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Comparison of different measures of obesity in their association with health-related quality of life in older adults – results from the KORA-Age study

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Abstract

Objective: As ageing is associated with changes in body composition, BMI may not be the appropriate obesity measure for older adults. To date, little is known about associations between obesity measures and health-related quality of life (HRQoL). Thus, we aimed to compare different obesity measures in their association with HRQoL and self-rated physical constitution (SRPC) in older adults.

Design: Seven obesity measures (BMI, waist circumference (WC), waist-to-hip ratio, waist-to-height ratio, fat mass percentage based on bioelectrical impedance analysis, hypertriglyceridaemic waist (HTGW) and sarcopenic obesity) were assessed at baseline in 2009. HRQoL, using the EQ-5D questionnaire, and SRPC, using one single question, were collected at baseline and at the 3-year follow-up in 2012. Linear and logistic regression analyses were used to examine the associations between the obesity measures and both outcomes. Model comparisons were conducted by area under the receiver-operating characteristic curve, R^2, Akaike and Schwarz Bayesian information criteria.

Setting: KORA-Age study in Southern Germany (2009–2012).

Subjects: Older adults (n 883; aged ≥65 years).

Results: Nearly all obesity measures were significantly inversely associated with both outcomes in cross-sectional analyses. Concerning HRQoL, the WC model explained most of the variance and had the best model adaption, followed by the BMI model. Regarding SRPC, the HTGW and BMI models were best as rated by model quality criteria, followed closely by the WC model. Longitudinal analyses showed no significant associations.

Conclusions: These results suggest that, with regard to HRQoL/SRPC, simple anthropometric measures are sufficient to determine obesity in older adults in medical practice.

Keywords
Obesity
Quality of life
Older adults
KORA-Age

The proportion of overweight and obese individuals in the older population is growing worldwide[1]. Due to demographic changes resulting in a continuous increase in the number of older adults, this topic concerns a permanently growing part of the population[2]. Obesity in older adults is associated with various diseases, such as type 2 diabetes mellitus and CVD, as well as with restriction of physical function and health-related quality of life (HRQoL), and thus is highly problematic for the public health sector[3,4].

Obesity is usually defined by a BMI ≥ 30·0 kg/m^2 in both the younger and the older population. According to this definition, in Germany, 33·1 % of men and 34·8 % of women aged 60–69 years, and 31·3 % of men and 41·6 % of women aged 70–79 years, are obese[5].

For younger adults, BMI is a useful measure of total body fat. However, the ageing process leads to changes in body composition by loss of height and skeletal muscle mass along with a redistribution of body fat towards more visceral fat. Hence, the associations between BMI ≥ 30·0 kg/m^2 and the risk of various health consequences of obesity are attenuated and lose explanatory power[3,4,6–9]. Thus, other measures of obesity may be more appropriate for older adults. Despite existing research

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comparing different measures of obesity with respect to different outcomes in older individuals, it is still unclear which measure and which cut-off point best describe the influence of obesity on health in older adults[3,4].

There are methods to accurately measure body fat, for example MRI, but these are generally expensive and complicated and thus impractical in the general medical practice. Multiple other measures have been proposed to operationalize obesity[3,4,10]. In addition to BMI, the usual measure of obesity, there are other anthropometric methods like waist circumference (WC), waist-to-hip ratio (WHR) and waist-to-height ratio (WHtR), which can be assessed simply and inexpensively. Moreover, there are methods to easily measure body fat, such as bioelectrical impedance analysis (BIA). Furthermore, combined measures such as hypertriglyceridaemic waist (HTGW) and sarcopenic obesity (SO) can be determined, which are extensions to the current definitions of obesity by considering additional aspects. HTGW represents the combination of an increased WC and elevated serum TAG levels. Lemieux *et al.*[11] established this definition in 2000 as a substitute for the metabolic syndrome and Sam *et al.*[12] showed that HTGW is a better measure of visceral fat than WC alone. Thus, the assessment of HTGW allows better differentiation between metabolically healthy and ill obese individuals than WC. For SO, there is no standard definition so far, but it is mostly described by the combination of increased body fat and decreased skeletal muscle mass and/or strength, and thus better reflects the changes in body composition in older adults[13].

Previous studies comparing different measures of obesity in older adults focused mainly on outcomes like mortality, individual diseases and biomarkers[14–21]. Restrictions of HRQoL and physical constitution, which are important for healthy and successful ageing, have rarely been investigated in this context. To date, mainly one or two measures of obesity have been examined simultaneously in their cross-sectional and/or longitudinal association with HRQoL in older adults, and not much is known about the comparison of several measures in older age groups[22–25]. Most studies examined the measures continuously or categorized according to different percentiles to find the best measure *per se*. In practice, however, the determination of obesity is based on established cut-off points. Thus, the aim of the present study was to compare (cross-sectionally and longitudinally) a variety of measures of obesity in relation to HRQoL and self-rated physical constitution (SRPC) in older adults, using established obesity cut-off points.

