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Body Mass Index, waist circumference, and health-related quality of life in adults with chronic kidney disease

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Abstract

Purpose Obesity is linked to poor health-related quality of life (HRQOL) in the general population, but its role in chronic kidney disease (CKD) is uncertain.

Methods We conducted a cross-sectional study that investigated 1880 participants from the KoreaN cohort study for Outcome in patients With CKD (KNOW-CKD) who underwent complete baseline laboratory tests, health questionnaires, and HRQOL. HRQOL was assessed by physical component summary (PCS) and mental component summary (MCS) of the SF-36 questionnaire. We used multivariable linear regression models to examine the relationship between Body Mass Index (BMI) and sex-specific waist circumference (WC) with HRQOL.

Results Adults with higher BMI and greater WC showed lower PCS. After adjusting for age, sex, socioeconomic state, comorbidities, and laboratory findings, we found that WC, but not BMI, was associated with PCS. Greater WC quintiles were associated with lower PCS [WC-4th quintile (β, −2.63, 95% CI −5.19 to −0.06) and WC-5th quintile (β, −3.71, 95% CI −6.28 to −1.15)]. The association between WC and PCS was more pronounced in older adults, woman, patients with diabetes, cardiovascular disease, or lower eGFR. The relationship between BMI and WC with MCS was not significant.

Conclusions In adults with CKD, WC is a better indicator of poor physical HRQOL than BMI. The association between WC and physical HRQOL is modified by age, sex, eGFR, and comorbidities such as diabetes and cardiovascular disease.

Keywords BMI · Waist circumference · HRQOL · CKD

Introduction

Chronic kidney disease (CKD) is a global health problem affecting approximately 10% of the adult population [1]. CKD is a heterogeneous disease with different causes,

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manifestations, and comorbidities. Many cases of CKD occur insidiously and progresses to cardiovascular disease or end-stage renal disease (ESRD). Anemia, malnutrition, metabolic abnormalities, and cardiovascular disease gradually develop with compromised kidney function. Health-related quality of life (HRQOL) is a multi-domain concept representing the patient's general perception of the effect of illness on physical and mental health [2]. Renal and extra-renal conditions can produce poor HRQOL in patients with CKD. Although HRQOL is an important indicator of the symptomatic burden of CKD [2, 3], it remains an under-investigated issue in CKD [4].

Obesity poses a significant health burden and its prevalence is increasing [5, 6]. Obesity is associated with increased morbidity and mortality. Although obesity is a risk factor of renal progression, it is associated with a survival advantage in non-dialysis-dependent CKD [7–9]. Obesity is traditionally defined based on Body Mass Index (BMI). BMI carries certain limitations that it does not capture information regarding body fat distribution and does not discriminate between fat and lean mass [10]. The association between BMI and outcomes is modified by smoking, pre-existing illness, or reverse causation [11]. High BMI is considered a risk factor for mortality in the general population, but CKD patients with high BMI have a paradoxically lower mortality rates compared to those with an optimal BMI [12]. Compared to obesity defined by BMI, obesity defined by waist circumference (WC) is more closely associated with mortality and renal progression in patients with CKD [13, 14].

Obesity is associated with impaired physical and mental HRQOL. In a meta-analysis [15] of the association between BMI and HRQOL in the general population, physical HRQOL was shown to be impaired among adults with obesity, whereas mental HRQOL was better in individuals with overweight and modestly reduced among adults with severe obesity compared to those with an optimal BMI. There have been few studies on the association between obesity and HRQOL in CKD. A better understanding of HRQOL would enable medical providers to improve the overall well-being of patients with CKD. This study examined the association between obesity and HRQOL in non-dialysis-dependent CKD. Specially, we evaluated the relationship between BMI and WC with HRQOL and the differences of these associations according to age, sex, and comorbidities.

