incident type 2 diabetes. However, convincing evidence from clinical trials and epidemiologic studies has demonstrated that increasing physical activity or losing weight is associated with lower risk of type 2 diabetes, especially in high risk individuals (9, 13, 36, 37). Because of the lack of data about the type of diabetes, we could not distinguish precisely between type 1 and type 2 diabetes. However, most adults with diabetes have type 2 diabetes (>95%) (4). Moreover, because most participants in this study were middle-aged men, we suspect that there were likely to be few men with type 1 diabetes (generally known as juvenile-onset diabetes), as accepted in other epidemiologic studies (10, 14). The unavailability of diabetes medication, the oral glucose tolerance test, and sufficient diet information warrant consideration. The higher proportion of men who are current smokers in this population compared with North American or European men should be considered. Although we observed a slight positive correlation ($r = 0.05$) between physical activity and BMI at baseline, it is possible that both exposures are influenced by each other. Another limitation is the potential selection bias due to incomplete outcome ascertainment in men lost to follow-up, although it was small (<8%).

In summary, this study found that overweight or obesity regardless of physical activity levels, as well as the recommended levels of physical activity regardless of BMI levels, is independently associated with developing type 2 diabetes in Korean men. In addition, meeting physical activity recommendations may ameliorate some of the negative effects of overweight or obesity, and the increased risk of type 2 diabetes associated with inactivity was lower in normal weight men. Both preventing overweight or obesity and increasing physical activity should be encouraged to reduce the global epidemic and burden of type 2 diabetes, regardless of body weight and activity levels.

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