Participants and methods

Study population

The population-based Cooperative Health Research in the Region of Augsburg (KORA)-Age cohort study is a follow-up of all participants born before 1944 (i.e. ≥65 years at the baseline examination in 2009) who took part in one of the four MONICA/KORA surveys carried out in Southern Germany[26]. The baseline examination included 5991 participants, of whom 4565 returned a postal questionnaire and 4127 took part in a telephone interview. Additionally, a sub-sample of 1079 participants was intensively examined at the study centre. Eight hundred and twenty-two participants were re-examined in 2012. All interviews and examinations were conducted by trained staff[27]. A detailed description of the study population, the assessment and classification of variables, and the statistical analysis can be found in the online supplementary material (section ‘Additional Information on Subjects and Methods’).

Measures of obesity

We compared seven measures of obesity (BMI, WC, WHR, WHtR, fat mass percentage (FMp), HTGW, SO), which were collected at baseline.

Weight was measured with an electronic scale, standing height with a stadiometer. WC was quantified with an inelastic measuring tape at the smallest abdominal girth or, in obese participants, in the middle between the lowest rib and the iliac crest. Hip circumference was measured at the most protruding part of the hips. Fat-free mass was computed by Kyle’s equation[28,29] using body composition parameters assessed by BIA (BIA 2000-S; DATA-INPUT GmbH, Frankfurt, Germany). Fat mass (weight – fat-free mass) and FMp (fat mass/weight) were calculated. TAG levels were determined in non-fasting blood samples (TGL Flex reagent cartridge; Dade Behring, Eschborn, Germany). Mean grip strength from three consecutive measurements was assessed with the JAMAR Dynamometer (Saehan Corp., Masan, Korea).

The measures of obesity were dichotomized at their established, sex-specific if available, obesity cut-off points for the general adult population. Participants were classified as obese at a BMI (weight/height^2) of ≥30·0 kg/m^2, a WC of ≥102/88 cm or a WHR (WC/hip circumference) of ≥1·00/0·85 for men and women, respectively[30], or a WHtR[31,32] (WC/height) of ≥0·6. For consistency and comparability with WC, HTGW was defined as a WC ≥102/88 cm for men and women, respectively, and TAG levels of ≥1·7 mmol/l[33,34]. The following two groups were established: one group with individuals fulfilling both criteria and another group with individuals fulfilling only one or none of the two criteria. Likewise, SO was defined as a combination of a FMp higher than the sex-specific 60th percentile of the study population[35] (≥30·41/41·10 % for men and women, respectively) and decreased handgrip strength (<30/20 kg for men and women, respectively)[36]. As muscle quality is more important than muscle mass *per se*, handgrip strength was preferred to muscle mass[37]. However, muscle mass was included in the definition of SO in a sensitivity analysis (see online supplementary material, section 'Sensitivity Analysis for the Definition of SO'). For reasons of consistency and comparability with SO, FMp was also dichotomized at the sex-specific 60th percentile of the study population (Table 2).

Outcomes

HRQoL and SRPC were inquired in the postal questionnaires at baseline and at the 3-year follow-up (2·9 (SD 0·1) years). HRQoL, the primary outcome, was assessed with the Euroqol (EQ)-5D. This generic measure includes five questions concerning mobility, self-care, usual activities, pain/physical discomfort and anxiety/depression[38]. The continuous EQ-5D index (range: –0·205 to 0·999; 0·999 = no restriction) was calculated using the scoring algorithm for the German population derived by Greiner *et al.*[39].

SRPC, the secondary outcome, was assessed with the question 'How would you rate your present physical constitution?', with four response options ('excellent', 'good', 'fair' and 'poor'). The answers were dichotomized as 'excellent/good' and 'fair/poor' to obtain adequate group sizes.

Assessment of covariables

Covariables, all collected at baseline, were selected based on theoretical considerations and existing literature investigating this topic[22,23,25]. Age and physical activity were considered continuously, all other variables were grouped into categories.

Sociodemographic variables included age (years), sex (reference = male), marital status (unmarried (= reference), married, divorced, widowed) and years of education (<10 (= reference), 10–<12, ≥12). Lifestyle variables included physical activity (assessed by the Physical Activity Scale for the Elderly (PASE); score range: 0–365)[40], smoking status (never (= reference), former, current) and alcohol consumption (no (0 g/d; = reference), moderate (>0–<40/20 g/d for men and women, respectively) and high (≥40/20 g/d for men and women, respectively))[41]. Additionally, the presence (yes, no (= reference)) of the following diseases was assessed: hip/femoral neck fracture in the last 5 years[42], hypertension, diabetes mellitus, lung disease, joint disease, gastrointestinal disease, heart problems, heart attack in the last 3 years, kidney disease, liver disease, cancer occurring in the last 3 years, neurological disease, stroke in the last 3 years and eye disease.