Methods

Participants

The KoreaN cohort study for Outcome in patients With CKD (KNOW-CKD) study [16] was a multicenter, prospective, observational study of adults with CKD in Korea. The design on KNOW-CKD study has been published previously. Nine clinical centers in university-affiliated hospitals enrolled 2238 adults with CKD from 2011 to 2016. KNOW-CKD enrolled Koreans between 20 and 75 years of age with CKD for all stages of estimated glomerular filtration rate (eGFR). Subjects were excluded if they had a history of malignancy, liver cirrhosis, advanced heart failure, a single kidney, or other factors according to the KNOW-CKD protocol. We analyzed 1880 participants from this cohort who underwent complete baseline HRQOL, health questionnaire, laboratory tests, and anthropometry (Supplementary Fig. S1). We defined CKD according to the KDIGO 2012 guideline [17]: eGFR < 60 ml/min/1.73 m^2, albuminuria (AER ≥ 30 mg/24 h or ACR ≥ 30 mg/g), or structural abnormalities for > 3 months. Serum creatinine was measured at least twice before enrollment into the KNOW-CKD study.

Obesity measures and covariates

BMI was calculated as weight (kg)/height (m^2) and categorized as < 18.5 (underweight), 18.5–22.9 (ideal), 23.0–24.9 (overweight), 25.0–29.9 (class I obesity), and ≥ 30 kg/m^2 (class II obesity) according to the World Health Organization BMI categories for Asian population [18]. WC was measured midway between the lowest rib and the iliac crest using a tape measure with the participant in standing position and was categorized in sex-specific quintiles.

The measured variables for this study included both baseline health questionnaire data and laboratory data: age, gender, marriage status, household income, education level, smoking, physical activity, diabetes mellitus, hypertension, cardiovascular disease, and laboratory tests. Low income was defined as a monthly family income less than approximately 1500 US dollars. Low education level was defined as an academic background less than a high school diploma. Health-enhancing physical activity was defined as more than 150 min/week of moderate activity, 75 min/week of vigorous activity, or an equivalent combination according to the global recommendations of the World Health Organization [19]. Cardiovascular disease was defined as a medical history of myocardial infarction, heart failure, peripheral vascular disease, or stroke. Diabetes mellitus and hypertension were defined based on the KNOW-CKD protocol. Serum creatinine levels were measured using the isotope dilution mass spectroscopy traceable method. The eGFR was calculated using the four-variable CKD-EPI equation [17].

HRQOL

HRQOL was assessed by the short form-36 (SF-36) [20, 21], a validated tool for assessing HRQOL that has been utilized in many studies in Korea. SF-36 includes eight subscales:

physical function, role physical limitation due to physical problems, bodily pain, general health, vitality, role emotional limitation due to emotional problems, social function, and mental health. Questionnaires were completed with the aid of study personnel if participants had difficulty with self-administration. Responses to each question were transformed into SF-36 equivalent scores, with each scale ranging from 0 to 100 and higher numerical scores indicating better HRQOL or less impairment in that subscale. The first four subscales as described above were summarized into a physical component summary (PCS), and the last four subscales were summarized into a mental component summary (MCS). In this study, the PCS and MCS scores were used as the outcomes of interest.

Statistical analysis

Data were expressed as a percentile for categorical variables and mean ± standard deviation or median [first and third quartiles] for continuous variables. Tests for a linear trend for the mean values in categories were performed using linear regression analysis with the mean values as continuous variables. Because many parameters might be interrelated with HRQOL, we constructed a multivariable linear regression models to determine the relationship between HRQOL with BMI and sex-specific WC. Results were reported as the regression coefficient β and 95% confidence interval (CI). Multiple parameters were selected based on our baseline data and other HRQOL studies in CKD. We analyzed the association between BMI and HRQOL in reference to optimal BMI. Participants in the second WC quintile (WC-Q) exhibited the highest adjusted means of SF-36, and thus we analyzed the association between WC and HRQOL using WC-Q2 as a reference. For our multivariable linear regression models, model 1 was adjusted for age, sex, diabetes, hypertension, cardiovascular disease, eGFR, hemoglobin, and albumin. Model 2 was adjusted using the same parameters as for model 1 as well as marriage status, education, income, smoking, and health-enhancing physical activity. We used multivariable regression models of the relationship between BMI and WC with HRQOL. For further analysis of non-linear data, we used general linear models and analysis of covariance (ANCOVA). Marginal effect was estimated by the margin command and was plotted by the marginsplot command in Stata software adjusted for the predictors used for model 2. All statistical analyses were performed using Stata Version 14 (StataCorp LP, College Station, TX, USA).

