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Association between obstructive sleep apnea and albuminuria in Korean adults: a nationwide population-based study

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Background: Obstructive sleep apnea (OSA) is a sleep disorder associated with an increased risk of cardiovascular and metabolic complications. Albuminuria, an early marker of kidney damage, is a proposed risk factor for OSA and its adverse outcomes. The study explored the association between OSA and albuminuria in Korean adults.

Methods: We screened participants from the cross-sectional Korean National Health and Nutrition Examination Survey (2019–2021). The study included participants aged 40 years and older who completed the STOP-BANG questionnaire, a tool used to assess the OSA risk. Albuminuria was defined as a urine albumin-to-creatinine ratio ≥30 mg/g Cr. The participants were categorized based on albuminuria presence and severity. A multivariate logistic regression analysis examined the association between albuminuria and OSA.

Results: This study included 10,923 participants. Participants with albuminuria had significantly higher STOP-BANG scores than those without. Moreover, albuminuria remained strongly associated with an increased risk of OSA (odds ratio, 2.01; 95% confidence interval, 1.66–2.43), after multivariate adjustment. This association was more pronounced as albuminuria severity increased. Participants with high STOP-BANG scores were more likely to have albuminuria (odds ratio, 2.51; 95% confidence interval, 1.89–3.31), highlighting the bidirectional relationship between albuminuria and OSA.

Conclusion: The present study demonstrated a significant association between albuminuria and an elevated risk of OSA. These findings underscore the importance of early screening for OSA in patients with albuminuria, particularly in those with additional metabolic risk factors, to improve their long-term outcomes.

Keywords: Albuminuria, Chronic kidney disease, Obstructive sleep apnea, STOP-BANG

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Introduction

Obstructive sleep apnea (OSA) is a sleep disorder characterized by repeated episodes of upper-airway closure during sleep, which results in recurrent oxyhemoglobin desaturation or sleep fragmentation, eventually leading to clinical symptoms [1]. Previous reports highlighted that OSA is significantly associated with an increased risk of cardiovascular diseases and metabolic complications, including obesity and type 2 diabetes mellitus [2]. The rising global prevalence of OSA and its associated adverse outcomes pose a substantial health burden [3]. However, many patients remain undiagnosed or untreated. Thus, it is important to identify the population at risk for OSA to reduce further complications.

The STOP-BANG questionnaire is a simplified screening tool for OSA that consists of four self-reported (STOP: snoring, tiredness, observed apnea, and elevated blood pressure) and four demographic (BANG: body mass index [BMI], age, neck circumference, and gender) components [4]. A STOP-BANG score ≥3 points has a sensitivity of 84% for predicting any OSA, while a score ≥5 is highly predictive of clinically relevant moderate to severe OSA [5]. The STOP-BANG questionnaire is an easily accessible and cost-effective tool that can be used in large population-based studies. Therefore, it may be useful for the early diagnosis of OSA.

The incidence of sleep disorders, important health problems in patients with chronic kidney disease (CKD), is gradually increasing [6]. OSA is more commonly observed in patients with CKD than in the general population [7]. Previous studies demonstrated the physiological link between OSA and CKD [7]. OSA contributes to CKD progression through hypoxia, sympathetic nerve activation, hypertension, and the renin-angiotensin system [8–11]. Conversely, CKD may contribute to OSA severity through fluid overload [12]. OSA in CKD patients is associated with increased mortality [13,14]. Nocturnal hypoxemia, which results from OSA, is a risk factor for kidney dysfunction [15].

Albuminuria, which reflects increased glomerular permeability to macromolecules, is a widely used parameter for early kidney injury [16]. Several cross-sectional studies have used polysomnography (PSG) to identify albuminuria in patients diagnosed with OSA [17,18]. However, it is difficult to demonstrate an association between albuminuria and OSA.

In the present study, we used the STOP-BANG questionnaire to explore the prevalence, clinical characteristics, and comorbidities of OSA in Korean adults with albuminuria. We hypothesized that albuminuria is significantly associated with an increased risk of OSA and examined the association between albuminuria and OSA.