Statistical analysis

As all measures of obesity showed an almost linear relationship with continuous baseline HRQoL and its change over 3 years of follow-up (HRQoL at follow-up – HRQoL at baseline), linear regression was used for HRQoL. Associations with dichotomized baseline SRPC (reference = excellent/good) and its deterioration/improvement over time (reference = no change) were examined with binary logistic regression. Prior to analyses, participants who reported a weight change of >5 kg in the last 6 months (*n* 65) and those with missing values in at least one of the seven different measures of obesity (additional: *n* 76), both outcomes (additional: *n* 21 (cross-sectional) /*n* 233 (longitudinal)) or the covariables (additional: *n* 34 (cross-sectional)/*n* 16 (longitudinal)) were excluded. Thus, the sample size varied between the five analyses (*n* 883 (baseline HRQoL/baseline SRPC), *n* 689 (change in HRQoL), *n* 622/605 (deterioration of SRPC/improvement of SRPC); see online supplementary material, Supplemental Fig. 1). Within each analysis and for each of the seven measures of obesity, three models with different sets of covariables were conducted, respectively: model 1 was adjusted for age and sex; model 2 was additionally adjusted for further sociodemographic and lifestyle variables; model 3 was additionally adjusted for the presence of diseases. In each case, we compared the respective seven models, which differed only in the measure of obesity used, but included the same sample size and covariables, to assess the measure of obesity showing the strongest association with each of the five outcomes. Only measures which were significantly associated with the respective outcome were further examined (linear regression: β estimate (F test); logistic regression: OR and 95 % CI (Wald test)). R^2, Akaike information criterion (AIC) and Schwarz Bayesian information criterion (BIC) were used to find the model with the best goodness-of-fit and thus the best measure of obesity for the prediction of the outcomes. The larger the R^2 and the smaller the AIC and BIC, the better the model adaptation. Additionally, the (changes of the) areas under the receiver-operating characteristic curves ((Δ)AUC) were compared in logistic regression models (see online supplementary material, Supplemental Fig. 2). The AUC ranges between 0·5 (poor discrimination) and 1·0 (optimal discrimination). ΔAUC was applied to verify if the addition of each measure of obesity improved the model. We calculated the ΔAUC by the difference between the AUC of the model with the respective obesity measure and the model without the respective obesity measure containing only the covariables. The ΔAUC were compared between the models with different obesity measures and the higher the AUC/ΔAUC, the better the model.

All analyses were repeated using continuous versions of the investigated measures of obesity to demonstrate which measure *per se* shows the strongest association with the outcomes, independent of the recommended cut-off points (see online supplementary material, section 'Sensitivity Analysis with Continuous Versions of the Investigated Measures of Obesity'). To provide comparable β estimates, all measures of obesity were Z-transformed ($Z = (X - \text{mean})/\text{SD}$) prior to analysis. P values of <0·05 were considered statistically significant in all analyses, which were performed using the statistical software package SAS version 9.3.

Results

Table 1 displays the characteristics of the study population of the cross-sectional analyses in total and stratified by sex. Participants were 65–93 years old and the proportion of men and women was approximately equal. Men were significantly more physically active ($P=0.02$), better educated, and consumed more cigarettes and alcohol (all $P<0.0001$). Marital status ($P<0.0001$) as well as the prevalence of gastrointestinal diseases ($P=0.05$), eye diseases ($P=0.0001$) and cancer ($P=0.01$) also differed significantly by sex. HRQoL at baseline was high (median = 0·887) and 28·2 % of the participants classified their baseline SRPC as fair/poor. Over 3 years of follow-up, the median change of 0 showed no change in HRQoL, but the 25th percentile of –0·112 indicated a slight decrease. Of the study population, 12·2 % reported a deterioration and 9·7 % an improvement of SRPC.

Table 2 displays the prevalence of obesity according to the different obesity measures in total and stratified by HRQoL (no, any restriction) and SRPC (excellent/good, fair/poor). In total, the prevalence of obesity varied considerably between 15·2 % as defined by SO and 60·5 % as defined by WC. Regardless of the measure of obesity, the proportion of obese participants was significantly higher in the group with restrictions or fair/poor health as compared with the group without restrictions or excellent/good health ($P=0.01$ to $P<0.0001$).

The results of the linear regression and the model quality criteria of the cross-sectional analysis of HRQoL are shown in Table 3. Obesity, regardless of the measure, was significantly associated with worse HRQoL ($P=0.01$ to $P<0.0001$) after adjustment for different sets of covariables. For the fully adjusted model 3, the lowest AIC and BIC were found for the WC model. Regarding R^2, this model explained 17·04 % of the variance of HRQoL and thus more than the BMI model ($R^2=16.29\,\%$) with the second best model adaption. The results of the binary logistic regression and the model quality criteria of the cross-sectional analysis of SRPC are presented in Table 4. Again, only the results from the fully adjusted model 3 are reported here. Obesity, defined by all measures except SO, was significantly associated with higher odds for fair/poor SRPC ($P=0.01$ to $P<0.0001$), with obesity defined by BMI and HTGW nearly doubling the odds (OR = 1·98). The BMI and HTGW models showed the highest R^2 and (Δ)AUC as well as the lowest AIC and BIC. The WC model had the third best model adaption. The results of the sensitivity analysis using continuous measures of obesity are presented in Tables 5 and 6. Except SO, all measures of obesity were significantly associated with both outcomes in the fully adjusted model 3 ($P=0.01$ to $P<0.0001$). Regarding HRQoL, the BMI model showed the best model quality criteria R^2, AIC and BIC, followed by the models with WHtR and WC. For every SD increase of Z-standardized BMI, HRQoL decreased by $\beta=-0.033$. Regarding SRPC, the WHtR model had the best goodness-of-fit assessed by (Δ)AUC, R^2, AIC and BIC, followed by the models with WC and BMI. In the longitudinal analyses (see online supplementary material, Supplemental Tables 1–6), neither the dichotomized nor the continuous measures of obesity were significantly associated with change in HRQoL and SRPC over time. Cross-sectionally and longitudinally, SO as defined by extended definitions was not associated with either outcome (Supplemental Tables 7 and 8).