Results

Participant characteristics

Of the 2238 KNOW-CKD participants, 1880 (84%) had complete HRQOL data, variables of interests, and anthropometry. The baseline mean age was 54 ± 12 years and 62% of the participants were male. The mean eGFR was 53 ± 31 ml/min per 1.73 m^2 and 65% of the participants had an eGFR < 60 ml/min per 1.73 m^2. Comorbidities included diabetes 33%, hypertension 96%, and cardiovascular disease 11% (Supplementary Table 1). The mean BMI was 24.8 ± 3.2 for men and 24.0 ± 3.7 kg/m^2 for women. The mean WC was 89.8 ± 8.6 cm for men and 83.3 ± 10.1 cm for women. Subjects with a greater sex-specific WC exhibited a lower PCS and MCS than those with a low WC. Although PCS and MCS showed no difference according to BMI category (p for trend > 0.05) (Table 1), they did decrease with increased WC quintile (p for trend < 0.05) (Table 2). With respect to subscale items of SF-36 based on BMI category and WC quintile, scores for physical function, role physical, and body pain were gradually worse for increasing BMI categories and WC quintile categories (p for trend < 0.05) (Supplementary Fig. S2).

Relationship of BMI, WC with HRQOL

In the multivariable linear regression models adjusted for age, sex, diabetes, hypertension, cardiovascular disease, eGFR, hemoglobin, albumin, marriage, education, income, smoking, and health-enhancing physical activity (model 2), greater WC-Q groups had an association with lower PCS compared to the reference WC-Q2 [WC-Q4 (β, −2.63; 95% CI, −5.19 to −0.06) and WC-Q5 (β, −3.71; 95% CI, −6.28 to −1.15)]. Adults with BMI class II obesity had a lower PCS than those with an ideal BMI in univariable analysis and model 1 regression analysis, but this difference was not statistically significant in the full adjusted model 2 regression analysis (Table 3).

In marginal plots of BMI categories and sex-specific WC-Q with PCS, adults with underweight and those with BMI class II obesity had a lower PCS, but PCS was not statistically different for any of the BMI categories. Adults with WC-Q4 and WC-Q5 had a significantly lower PCS compared to the reference WC-Q2. There was an inverse J-shaped association between WC and PCS (Fig. 1a). MCS exhibited an increasing trend with increasing BMI categories, but decreasing trend with increasing WC quintiles. However, MCS was not statistically different for any of the BMI categories or WC quintiles (Fig. 1b).

Subgroup analyses

The association between WC and PCS was greater in adults aged ≥ 65 years, females, adults with diabetes, cardiovascular disease, or eGFR < 60 ml/min per 1.73 m^2 (p for interaction < 0.05) (Fig. 2). Greater WC was closely correlated with lower PCS in older adults, women, adults who had diabetes, cardiovascular disease, or advanced CKD. Thus, the

Table 1 Baseline characteristics of 1880 adults with chronic kidney disease based on BMI category