Methods

Ethical considerations

This study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of Seoul National University Hospital (No. 2312-091-1492). Informed consent was obtained from all participants before the administration of the Korea National Health and Nutrition Examination Survey (KNHANES). All data were presented to the authors in anonymized and de-identified forms prior to the analysis.

Study population

This nationwide population-based cross-sectional study used data from the KNHANES VIII conducted in 2019 to 2021. The survey was initially conducted by National Institute of Health in 1998. The survey collected information on health screening examinations, health surveys, and nutritional assessments. The STOP-BANG questionnaire used to evaluate OSA risk was available in the KNHANES VIII.

Among the 22,559 participants in the KNHANES VIII, those older than 40 years who completed the STOP-BANG questionnaire were considered for further analysis. After the exclusion of participants for whom data were missing, 10,923 participants were included in the analysis. Participants with a urine albumin-to-creatinine ratio (UACR) >30 mg/g Cr were grouped into the albuminuria group, while the others were grouped into the non-albuminuria group (Fig. 1). To accurately reflect the demographic characteristics of the Korean population and enhance the representativeness and validity of the findings, an analysis was conducted using weighted values adjusted for age, sex, and region.

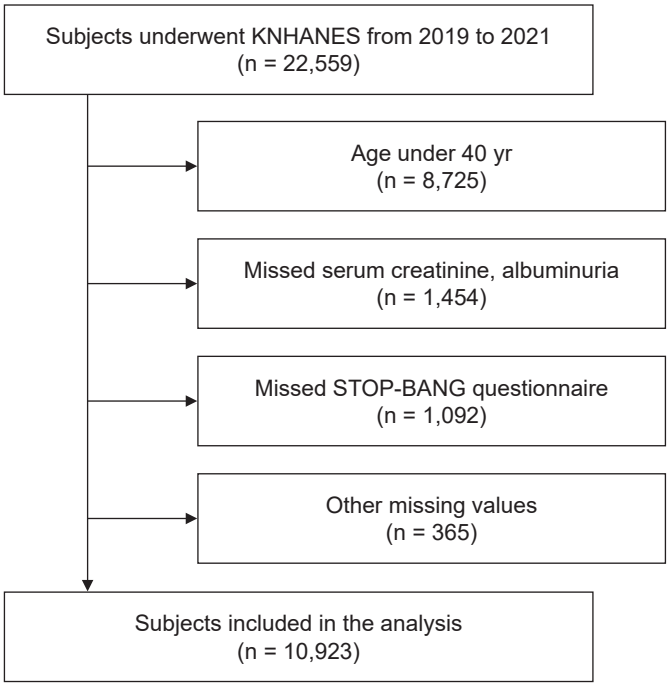


Figure 1. Study population.
KNHANES, Korea National Health and Nutrition Examination Survey.

Data acquisition and definitions

Participant heights, waist circumferences, and neck circumferences were measured to the nearest 0.1 cm, while their body weight was measured to the nearest 0.1 kg. BMI was calculated as weight (kg) divided by height (m^2). Obesity was defined as a BMI >25 kg/m^2 [19].

Each component of the STOP-BANG questionnaire was independently analyzed to assess the contribution of individual risk factors (snoring, tiredness, observed apnea, elevated blood pressure, BMI, age, neck circumference, and gender) to the overall risk of OSA and its association with albuminuria.

Confounding factors included age, sex, residence, occupation, household income, education, smoking, alcohol intake, physical activity, and diagnosis of diabetes mellitus, hypertension, and hypercholesterolemia. Age was classified into 40–49, 50–59, 60–69, 70–79, and ≥80 years. Residence was classified as urban or rural. Household income was classified into quantiles. Educational level was classified as less than high school, high school, or more than high school. Smoking status was classified as a nonsmoker, former smoker, or current smoker. Alcohol consumption was classified as non- (less than once per month), mild to moderate, or heavy (>4 times per week) drinker. Physical activity was defined as 20 minutes of vigorous-intensity physical activity performed 3 or more days per week or 30 minutes of moderate-intensity physical activity performed 5 or more days per week.