Discussion

In this population of older adults, nearly all measures of obesity were significantly inversely associated with baseline HRQoL/SRPC. For the categorized measures, the strongest inverse association with HRQoL as well as the best model adaption was found for WC. Thus, a WC of ≥102 cm for men and of ≥88 cm for women had a slightly better predictive power for HRQoL than a BMI of $\geq 30.0\,kg/m^2$. However, BMI and HTGW had the best predictive power for SRPC, with WC being almost equally as good. In the longitudinal analysis, none of the obesity measures was significantly associated with change in HRQoL or SRPC over the follow-up period.

These results suggest that with regard to quality of life, simple anthropometric measures are preferable to more complex measures or BIA to determine obesity in older adults. As, in the sensitivity analysis, the continuous BMI remained the best measure *per se* in connection with HRQoL, the cut-off point of $\geq 30.0\,kg/m^2$ may not be ideal for older adults. Similarly, WHtR was the best continuous measure concerning SRPC, but performed poorly in the comparison of dichotomized measures. This indicates that the cut-off point of ≥0·6 is not optimal for the older population. Since WC, dichotomized or continuous, was either the best or one of the best measures and easier to assess than HTGW, measuring WC may be a valuable addition to BMI with regard to quality of life.

Overall, the present study confirms the inverse relationship between obesity and HRQoL described in the literature[22–25,43,44]. Our results are in line with the only study comparing several measures of obesity with regard to HRQoL in older age groups. Tan *et al.*[23] used anthropometric measures (BMI, WC, waist residuals (regression of WC *v.* BMI), WHR, WHtR, height) in quintiles. HRQoL was assessed with the Short-Form 36 questionnaire version 2 and was separately analysed for a physical and a mental component. By contrast, the EQ-5D, used in the present study, considers the two parts together, but is dominated by the physical component. Tan *et al.* examined cross-sectional associations in a slightly younger (mean age: 50·6 (SD 12·2)/49·3 (SD 11·6) years for men/women, respectively) multi-ethnic Asian population (n 4981), stratified by sex. They studied the same model

Table 1 Characteristics of the study population used in the cross-sectional analyses

	Total (*n* 883)		Sex				
			Men (*n* 447)		Women (*n* 436)		
	Median or *n*	P25, P75 or %	Median or *n*	P25, P75 or %	Median or *n*	P25, P75 or %	*P* value*
Sociodemographic variables							
Age (years)†	76·0	70·0, 80·0	76·0	70·0, 80·0	75·0	70·0, 80·0	0·89
Marital status‡							
Unmarried	36	4·1	14	3·1	22	5·0	**<0·0001**
Married	572	64·8	360	80·5	212	48·6	
Divorced	42	4·8	18	4·0	24	5·5	
Widowed	233	26·4	55	12·3	178	40·8	
Years of education‡							
<10	169	19·1	34	7·6	135	31·0	**<0·0001**
10–<12	472	53·5	233	52·1	239	54·8	
≥12	242	27·4	180	40·3	62	14·2	
Lifestyle variables							
PASE score†	117·0	81·0, 154·0	121·0	82·0, 162·0	115·0	80·0, 146·0	**0·02**
Smoking status‡							
Non-smoker	509	57·6	176	39·4	333	76·4	**<0·0001**
Ex-smoker	334	37·8	247	55·3	87	20·0	
Smoker	40	4·5	24	5·4	16	3·7	
Alcohol consumption‡							
0 g/d	303	34·3	97	21·7	206	47·2	**<0·0001**
0–<40/20 g/d (M/F)	462	52·3	280	62·6	182	41·7	
≥40/20 g/d (M/F)	118	13·4	70	15·7	48	11·0	
Presence of diseases‡							
Hip/femoral neck fracture in the last 5 years	14	1·6	4	0·9	10	2·3	0·10
Hypertension	668	75·7	339	75·8	329	75·5	0·90
Diabetes mellitus	151	17·1	79	17·7	72	16·5	0·65
Lung disease	80	9·1	42	9·4	38	8·7	0·72
Joint disease	150	17·0	73	16·3	77	17·7	0·60
Gastrointestinal disease	71	8·0	28	6·3	43	9·9	**0·05**
Heart disease	239	27·1	123	27·5	116	26·6	0·76
Heart attack in the last 3 years	9	1·0	6	1·3	3	0·7	0·51
Kidney disease	38	4·3	19	4·3	19	4·4	0·94
Liver disease	23	2·6	12	2·7	11	2·5	0·88
Cancer in the last 3 years	32	3·6	24	5·4	8	1·8	**0·01**
Neurological disease	27	3·1	11	2·5	16	3·7	0·30
Stroke in the last 3 years	23	2·6	9	2·0	14	3·2	0·26
Eye disease	390	44·2	169	37·8	221	50·7	**0·0001**
Outcomes at baseline							
HRQoL†	0·887	0·788, 0·999	0·887	0·788, 0·999	0·887	0·788, 0·999	**0·02**
Fair/poor SRPC‡	249	28·2	114	25·5	135	31·0	0·07
Outcomes at follow-up							
HRQoL†	0·887	0·788, 0·900	0·887	0·788, 0·999	0·788	0·788, 0·887	**0·05**
Fair/poor SRPC‡	188	27·3	83	23·7	105	31·0	**0·03**
Change of outcomes between baseline and follow-up							
HRQoL†	0	−0·112, 0	0	−0·112, 0	0	−0·099, 0	0·94
No change in SRPC‡	538	78·1	279	79·7	259	76·4	0·51
Deterioration of SRPC‡	84	12·2	38	10·9	46	13·6	
Improvement of SRPC‡	67	9·7	33	9·4	34	10·0	