	All	BMI category (kg/m²)					p for trend
		< 18.5 underweight	18.5–22.9 ideal	23.0–24.9 overweight	25.0–29.9 obesity I	≥30.0 obesity II	
No. of participants	1880	47	570	491	657	115	
Age (years)	54 ± 12	45 ± 13	52 ± 12	55 ± 12	55 ± 12	52 ± 13	< 0.001
Sex (male) (%)	62	30	53	67	67	63	< 0.001
WC (cm)	87.3 ± 9.7	71.2 ± 5.8	79.4 ± 6.8	86.6 ± 5.9	92.9 ± 6.0	104.3 ± 8.4	< 0.001
Current smoker (%)	16	13	13	18	18	18	0.1
HEPA (%)	42	24	38	48	44	38	0.02
Unmarried (%)	16	30	17	13	14	32	0.8
Low income (%)	23	13	22	23	25	27	0.03
Low education (%)	23	15	20	22	26	22	0.01
Diabetes (%)	33	13	24	35	37	55	< 0.001
Hypertension (%)	96	85	92	97	99	98	< 0.001
CVD (%)	11	7	11	10	12	15	0.2
eGFR (ml/min per 1.73 m²)	53 ± 31	53 ± 36	55 ± 34	51 ± 29	53 ± 29	55 ± 33	0.5
24-hU protein (mg/day)	555 [170, 1579]	500 [158, 995]	420 [128, 1223]	598 [182, 1691]	598 [233, 1814]	867 [306, 2758]	< 0.001
Hemoglobin (g/dl)	12.8 ± 2.0	11.8 ± 1.7	12.4 ± 1.9	12.8 ± 2.0	13.2 ± 2.1	13.4 ± 2.1	< 0.001
Serum albumin (g/dl)	4.18 ± 0.43	4.19 ± 0.40	4.18 ± 0.43	4.15 ± 0.45	4.21 ± 0.40	4.16 ± 0.48	0.6
PCS	72 ± 19	71 ± 17	73 ± 18	73 ± 18	72 ± 19	69 ± 21	0.2
MCS	70 ± 18	67 ± 17	69 ± 19	70 ± 19	70 ± 18	69 ± 18	0.4

The values are mean ± SD or median [first and third quartiles]

BMI Body Mass IndexBody Mass Index, *WC* waist circumference, *HEPA* health-enhancing physical activity, *CVD* cardiovascular disease, *eGFR* estimated glomerular filtration rate, *24-hU* 24-h urine, *PCS* physical component score, *MCS* mental component score

association between WC and physical HRQOL appeared to be modified by age, sex, eGFR, and presence of comorbidities such as diabetes and cardiovascular disease.

Discussion

In this cross-sectional study of adults with non-dialysis CKD, different patterns were observed for the relationship between BMI and WC with HRQOL. Greater WC as a marker of abdominal obesity was associated with reduced physical HRQOL, while higher BMI was not associated with physical HRQOL. WC is a better indicator of poor physical HRQOL than BMI in adults with CKD. WC had a greater association with poor physical HRQOL in older adults, women, and adults who had diabetes, cardiovascular disease, or advanced CKD (eGFR < 60 ml/min/1.73 m²). Whereas, WC and BMI were not associated with mental HRQOL in adults with CKD.

Obesity is defined as excessive or abnormal fat accumulation in the body and is a major health concern worldwide [5, 6]. As obesity is a risk factor for chronic disease and mortality, simple and valid measures are essential to define this condition. BMI is the current metric used for defining anthropometric characteristics and is widely used as the epidemiological standard measure of obesity. However, BMI does not capture body fat distribution, nor does it distinguish between fat mass and lean mass [10]. In addition, the association between body fat percentage and BMI varies according to age, sex, ethnicity, and chronic disease [10, 11, 22]. Kittiskulnam et al. [23] reported that BMI misclassified body fat percentage obesity among patients receiving hemodialysis and misidentification of obesity was less common using WC (15.2%) than BMI (31.3%). However, body composition analysis, which displays fat distribution and distinguishes between fat and lean mass, identified poor outcomes in patients with CKD [24].

Table 2 Baseline characteristics of 1880 adults with chronic kidney disease based on sex-specific WC quintile