The KNHANES data were also used to diagnose comorbidities, including diabetes mellitus, hypertension, and hypercholesterolemia. Diabetes was defined as diagnosed by a doctor, taking diabetes mellitus medication or insulin, or having a fasting plasma glucose ≥126 mg/dL or glycated hemoglobin (HbA1c) ≥6.5%. Hypertension was defined as a diagnosis by a doctor, taking hypertension medication, or having a measured systolic blood pressure ≥140 mmHg or diastolic blood pressure ≥90 mmHg. Hypercholesterolemia was defined as a total cholesterol level ≥240 mg/dL or the use of hypercholesterolemia medication.

The UACR was calculated by dividing the urine albumin concentration by the urine creatinine concentration. A random urine sample was collected during the first-morning void, and urinary albumin (μg) was measured using the turbidimetric assay method (Hitachi Automatic Analyzer 7600), while urinary creatinine (mg) was measured using the kinetic colorimetric assay method (Hitachi Automatic Analyzer 7600). All measurements were conducted using standardized equipment and reagents. Albuminuria was defined as UACR ≥30 mg/g. The estimated glomerular filtration rate (eGFR) was calculated using the Modification of Diet in Renal Disease equation [20].

Obstructive sleep apnea risk evaluation

STOP-BANG score was used to evaluate OSA risk. The questionnaire consists of eight yes-or-no questions related to various risk factors for OSA [21]. Each question was designed to identify the specific symptoms or characteristics associated with sleep apnea: 1) Snoring: Is your snoring louder than your conversation or loud enough to be heard in the next room?; 2) Tired: Do you often feel tired or sleepy during the day?; 3) Observed: Has anyone ever observed your breathing stopping when you are asleep?; 4) Pressure: Diagnosed hypertension; 5) BMI, >30 kg/m^2; 6) Age, >50 years; 7) Neck circumference, >36.3 cm; 8) Sex: Male. A response of "yes" to each question was assigned one point,

resulting in total scores of 0–8. OSA risk was classified as low at a total score of 0–2, intermediate at 3–4, and high at 5–8 points.

Study groups and outcomes

The participants were divided into two to three groups based on the presence or severity of albuminuria. The severity of albuminuria was classified as follows: normal, <30 mg/g Cr; moderately increased albuminuria, 30–300 mg/g Cr; and severely increased, >300 mg/g Cr.

The primary outcomes were the diagnosis and high risk of OSA. A diagnosis of OSA was defined as an answer of "yes" to the question "Have you ever been diagnosed with OSA by a doctor using PSG?" in the STOP-BANG questionnaire.

A high risk of OSA was defined as a STOP-BANG score of ≥5.

Statistical analysis

Continuous variables are presented as mean ± standard error (SE), whereas categorical variables are presented as percentages (SE) corresponding to the number of participants. The Student t test, analysis of variance, and the chi-square test were used to compare the values among study groups. Two-sided p-values were derived, and the significance level was set at 0.05. A multiple logistic regression model was used to analyze the relationship between albuminuria and OSA. The following variables were used for the multivariate adjustment: age; sex; residence; occupation; income status; education level; smoking status; alcohol consumption status; physical exercise; obesity; and comorbidities, including hypertension, diabetes mellitus, and hypercholesterolemia. SAS version 9.4 (SAS Institute) was used for the statistical analysis.

Results

Study population

Table 1 presents the baseline characteristics of the study participants, categorized into two groups: those with and without albuminuria. The albuminuria group had a higher proportion of males, were older, and had higher BMI, neck