P25, 25th percentile; P75, 75th percentile; PASE, Physical Activity Scale for the Elderly (score range: 0–365); M, male; F, female; HRQoL, health-related quality of life (range: −0·205–0·999); SRPC, self-rated physical constitution.
Data of the KORA-Age study conducted in Southern Germany between 2009 and 2012. Outcomes at follow-up and change of outcomes between baseline and follow-up: *n* 689 (men, *n* 350; women, *n* 339).
Significant results ($P<0·05$) are highlighted.
*Mann–Whitney–Wilcoxon *U* test for continuous variables; Pearson's χ^2 test for categorical variables (Fisher's exact test if expected frequencies were too low).
†Data are presented as median (P25, P75).
‡Data are presented as *n* and column %.

quality criteria R^2, AIC and BIC, which, as in our study, were similar for all measures of obesity. They concluded that BMI, WHtR and WC were the best measures for women in the physical component. For men, there were no significant results. We did not conduct sex-stratified analyses, as no sex-specific differences were found (see online supplementary material, section 'Analyses to Test for Sex-specific Differences' and Supplemental Tables 9 and 10). Despite this consistency, the body composition between Asians and Europeans is known to differ greatly[45]. Therefore, further studies in Europeans are needed to confirm our results. Our results are also consistent with studies using

Table 2 Prevalence of obesity using different obesity measures in the study population used in the cross-sectional analyses

				HRQoL*					SRPC				
		Total (*n* 883)		Any restriction (*n* 589)		No restriction (*n* 294)			Fair/poor (*n* 249)		Excellent/ good (*n* 634)		
Measure of obesity	Cut-off point	*n*	%	*n*	%	*n*	%	*P* value†	*n*	%	*n*	%	*P* value†
BMI	≥30·0 kg/m^2	276	31·3	208	35·3	68	23·1	**0·0002**	104	41·8	172	27·1	**<0·0001**
WC	≥102/88 cm (M/F)	534	60·5	389	66·0	145	49·3	**<0·0001**	177	71·1	357	56·3	**<0·0001**
WHR	≥1·00/0·85 (M/F)	385	43·6	276	46·9	109	37·1	**0·01**	135	54·2	250	39·4	**<0·0001**
WHtR	≥0·6	427	48·4	307	52·1	120	40·8	**0·002**	146	58·6	281	44·3	**0·0001**
FMp	≥30·41/41·10 % (M/F)	351	39·8	262	44·5	89	30·3	**<0·0001**	122	49·0	229	36·1	**0·0004**
HTGW	WC ≥ 102/88 cm (M/F) and TAG ≥ 1·7 mmol/l	244	27·6	185	31·4	59	20·1	**0·0004**	95	38·2	149	23·5	**<0·0001**
SO	FMp ≥ 30·41/41·10 % (M/F) and handgrip strength <30/20 kg (M/F)	134	15·2	106	18·0	28	9·5	**0·001**	54	21·7	80	12·6	**0·001**

HRQoL, health-related quality of life; SRPC, self-rated physical constitution; WC, waist circumference; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio; FMp, fat mass percentage; HTGW, hypertriglyceridaemic waist; SO, sarcopenic obesity; M, male; F, female.
Data of the KORA-Age study conducted in Southern Germany between 2009 and 2012.
Significant results ($P < 0·05$) are highlighted.
*Restriction in HRQoL (EQ-5D index <0·999) *v.* no restriction (EQ-5D index = 0·999).
†Pearson's χ^2 test for categorical variables (Fisher's exact test if expected frequencies were too low).

Table 3 Comparison of cross-sectional associations between the categorized measures of obesity and HRQoL

Measure of obesity	*β* estimate	*F* test	*P* value	R^2	AIC	BIC
Model 1 (*n* 883)						
BMI	−0·049	17·22	**<0·0001**	0·0609	−3205	−3186
WC	−0·058	27·05	**<0·0001**	0·0711	−3215	−3196
WHR	−0·032	7·65	**0·01**	0·0508	−3196	−3176
WHtR	−0·044	15·95	**<0·0001**	0·0596	−3204	−3185
FMp	−0·044	15·25	**0·0001**	0·0588	−3203	−3184
HTGW	−0·049	15·83	**<0·0001**	0·0594	−3204	−3185
SO	−0·065	17·29	**<0·0001**	0·0610	−3205	−3186
Model 2 (*n* 883)						
BMI	−0·040	11·24	**0·001**	0·1049	−3227	−3160
WC	−0·050	19·99	**<0·0001**	0·1137	−3236	−3169
WHR	−0·025	4·95	**0·03**	0·0984	−3221	−3154
WHtR	−0·032	8·03	**0·005**	0·1016	−3224	−3157
FMp	−0·035	9·71	**0·002**	0·1033	−3226	−3159
HTGW	−0·040	10·96	**0·001**	0·1046	−3227	−3160
SO	−0·055	12·50	**0·0004**	0·1061	−3229	−3162
Model 3 (*n* 883)						
BMI	−0·042	12·43	**0·0004**	0·1629	−3259	−3125
WC	−0·050	20·34	**<0·0001**	0·1704	−3267	−3133
WHR	−0·024	4·27	**0·04**	0·1549	−3250	−3116
WHtR	−0·029	6·81	**0·01**	0·1574	−3253	−3119
FMp	−0·029	6·78	**0·01**	0·1574	−3253	−3119
HTGW	−0·040	10·83	**0·001**	0·1613	−3257	−3123
SO	−0·044	8·17	**0·004**	0·1587	−3254	−3120