	Sex-specific WC Quintile (cm)					
	WC-Q1 (*n* = 376)	WC-Q2 (*n* = 376)	WC-Q3 (*n* = 376)	WC-Q4 (*n* = 376)	WC-Q5 (*n* = 376)	*p* for trend
WC (cm)						
Male	64.5–82.7	82.8–87.7	87.8–92.3	92.4–96.9	97.0–130.0	
Female	53.8–74.9	75.0–80.4	80.5–85.1	85.2–91.4	91.5–117.0	
Age (years)	50 ± 13	52 ± 12	53 ± 12	57 ± 11	55 ± 13	< 0.001
BMI (kg/m^2)	21.1 ± 2.1	23.0 ± 2.0	24.5 ± 2.1	25.6 ± 2.0	28.5 ± 3.2	< 0.001
Current smoker (%)	14	16	18	13	20	0.1
HEPA (%)	40	46	48	40	38	0.3
Unmarried (%)	23	14	12	11	22	0.4
Low income (%)	19	18	21	29	30	< 0.001
Low education (%)	14	20	19	33	28	< 0.001
Diabetes (%)	18	28	32	39	50	< 0.001
Hypertension (%)	92	94	96	98	100	< 0.001
CVD (%)	9	9	9	16	13	0.004
eGFR (ml/min per 1.73 m^2)	55 ± 33	55 ± 32	53 ± 30	52 ± 29	50 ± 30	0.01
24-hU protein (mg/day)	436 [123, 1256]	517 [154, 1351]	537 [154, 1550]	583 [211, 1616]	755 [297, 2001]	< 0.001
Hemoglobin (g/dl)	12.6 ± 1.9	12.7 ± 2.0	13.0 ± 2.0	12.9 ± 2.0	13.0 ± 2.1	0.001
Serum albumin, (g/dl)	4.17 ± 0.47	4.18 ± 0.40	4.20 ± 0.44	4.18 ± 0.41	4.17 ± 0.41	0.9
PCS	75 ± 16	75 ± 17	75 ± 17	70 ± 20	68 ± 22	< 0.001
MCS	70 ± 17	70 ± 19	71 ± 17	68 ± 19	68 ± 19	0.03

The values are mean ± SD or median [first and third quartiles]

WC waist circumference, *BMI* Body Mass Index, *HEPA* health-enhancing physical activity, *CVD* cardiovascular disease, *eGFR* estimated glomerular filtration rate, *24-hU* 24-h urine, *PCS* physical component score, *MCS* mental component score

Body fat distribution is an important risk factor for obesity-related disease. Abdominal obesity is linked to increased cardiometabolic disease and mortality [25–27]. Visceral fat (intra-abdominal fat) is a surrogate maker for global fat dysfunction and leads to adiposopathic endocrinopathy. WC measures fat deposits at the waist level, making it a better predictor of visceral fat compared to BMI. Furthermore, recent studies in CKD populations have shown that WC is more closely associated with inflammation and poor outcomes than BMI [28]. In the Reasons for Geographic and Racial Differences in Stroke (REGARDS) study, a prospective cohort of older adults with stages 1–4 CKD showed that higher mortality rates were associated with higher WC after multiple adjustments for covariates including BMI [13]. A separate analysis of the REGARDS study showed that obesity measured by WC was associated with higher ESRD risk even after adjusting for BMI, whereas obesity defined by BMI was not associated with higher ESRD risk after adjusting for WC [14]. Therefore, these studies suggest that abdominal obesity measured by WC is more closely associated with high risk of a poor outcome than obesity defined by BMI in adults with CKD.

In the general population, obesity is associated with impaired HRQOL, and the relationship may differ for physical and mental HRQOL. Specifically, a meta-analysis [15] of the association between obesity and HRQOL in the general adult population assessed by BMI and SF-36 showed that adults with a higher than optimal BMI had a significantly reduced physical HRQOL, and identified corresponding dose–response relationship between BMI and HRQOL. On the other hander, a different pattern was observed with respect to mental HRQOL. Mental HRQOL was increased among overweight adults and was modestly reduced among adults with severe obesity (BMI ≥ 40 kg/m^2) compared to individuals with an optimal BMI. Similarly, a cross-sectional study from China's National Health Service Survey demonstrated an inverse U-shaped association between BMI and overall HRQOL [29]. A recent cross-sectional study of the US population also identified an inverse U-shaped association between BMI and HRQOL and showed that this association was more pronounced in women, older adults, and Hispanics [30]. Indeed, age, sex, ethnicity, and comorbidities can affect the relationship between BMI with percent body fat. In patients with chronic wasting diseases such as cancer, coronary heart disease, and CKD, obesity paradoxically appears to better outcomes compared to optimal BMI [10, 31]. This effect is mostly observed when BMI is used to define obesity. When lean tissue or muscle mass is taken into account, high BMI has no protective effect in patients with chronic wasting disease [32]. The association