Table 1. Baseline characteristics

Characteristic	Non-albuminuria group	Albuminuria group	p-value
No. of patients	9,857	1,066	
Age (yr) group (%)			<0.001
40–49	30.9 ± 0.8	16.5 ± 1.5	
50–59	31.6 ± 0.7	27.5 ± 2.0	
60–69	22.9 ± 0.6	25.9 ± 1.5	
70–79	11.3 ± 0.4	21.5 ± 1.4	
≥80	3.3 ± 0.2	8.7 ± 0.9	
Male sex (%)	48.7 ± 0.5	53.1 ± 1.9	0.03
Residence, urban (%)	82.6 ± 1.6	78.2 ± 2.3	0.004
Occupation, yes (%)	65.5 ± 0.7	53.8 ± 2.0	<0.001
Income status (%)			<0.001
0–20	11.3 ± 0.5	25.3 ± 1.6	
20–40	17.2 ± 0.6	19.4 ± 1.5	
40–60	21.1 ± 0.6	18.7 ± 1.5	
60–80	24.5 ± 0.7	18.9 ± 1.5	
80–100	25.9 ± 1.0	17.7 ± 1.6	
Education level (%)			<0.001
Less than high school	27.0 ± 0.8	41.7 ± 1.9	
High school	36.0 ± 0.7	33.4 ± 1.9	
More than high school	37.1 ± 1.0	25.0 ± 1.9	
Smoking status (%)			0.03
Nonsmoker	57.6 ± 0.6	53.4 ± 1.9	
Former smoker	25.5 ± 0.5	26.1 ± 1.7	
Current smoker	16.9 ± 0.5	20.5 ± 1.6	
Alcohol status (%)			0.08
Non-drinker	48.9 ± 0.6	50.3 ± 1.8	
Mild to moderate drinker	44.2 ± 0.6	41.1 ± 1.8	
Heavy drinker	6.9 ± 0.3	8.6 ± 1.0	
Physical activity (%)	40.6 ± 0.7	34.3 ± 1.7	<0.001
Diabetes mellitus (%)	15.7 ± 0.5	45.4 ± 1.8	<0.001
Hypertension (%)	35.2 ± 0.7	67.5 ± 1.8	<0.001
Hypercholesterolemia (%)	31.4 ± 0.6	40.0 ± 1.8	<0.001
BMI (kg/m^2) group (%)			<0.001
<18.5	2.4 ± 0.2	2.0 ± 0.6	
≥18.5 to <23	35.0 ± 0.6	26.8 ± 1.6	
≥23 to <25	25.1 ± 0.5	22.5 ± 1.5	
≥25 to <30	32.1 ± 0.6	40.3 ± 1.8	
≥30	5.4 ± 0.3	8.4 ± 1.1	
Age (yr)	56.7 ± 0.2	61.9 ± 0.5	<0.001
Height (cm)	163.5 ± 0.1	162.6 ± 0.4	0.02
Weight (kg)	65.1 ± 0.2	66.5 ± 0.5	0.005
BMI (kg/m^2)	24.2 ± 0.0	25.0 ± 0.1	<0.001
Waist circumference (cm)	85.2 ± 0.1	88.8 ± 0.4	<0.001
Neck circumference (cm)	35.3 ± 0.0	36.3 ± 0.1	<0.001
Fasting glucose (mg/dL)	102.7 ± 0.3	122.2 ± 1.8	<0.001

(Continued to the next page)

Table 1. Continued

Characteristic	Non-albuminuria group	Albuminuria group	p-value
HbA1c (%)	5.9 ± 0.0	6.6 ± 0.1	<0.001
SBP (mmHg)	120.4 ± 0.2	132.7 ± 0.7	<0.001
DBP (mmHg)	76.4 ± 0.1	79.4 ± 0.4	<0.001
Total cholesterol (mg/dL)	194.8 ± 0.5	184.5 ± 1.6	<0.001
HDL-C (mg/dL)	51.6 ± 0.2	48.1 ± 0.4	<0.001
LDL-C (mg/dL)	117.3 ± 0.5	105.7 ± 1.4	<0.001
Triglyceride (mg/dL)	137.7 ± 1.4	167.3 ± 5.7	<0.001
eGFR (mL/min/1.73 m^2)	92.4 ± 0.2	83.4 ± 0.8	<0.001

Data are expressed as number only or mean ± standard error.
BMI, body mass index; DBP, diastolic blood pressure; eGFR, estimated glomerular filtration rate; HbA1c, glycated hemoglobin; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; SBP, systolic blood pressure.

circumference, waist circumference, and blood pressure values. Moreover, the participants with albuminuria had a higher prevalence of diabetes mellitus, hypertension, and hypercholesterolemia than those without albuminuria. In addition, the analysis showed that participants with albuminuria had a lower eGFR than those without albuminuria and that the eGFR tended to decrease as albuminuria severity increased.

STOP-BANG score distributions according to questionnaire items by group

The participants with albuminuria exhibited higher STOP-BANG scores than those without albuminuria (Fig. 2). The mean STOP-BANG score of participants with albuminuria was 3.30, higher than the mean of 2.59 for participants without albuminuria. Participants with albuminuria had a higher frequency of all components of the STOP-BANG questionnaire (Supplementary Table 1, available online).