HRQoL, health-related quality of life; AIC, Akaike information criterion; BIC, Schwarz Bayesian information criterion; WC, waist circumference; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio; FMp, fat mass percentage; HTGW, hypertriglyceridaemic waist; SO, sarcopenic obesity; PASE, Physical Activity Scale for the Elderly; M, male; F, female.
Data of the KORA-Age study conducted in Southern Germany between 2009 and 2012.
Linear regression models. Model 1 adjusted for age and sex; model 2 additionally adjusted for further sociodemographic (marital status, years of education) and lifestyle (PASE score, smoking status, alcohol consumption) variables; model 3 additionally adjusted for the presence of diseases (hip/femoral neck fracture in the last 5 years, hypertension, diabetes mellitus, lung disease, joint disease, gastrointestinal disease, heart disease, heart attack in the last 3 years, kidney disease, liver disease, cancer occurring in the last 3 years, neurological disease, stroke in the last 3 years, eye disease).
Results are shown for the following obesity categories: BMI ≥ 30·0 kg/m^2; WC ≥ 102/88 cm (M/F); WHR ≥ 1·00/0·85 (M/F); WHtR ≥ 0·6; FMp ≥ 30·41/41·10 % (M/F); HTGW: WC ≥ 102/88 cm (M/F) and TAG ≥ 1·7 mmol/l; SO: FMp ≥ 30·41/41·10 % (M/F) and handgrip strength <30/20 kg (M/F).
Significant results ($P<0·05$) are highlighted.

disability as an outcome, which is important for successful ageing as well. Simple anthropometric measures like BMI and WC showed the strongest associations and complex measures like SO were only rarely associated with disability[46–50].

One strength of our study is the investigation of a population-based sample. Our results are thus generalizable to older adults in Germany. Further, in contrast to other studies investigating this topic, a greater variety of

Table 4 Comparison of cross-sectional associations between the categorized measures of obesity and SRPC

Measure of obesity	*β* estimate	*P* value	OR	95 % CI	AUC	ΔAUC	R^2	AIC	BIC
Model 1 (*n* 883)									
BMI	0·679	**<0·0001**	1·97	1·45, 2·69	0·6310	0·0348	0·0400	1022·39	1041·53
WC	0·638	**<0·0001**	1·89	1·37, 2·61	0·6214	0·0252	0·0376	1024·63	1043·77
WHR	0·546	**0·001**	1·73	1·27, 2·35	0·6155	0·0193	0·0334	1028·46	1047·60
WHtR	0·557	**0·0003**	1·75	1·29, 2·36	0·6176	0·0214	0·0346	1027·36	1046·49
FMp	0·513	**0·001**	1·67	1·24, 2·25	0·6187	0·0225	0·0325	1029·30	1048·44
HTGW	0·720	**<0·0001**	2·06	1·49, 2·83	0·6303	0·0341	0·0412	1021·30	1040·43
SO	0·488	**0·02**	1·63	1·10, 2·41	0·6104	0·0142	0·0264	1034·80	1053·93
Model 2 (*n* 883)									
BMI	0·594	**0·0004**	1·81	1·31, 2·51	0·6964	0·0200	0·0910	994·25	1061·21
WC	0·562	**0·001**	1·76	1·26, 2·45	0·6879	0·0115	0·0896	995·56	1062·53
WHR	0·523	**0·002**	1·69	1·22, 2·33	0·6863	0·0099	0·0885	996·66	1063·63
WHtR	0·411	**0·01**	1·51	1·10, 2·08	0·6848	0·0084	0·0846	1000·38	1067·35
FMp	0·439	**0·01**	1·55	1·13, 2·12	0·6899	0·0135	0·0857	999·31	1066·28
HTGW	0·647	**0·0001**	1·91	1·37, 2·66	0·6922	0·0158	0·0929	992·41	1059·38
SO	0·393	0·06	1·48	0·98, 2·24	0·6817	0·0053	0·0815	1003·37	1070·34
Model 3 (*n* 883)									
BMI	0·681	**0·0002**	1·98	1·39, 2·81	0·7468	0·0129	0·1565	956·19	1090·12
WC	0·563	**0·002**	1·76	1·23, 2·51	0·7417	0·0078	0·1522	960·72	1094·65
WHR	0·475	**0·01**	1·61	1·14, 2·27	0·7395	0·0056	0·1498	963·18	1097·11
WHtR	0·362	**0·04**	1·44	1·02, 2·02	0·7379	0·0040	0·1469	966·16	1100·09
FMp	0·395	**0·02**	1·48	1·06, 2·08	0·7382	0·0043	0·1478	965·19	1099·13
HTGW	0·685	**0·0001**	1·98	1·39, 2·82	0·7436	0·0097	0·1565	956·15	1090·09
SO	0·292	0·19	1·34	0·87, 2·07	0·7341	0·0002	0·1444	968·81	1102·74