Table 3 Linear regression models for PCS and MCS of SF-36 according to BMI and WC

Variable	Univariable		Model 1		Model 2	
	Beta (95% CI)	*p*	Beta (95% CI)	*p*	Beta (95% CI)	*p*
Physical component summary						
BMI (kg/m^2)						
< 18.5	−1.90 (−7.46 to 3.65)	0.5	−1.34 (−6.43 to 3.74)	0.6	−2.83 (−7.95 to 2.28)	0.3
18.5–22.9	Reference		Reference		Reference	
23.0–24.9	0.24 (−1.99 to 2.48)	0.8	0.41 (−1.67 to 2.49)	0.7	−0.21 (−2.34 to 1.92)	0.8
25.0–29.9	−0.43 (−2.50 to 1.65)	0.7	−0.94 (−2.92 to 1.04)	0.4	−0.26 (−2.29 to 1.77)	0.8
≥ 30.0	−4.35 (−8.05 to −0.65)	0.02	−4.33 (−7.81 to −0.84)	0.02	−1.64 (−5.23 to 1.95)	0.4
WC-Q sex-specific						
WC-Q1	−0.56 (−3.15 to 2.03)	0.7	−1.46 (−3.85 to 0.93)	0.2	−1.39 (−3.83 to 1.04)	0.3
WC-Q2	Reference		Reference		Reference	
WC-Q3	−0.68 (−3.26 to 1.89)	0.6	−1.01 (−3.39 to 1.38)	0.4	−1.38 (−3.83 to 1.04)	0.3
WC-Q4	−5.48 (−8.12 to −2.84)	< 0.001	−4.04 (−6.51 to −1.57)	0.001	−2.63 (−5.19 to −0.06)	0.04
WC-Q5	−7.25 (−9.85 to −4.66)	< 0.001	−5.81 (−8.26 to −3.36)	< 0.001	−3.71 (−6.28 to −1.15)	0.005
Mental component summary						
BMI (kg/m^2)						
< 18.5	−2.59 (−8.10 to 2.92)	0.4	−1.87 (−7.21 to 3.48)	0.5	−2.98 (−8.36 to 2.39)	0.3
18.5–22.9	Reference		Reference		Reference	
23.0–24.9	0.79 (−1.42 to 3.00)	0.5	0.99 (−1.19 to 3.17)	0.4	0.14 (−2.11 to 2.38)	0.9
25.0–29.9	0.76 (−1.30 to 2.81)	0.5	0.31 (−1.78 to 2.39)	0.8	0.77 (−1.36 to 2.91)	0.5
≥ 30.0	0.10 (−3.58 to 3.77)	0.9	0.12 (−3.54 to 3.78)	0.9	2.85 (−0.92 to 6.62)	0.1
WC-Q sex-specific						
WC-Q1	0.03 (−2.56 to 2.63)	0.9	−0.37 (−2.89 to 2.16)	0.8	−0.39 (−2.95 to 2.18)	0.8
WC-Q2	Reference		Reference		Reference	
WC-Q3	0.79 (−1.79 to 3.37)	0.6	0.44 (−2.08 to 2.95)	0.7	−0.32 (−2.91 to 2.27)	0.8
WC-Q4	−1.88 (−4.52 to 0.76)	0.2	−1.27 (−3.87 to 1.34)	0.4	−0.30 (−3.01 to 2.41)	0.8
WC-Q5	−2.37 (−4.97 to 0.24)	0.07	−1.49 (−4.08 to 1.09)	0.3	−0.15 (−2.85 to 2.56)	0.9

Model 1 is adjusted for age, sex, diabetes, hypertension, cardiovascular disease, eGFR, hemoglobin, and albumin

Model 2 is adjusted for model 1 variables plus marriage status, education, income, smoking, and health-enhancing physical activity

PCS physical component summary, *BMI* Body Mass Index, *WC-Q* waist circumference quintile

between obesity and HRQOL is uncertain in CKD. Therefore, we evaluated the relationship of obesity with HRQOL in KNOW-CKD study. WC, but not BMI, was associated with physical HRQOL. The associations between WC and physical HRQOL were pronounced in older adults, women, adults with diabetes, cardiovascular disease, or advanced CKD.