Impact of albuminuria on obstructive sleep apnea and STOP-BANG scores

OSA occurred in 0.85% and 0.65% of the participants in the albuminuria and non-albuminuria groups, respectively. The prevalence of OSA was 1.33-fold more common in the participants with versus without albuminuria. Analysis of the STOP-BANG components revealed that 'snoring,' 'tired,' 'observed,' and male gender were significantly associated with OSA (Table 2).

A high risk of OSA was confirmed in 21.3% of participants in the albuminuria group. In the multivariate-adjusted logistic regression models, the presence of albuminuria was significantly associated with a high risk of OSA (odds ratio [OR], 1.53; 95% confidence interval [CI], 1.20–1.95). Furthermore, when divided into three groups by albuminuria severity, the significance gradually increased with albuminuria severity (Table 3). Additionally, a high STOP-BANG score was associated with albuminuria (OR, 2.51; 95% CI, 1.89–3.31) (Supplementary Table 2, available online).

Subgroup analysis

Subgroups were stratified by sex, age, BMI, and the presence of chronic diseases such as diabetes mellitus, hypertension, and hypercholesterolemia. When analyzed by sex, age, and BMI, albuminuria was associated with a high-risk OSA, which is consistent with previous findings. Albuminuria was particularly associated with an increased risk of OSA in women, with a 2.25-fold increased risk of high-risk OSA in women compared to a 1.45-fold increased risk in men. Those without chronic diseases, such as diabetes mellitus, hypertension, or hypercholesterolemia, tended to have a higher OR. In contrast, among those with chronic diseases, the associations were not significant, with an OR of 1.08 (95% CI, 0.78–1.48) for diabetes mellitus, 1.05 (95% CI, 0.81–1.36) for hypertension, and 1.25 (95% CI, 0.85–1.82) for hypercholesterolemia (Table 4).

Discussion

In the present study, we investigated the association between albuminuria and OSA using a nationwide population-based dataset from Korea and demonstrated that albuminuria was significantly associated with high OSA risk. This study demonstrated a significant association between albuminuria and an increased risk of OSA, reinforcing the findings of previous studies and expanding the evidence to a nationwide cohort. Our study findings suggested that albuminuria is an important risk factor for OSA. Moreover, these results emphasize the need to actively screen patients with albuminuria for OSA.

PSG is the gold standard for diagnosing OSA. In addition,

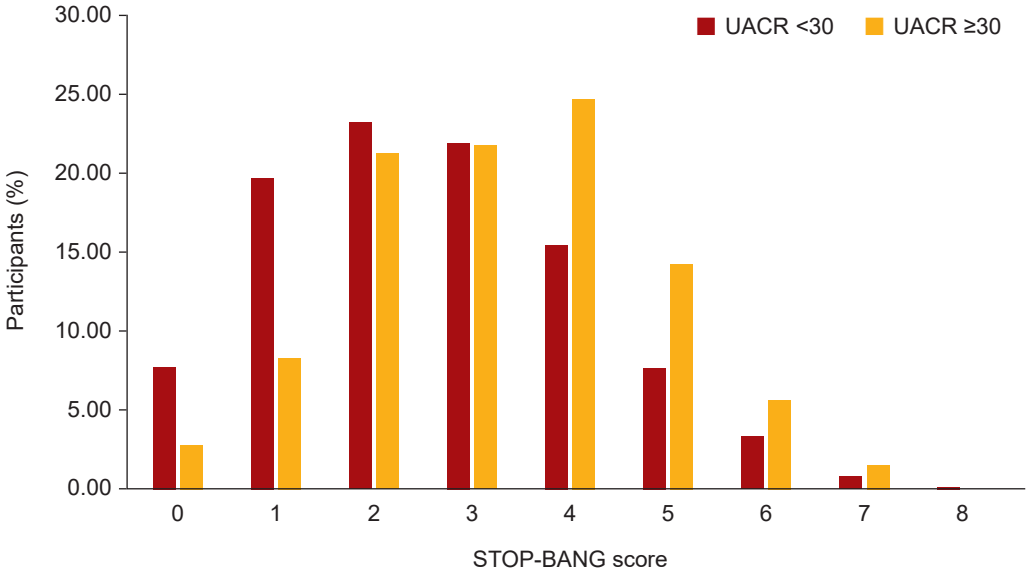


Figure 2. Distribution of total STOP-BANG scores. Distribution of STOP-BANG scores in the presence of albuminuria. The participants with albuminuria tended to have higher STOP-BANG scores.
UACR, urine albumin-to-creatinine ratio.