SRPC, self-rated physical constitution; AUC, area under the receiver-operating characteristic curve; Δ, change; AIC, Akaike information criterion; BIC, Schwarz Bayesian information criterion; WC, waist circumference; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio; FMp, fat mass percentage; HTGW, hypertriglyceridaemic waist; SO, sarcopenic obesity; PASE, Physical Activity Scale for the Elderly; M, male; F, female.
Data of the KORA-Age study conducted in Southern Germany between 2009 and 2012.
Logistic regression models: reference category = excellent/good SRPC. Model 1 adjusted for age and sex; model 2 additionally adjusted for further sociodemographic (marital status, years of education) and lifestyle (PASE score, smoking status, alcohol consumption) variables; model 3 additionally adjusted for the presence of diseases (hip/femoral neck fracture in the last 5 years, hypertension, diabetes mellitus, lung disease, joint disease, gastrointestinal disease, heart disease, heart attack in the last 3 years, kidney disease, liver disease, cancer occurring in the last 3 years, neurological disease, stroke in the last 3 years, eye disease).
Results are shown for the following obesity categories: BMI ≥ 30·0 kg/m^2; WC ≥ 102/88 cm (M/F); WHR ≥ 1·00/0·85 (M/F); WHtR ≥ 0·6; FMp ≥ 30·41/41·10 % (M/F); HTGW: WC ≥ 102/88 cm (M/F) and TAG ≥ 1·7 mmol/l; SO: FMp ≥ 30·41/41·10 % (M/F) and handgrip strength <30/20 kg (M/F).
Significant results ($P < 0·05$) are highlighted.

Table 5 Comparison of cross-sectional associations between the continuous measures of obesity and HRQoL

Measure of obesity	β estimate	F test	P value	R^2	AIC	BIC
Model 1 (n 883)						
BMI	−0·036	45·85	**<0·0001**	0·0900	−3233	−3214
WC	−0·037	37·29	**<0·0001**	0·0815	−3225	−3205
WHR	−0·025	11·00	**0·001**	0·0543	−3199	−3180
WHtR	−0·035	40·93	**<0·0001**	0·0851	−3228	−3209
FMp	−0·043	27·20	**<0·0001**	0·0712	−3215	−3196
HTGW	−0·015	7·10	**0·01**	0·0502	−3195	−3176
SO	−0·015	7·21	**0·01**	0·0503	−3195	−3176
Model 2 (n 883)						
BMI	−0·032	33·27	**<0·0001**	0·1267	−3249	−3182
WC	−0·030	24·24	**<0·0001**	0·1179	−3240	−3173
WHR	−0·017	5·17	**0·02**	0·0987	−3221	−3154
WHtR	−0·029	26·63	**<0·0001**	0·1203	−3243	−3176
FMp	−0·035	17·68	**<0·0001**	0·1114	−3234	−3167
HTGW	−0·014	6·31	**0·01**	0·0998	−3222	−3155
SO	−0·012	4·82	**0·03**	0·0983	−3221	−3154
Model 3 (n 883)						
BMI	−0·033	35·61	**<0·0001**	0·1846	−3282	−3148
WC	−0·031	24·25	**<0·0001**	0·1741	−3270	−3137
WHR	−0·017	4·92	**0·03**	0·1555	−3251	−3117
WHtR	−0·030	27·10	**<0·0001**	0·1768	−3273	−3139
FMp	−0·035	17·32	**<0·0001**	0·1675	−3263	−3130
HTGW	−0·013	5·50	**0·02**	0·1561	−3251	−3117
SO	−0·009	2·69	0·10	0·1533	−3249	−3115

HRQoL, health-related quality of life; AIC, Akaike information criterion; BIC, Schwarz Bayesian information criterion; WC, waist circumference; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio; FMp, fat mass percentage; HTGW, hypertriglyceridaemic waist; SO, sarcopenic obesity; PASE, Physical Activity Scale for the Elderly; M, male; F, female.
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Linear regression models. Model 1 adjusted for age and sex; model 2 additionally adjusted for further sociodemographic (marital status, years of education) and lifestyle (PASE score, smoking status, alcohol consumption) variables; model 3 additionally adjusted for the presence of diseases (hip/femoral neck fracture in the last 5 years, hypertension, diabetes mellitus, lung disease, joint disease, gastrointestinal disease, heart disease, heart attack in the last 3 years, kidney disease, liver disease, cancer occurring in the last 3 years, neurological disease, stroke in the last 3 years, eye disease).
Results are shown for 1 SD increase in measures of obesity, as they were Z-standardized for direct comparability.
Significant results (P<0·05) are highlighted.