The mechanisms linking obesity and HRQOL are not yet completely understand. Obesity is often comorbid with chronic pain and functional locomotor limitations, and these symptoms can affect the poor physical HRQOL. Psychosocial burdens of obesity such as lack of will-power, social isolation, or impaired sexual function can deteriorate mental HRQOL. CKD is a chronic wasting disease and sarcopenia is more severe due to loss of renal function. Low muscle strength and obesity may decrease the physical HRQOL in patients with CKD. Furthermore, sarcopenic obesity, which is prevalent among persons with CKD [33], may contribute to misclassification of BMI-defined obesity, and may be associated with poor physical HRQOL [34]. Present study showed that WC is a better indicator of poor physical HRQOL than BMI in adults with CKD.

There were several limitations of the present study that merit consideration. First, in this cross-sectional study, we were unable to establish causal inferences regarding the relationship between obesity and HRQOL in CKD. The relationship between obesity and HRQOL may be bidirectional. Second, we defined obesity by two anthropometric measurements such as BMI and WC. Dual-energy X-ray absorptiometry (DXA) is a more accurate measures of total body fat percentage. Likewise, magnetic resonance imaging (MRI) or computed tomography (CT) more accurately measures the abdominal fat deposits linked to cardiometabolic disease risk. We did not evaluate body composition by DXA, abdominal MRI, or CT in this study. Third, the study participants belonged to a single ethnic group of Koreans,