Table 2. Association of obstructive sleep apnea with STOP-BANG questionnaires and albuminuria

Variable	Model 1		Model 2		Model 3	
	OR (95% CI)	p-value	OR (95% CI)	p-value	OR (95% CI)	p-value
Albuminuria, UACR < 30	Reference	0.54	Reference	0.61	Reference	0.42
UACR ≥ 30	1.33 (0.54–3.23)		1.27 (0.51–3.14)		1.45 (0.59–3.57)	
Snoring	Reference	<0.001	Reference	<0.001	Reference	<0.001
	10.21 (5.02–20.79)		7.86 (3.80–16.27)		7.49 (3.54–15.87)	
Tired	Reference	0.02	Reference	0.006	Reference	0.005
	1.94 (1.14–3.32)		2.14 (1.25–3.67)		2.16 (1.26–3.69)	
Observed	Reference	<0.001	Reference	<0.001	Reference	<0.001
	42.01 (20.70–85.29)		30.53 (14.53–64.11)		29.13 (13.57–62.53)	
Hypertension, pressure	Reference	0.64	Reference	0.85	Reference	0.79
	1.14 (0.66–1.96)		1.06 (0.60–1.87)		0.93 (0.52–1.64)	
Body mass index	Reference	0.92	Reference	0.96	Reference	0.99
	1.05 (0.40–2.78)		1.03 (0.38–2.77)		1.01 (0.37–2.77)	
Age	Reference	0.56	Reference	0.17	Reference	0.28
	1.21 (0.64–2.30)		1.96 (0.75–5.15)		1.78 (0.62–5.05)	
Neck	Reference	<0.001	Reference	0.07	Reference	0.17
	6.45 (3.21–12.95)		2.43 (0.93–6.37)		2.09 (0.74–5.95)	
Gender, male	Reference	<0.001	Reference	<0.001	Reference	<0.001
	8.91 (4.02–19.77)		8.87 (4.01–19.63)		7.50 (3.12–18.02)	

Model 1: unadjusted; Model 2: adjusted for age and sex; Model 3: adjusted for age, sex, residence, occupation, household income, education, smoking, alcohol consumption, physical activity, diabetes mellitus, hypertension, hypercholesterolemia, and obesity.
CI, confidence interval; OR, odds ratio; UACR, urine albumin-to-creatinine ratio.

Table 3. Association of high obstructive sleep apnea risk group with STOP-BANG questionnaires and albuminuria

Variable	Model 1		Model 2		Model 3	
	OR (95% CI)	p-value	OR (95% CI)	p-value	OR (95% CI)	p-value
Presence of albuminuria						
UACR < 30 mg/g Cr	Reference	<0.001	Reference	<0.001	Reference	0.001
UACR ≥ 30 mg/g Cr	2.01 (1.66–2.43)		1.89 (1.51–2.35)		1.53 (1.20–1.95)	
Severity of albuminuria						
UACR < 30 mg/g Cr	Reference	<0.001	Reference	<0.001	Reference	0.003
UACR 30–300 mg/g Cr	1.88 (1.52–2.34)		1.83 (1.44–2.34)		1.51 (1.16–1.95)	
UACR > 300 mg/g Cr	2.82 (1.85–4.31)		2.16 (1.30–3.61)		1.65 (0.95–2.87)	

Model 1: unadjusted; Model 2: adjusted for age and sex; Model 3: adjusted for age, sex, residence, occupation, household income, education, smoking consumption, alcohol, physical activity, diabetes mellitus, and hypercholesterolemia.
CI, confidence interval; Cr, creatinine; OR, odds ratio; UACR, urine albumin-to-creatinine ratio.