measures of obesity (especially by BIA) was available, collected by trained staff using standardized assessment methods. As the outcomes were measured at two points in time, we were able to examine the longitudinal association between obesity at baseline and change in HRQoL/SRPC over the follow-up period. The longitudinal analysis was, however, limited by a short follow-up period, in which HRQoL/SRPC changed only little, as well as by a smaller sample size, compared with other studies in this context. Thus, our longitudinal analysis lacked statistical power, which, together with a possibly weak effect of obesity on future HRQoL/SRPC, might explain the non-significant results. Although the present study is the first comparing various measures of obesity in their longitudinal association with HRQoL/SRPC in older adults, our inability to draw meaningful conclusions on which obesity measure best predicted deterioration of HRQoL or SRPC limits the impact of our study. Further limitations are inaccuracies in the determination of fat and muscle mass by BIA with the equations of Kyle *et al.*[28,29] and Janssen *et al.*[51], even though both were validated in older adults. Outcomes and covariables were assessed by self-report and thus misreporting cannot be excluded. But, since all seven models included the same population sample, respectively, these errors had no effect with regard to the comparison of the obesity measures. The large number of covariables in model 3 could have led to over-adjustment. However, all three models showed a similar ranking of measures of obesity.

Conclusion

In conclusion, using established cut-off points of obesity, WC showed the strongest association with HRQoL as well as the best model adaption among the compared measures of obesity. Thus, in older adults, both in health checks and for research concerning HRQoL, WC should be measured in addition to BMI. As WHtR and BMI were appropriate continuous measures, but were less efficient when categorized, future research should focus on special obesity cut-off points for older adults. Our results suggest that the assessment of simple anthropometric measures is sufficient to determine obesity in older adults in medical practice, as more complex measurement techniques such as BIA do not provide additional information with regard to HRQoL.

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Table 6 Comparison of cross-sectional associations between the continuous measures of obesity and SRPC

Measure of obesity	β estimate	*P* value	OR	95 % CI	AUC	ΔAUC	R^2	AIC	BIC
Model 1 (*n* 883)									
BMI	0·411	**<0·0001**	1·51	1·30, 1·75	0·6445	0·0483	0·0525	1010·85	1029·99
WC	0·505	**<0·0001**	1·66	1·39, 1·97	0·6537	0·0575	0·0578	1005·88	1025·02
WHR	0·377	**0·001**	1·46	1·18, 1·80	0·6179	0·0217	0·0340	1027·93	1047·07
WHtR	0·469	**<0·0001**	1·60	1·37, 1·87	0·6530	0·0568	0·0598	1004·04	1023·17
FMp	0·561	**<0·0001**	1·75	1·38, 2·23	0·6407	0·0445	0·0442	1018·55	1037·69
HTGW	0·381	**0·001**	1·46	1·18, 1·82	0·6281	0·0319	0·0340	1027·94	1047·07
SO	0·076	0·30	1·08	0·93, 1·25	0·5986	0·0024	0·0213	1039·50	1058·63
Model 2 (*n* 883)									
BMI	0·345	**<0·0001**	1·41	1·21, 1·65	0·7029	0·0265	0·0975	987·89	1054·86
WC	0·435	**<0·0001**	1·55	1·29, 1·85	0·7073	0·0309	0·1018	983·70	1050·67
WHR	0·302	**0·01**	1·35	1·09, 1·69	0·6855	0·0091	0·0856	999·42	1066·39
WHtR	0·401	**<0·0001**	1·49	1·27, 1·76	0·7076	0·0312	0·1022	983·29	1050·26
FMp	0·482	**0·0002**	1·62	1·26, 2·09	0·6986	0·0222	0·0930	992·27	1059·24
HTGW	0·332	**0·004**	1·39	1·11, 1·74	0·6903	0·0139	0·0877	997·38	1064·34
SO	0·049	0·53	1·05	0·90, 1·22	0·6772	0·0008	0·0784	1006·40	1073·37
Model 3 (*n* 883)									
BMI	0·385	**<0·0001**	1·47	1·24, 1·75	0·7507	0·0168	0·1620	950·35	1084·29
WC	0·445	**<0·0001**	1·56	1·28, 1·90	0·7503	0·0164	0·1626	949·77	1083·70
WHR	0·247	**0·04**	1·28	1·01, 1·62	0·7375	0·0036	0·1469	966·18	1100·12
WHtR	0·413	**<0·0001**	1·51	1·26, 1·81	0·7525	0·0186	0·1631	949·21	1083·14
FMp	0·507	**0·0002**	1·66	1·27, 2·17	0·7448	0·0109	0·1566	956·04	1089·97
HTGW	0·357	**0·003**	1·43	1·13, 1·81	0·7436	0·0097	0·1519	960·98	1094·92
SO	0·019	0·82	1·02	0·87, 1·20	0·7337	−0·0002	0·1428	970·45	1104·38

SRPC, self-rated physical constitution; AUC, area under the receiver-operating characteristic curve; Δ, change; AIC, Akaike information criterion; BIC, Schwarz Bayesian information criterion; WC, waist circumference; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio; FMp, fat mass percentage; HTGW, hypertriglyceridaemic waist; SO, sarcopenic obesity; PASE, Physical Activity Scale for the Elderly; M, male; F, female.
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Results are shown for 1 SD increase in measures of obesity, as they were *Z*-standardized for direct comparability.
Significant results ($P<0·05$) are highlighted.

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Supplementary material

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