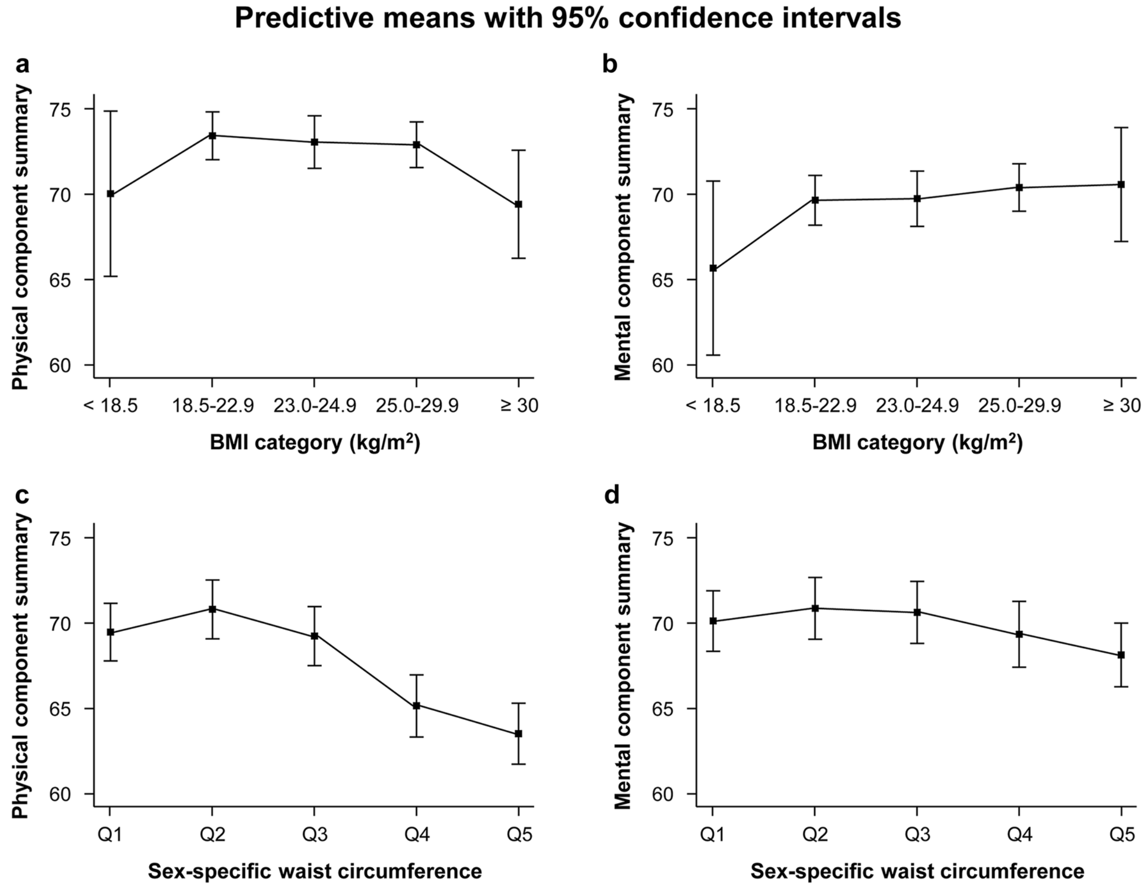
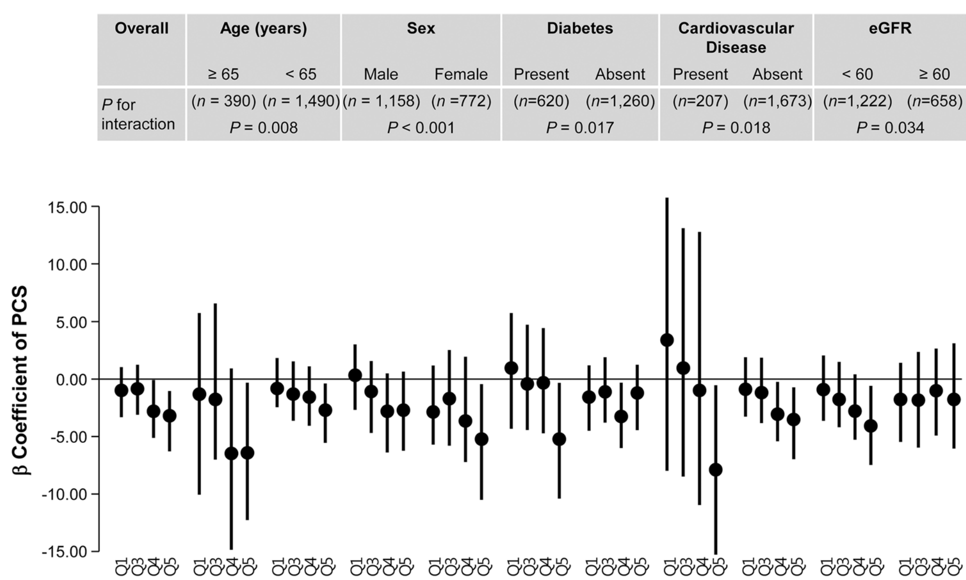


Fig. 1 Relationship of Body Mass Index categories and sex-specific waist circumference quintiles with **a** PCS and **b** MCS predicted by multivariable regression model. Marginal effect was estimated by Stata software adjusted for the predictors in Model 2. An inverse-J shaded association was observe for **c** PCS and **d** WC

Fig. 2 Association between waist circumference and physical component summary (PCS) of SF-36 by subgroups. Plot of PCS beta coefficients by subgroups adjusted for age, sex, marriage, education, economic status, diabetes, hypertension, cardiovascular disease, smoking, health-enhancing physical activity, eGFR, hemoglobin, and albumin



and the proportions of adults who were underweight and obesity class II were small, just 2.4% and 6.1%, respectively. Thus, our findings may not be generalizable to all adults with CKD. The strengths of this study included our analysis of KNOW-CKD study, which has a well-designed protocol and is a nationally representative cohort study. In addition, we used a rigorous protocol to measure demographics, comorbidities, and laboratory data.

Conclusion

WC, but not BMI, is associated with reduced physical HRQOL in adults with non-dialysis-dependent CKD. Our results suggest that WC is a better indicator of poor physical HRQOL compared to BMI in adults with CKD. The association between WC and physical HRQOL is modified by age, sex, comorbidities, and eGFR.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in the studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study

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