Table 4. Subgroup analysis

Variable	Non-albuminuria group		Albuminuria group		OR (95% CI)	p-value for interaction
	Number, event/total	Weighted (%)	Number, event/total	Weighted (%)		
Overall	1,072/9,857	11.9 ± 0.40	213/1,066	21.32 ± 1.54	1.53 (1.20–1.95)	
Sex						0.16
Male	984/4,270	22.71 ± 0.78	190/531	36.15 ± 2.53	1.45 (1.13–1.86)	
Female	88/5,587	1.63 ± 0.21	23/535	4.56 ± 1.14	2.25 (1.26–4.00)	
Age (yr)						0.26
40–49	151/2,474	7.01 ± 0.60	21/139	14.54 ± 3.69	1.67 (0.84–3.31)	
50–59	363/2,670	15.69 ± 0.87	50/198	28.54 ± 3.70	1.57 (0.97–2.54)	
60–69	343/2,583	14.86 ± 0.83	57/302	21.02 ± 2.76	1.13 (0.74–1.74)	
70–79	175/1,656	10.33 ± 0.78	65/307	19.96 ± 2.48	1.89 (1.25–2.85)	
≥80	37/474	6.26 ± 1.06	20/120	15.60 ± 3.82	3.00 (1.36–6.61)	
BMI (kg/m^2)						0.54
<25	370/6,237	6.14 ± 0.35	72/568	13.80 ± 1.89	1.68 (1.15–2.47)	
25–30	486/3,116	17.49 ± 0.83	95/411	24.32 ± 2.55	1.28 (0.90–1.83)	
≥30	216/504	45.40 ± 2.73	46/87	52.78 ± 5.85	1.63 (0.78–3.41)	
Diabetes mellitus						0.00
No	738/8,153	9.96 ± 0.41	95/577	18.26 ± 1.99	2.15 (1.58–2.94)	
Yes	334/1,704	22.27 ± 1.28	118/489	25.00 ± 2.33	1.08 (0.78–1.48)	
Hypertension						0.19
No	274/6,049	5.13 ± 0.35	24/318	9.13 ± 2.13	1.54 (0.89–2.68)	
Yes	798/3,808	24.34 ± 0.84	189/748	27.19 ± 1.92	1.05 (0.81–1.36)	
Hypercholesterolemia						0.13
No	655/6,635	10.21 ± 0.45	122/634	19.64 ± 1.91	1.77 (1.33–2.36)	
Yes	417/3,222	15.59 ± 0.74	91/432	23.84 ± 2.52	1.24 (0.85–1.82)	

Data are expressed as number only or mean ± standard error.
BMI, body mass index; CI, confidence interval; OR, odds ratio.

the apnea-hypopnea index is useful for diagnosing the OSA severity [22]. However, PSG requires an overnight hospital stay and is expensive to perform. These methods limit the use of PSG in clinics and may make it difficult to actively diagnose OSA. Therefore, the convenient and cost-effective STOP-BANG questionnaire may be the most useful tool for screening patients at risk for OSA [23,24]. Our data further support this finding by demonstrating an association be-

tween higher STOP-BANG scores and a higher prevalence of OSA, underscoring the efficacy of the STOP-BANG questionnaire as a reliable screening tool in clinical settings.

The relationship between OSA and CKD was reported previously. Chronic hypoxia is the most important factor causing kidney damage in patients with OSA [25]. Increased oxidative stress causes systemic inflammation, activates the sympathetic nervous system, and eventually causes elevated blood pressure. Uremia, metabolic acidosis, and fluid overload are commonly observed in patients with CKD, which can destabilize breathing patterns and eventually lead to narrowing of the pharyngeal area [26,27]. Several studies have demonstrated that OSA is common among patients with CKD [28]. The presence of OSA is significantly associated with impaired renal function [29,30].

Albuminuria is an important predictor of impaired kidney function [31]. Albuminuria, an early marker of kidney damage, increases cardiovascular risk, end-stage kidney disease progression, and mortality in patients with and without diabetes mellitus [32,33]. Considering the association between CKD and OSA, the early assessment of OSA risk in patients with albuminuria is anticipated to improve long-term clinical outcomes.

The present study demonstrates an association between albuminuria and an increased risk of OSA. In addition, patients with albuminuria showed high STOP-BANG scores, which correlated with OSA risk. Several single-center studies have reported a relationship between microalbuminuria and OSA risk [17,34]. Here we examined the association between albuminuria and OSA using a large-scale nationwide dataset and demonstrated an increased risk of OSA which gradually increased with albuminuria severity. In patients with mild albuminuria, management to prevent its progression reduces the risk of OSA. Moreover, these results highlight the importance of OSA screening, particularly in patients with severe albuminuria.

Albuminuria was significantly associated with a high risk of OSA. However, albuminuria was not significantly associated with previously diagnosed OSA. The apparent discrepancy between these results may be attributable to several factors. First, the diagnosis of OSA was based on self-reported data, which may have led to an underestimation of the actual prevalence of OSA. Second, it is important to consider that the STOP-BANG questionnaire is a highly sensitive tool designed to identify individuals at high risk of OSA, even in cases in which a formal diagnosis has not yet been made. Moreover, the relatively low prevalence of OSA in the dataset of the present cross-sectional study may have limited the statistical power to detect this association. The present analysis highlights the potential role of albuminuria in identifying individuals at risk of OSA, particularly those with high STOP-BANG scores.

OSA is associated with several chronic diseases [35–37]. Patients with chronic conditions such as diabetes mellitus, hypertension, and hypercholesterolemia may already be at an increased risk of OSA. In such cases, the additional effects of albuminuria may be less pronounced. In contrast, patients without chronic diseases may have a relatively low baseline risk, therefore the presence of albuminuria may have a greater impact on their risk of OSA.

In South Korea, OSA is more prevalent in males, affecting 27% of middle-aged men versus 16% of middle-aged women [38]. In the present study, the prevalence of OSA was 0.67%. This low prevalence may be attributable to underdiagnosis, reflecting the real-world situation in which OSA remains underrecognized in clinical practice due to limited screening and diagnostic measures. As a result, the low prevalence may have limited our ability to detect significant associations between OSA and albuminuria due to statistical power. Although we observed a 1.33-fold increase in the number of participants with albuminuria, this finding was not statistically significant.

Regarding the study results, active screening for OSA using the STOP-BANG questionnaire may assist the discovery of the population at risk for OSA, especially those with dipstick albuminuria detected during health examinations. Conversely, a high risk of OSA is associated with albuminuria. These results suggest that monitoring for albuminuria is crucial among patients diagnosed with OSA.

Despite the clinical significance of the present study, there were some limitations considering the nature of the dataset. First, the OSA diagnosis was based on a self-reported questionnaire. Compared with PSG, the STOP-BANG questionnaire may have led to an underdiagnosis of OSA. Second, because this was a cross-sectional study, we could not examine causal relationships and temporal sequences of events. Third, as the study included people >40 years of age, patient selection bias was unavoidable. Fourth, the possibility of transient changes in the UACR due to factors such as fever, infection, pregnancy, menstruation, exer-

cise, posture, and medication cannot be excluded. Given the nature of large-scale national epidemiological studies, controlling for these factors is infeasible. Finally, the use of continuous positive airway pressure (CPAP) for OSA treatment was not investigated. Several studies demonstrated the clinical benefits of CPAP for renal function, including albuminuria. Therefore, albuminuria severity in OSA patients with CPAP may have been underestimated [39].

In the present study, albuminuria was significantly associated with elevated OSA risk. Considering the accessibility of the STOP-BANG questionnaire used in the present study, OSA can be easily screened in clinical settings in patients with albuminuria. Among patients with albuminuria, active screening for and monitoring of OSA may enable the early detection of OSA and the reduction of further metabolic complications.

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Conflicts of interest

All authors have no conflicts of interest to declare.

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Data sharing statement

This study used data from the Korea National Health and Nutrition Examination Survey which can be found at https://knhanes.kdca.go.kr/knhanes/sub03/sub03-02-05.do.

Authors' contributions

Conceptualization, Formal analysis: YY, KH, SL
Data curation, Investigation: JHK, YSS, JMC, MK, MWK, SGK, SJ
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Methodology: YY, KH, SL
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