Body shape index in comparison with other anthropometric measures in prediction of total and cause-specific mortality

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ABSTRACT

Background The association of body mass index (BMI) with mortality remains controversial among the middle-aged and elderly. Moreover, the contribution of other anthropometric measures to predict mortality is unclear.

Methods We assessed the association of BMI, waist circumference (WC), waist-to-height ratio (WHtR), waist-to-hip ratio (WHR) and a body shape index (ABSI=WC/($BMI^{2/3}$×$height^{1/2}$)) with total, cardiovascular and cancer mortality by using Cox proportion hazard models among 2626 men and 3740 women from the prospective population-based Rotterdam Study. Predictive performance was assessed through informativeness, c-statistic, integrated discrimination improvement (IDI), and continuous net reclassification improvement (cNRI).

Results During 22 years of follow-up, 3675 deaths from all-causes, 1195 from cardiovascular disease, and 873 from cancer occurred. In the multivariable model, ABSI showed a stronger association with mortality compared with BMI, WC, WHtR and WHR. HRs and CIs (95% CIs) for total mortality per 1 SD increase in ABSI were 1.15 (1.09 to 1.21) for men and 1.09 (1.04 to 1.14) for women. For cardiovascular and cancer mortality, these HRs (95% CI) were 1.18 (1.08 to 1.29) and 1.10 (0.99 to 1.22) for men, 1.04 (0.96 to 1.12) and 1.18 (1.07 to 1.30) for women, respectively. The models including ABSI did not increase the c-statistics. Among men, in prediction of total mortality the model including ABSI was more informative (χ^2=26.4) and provided improvement in risk stratification (IDI 0.003, 95% CI 0.001 to 0.005; cNRI 0.13, 95% CI 0.06 to 0.21).

Conclusions In our population-based study, among different anthropometric measures, ABSI showed a stronger association with total, cardiovascular and cancer mortality. However, the added predictive value of ABSI in prediction of mortality was limited.

INTRODUCTION

Obesity is increasing globally and the association between body weight, morbidity and mortality has received widespread attention.[1] Among different anthropometric measures, most of the studies have focused on body mass index (BMI) in association with morbidity and mortality.[2 3] While BMI is a widely accepted and an easily applicable measure of obesity, its use has limitations. BMI depends only on height and weight, and does not distinguish between the distribution of adipose tissue and muscle mass.[4] Furthermore, focusing on BMI in relation to mortality has led to contradictory conclusions.[5 6] A number of studies examined waist circumference (WC), waist-to-height ratio (WHtR), and waist-to-hip ratio (WHR) separately in relation to morbidity and mortality.[7–9] While WC is sensitive to height, WHtR is indifferent to body weight and fat distribution.[10] In the measurement of WHR, a disproportionately large hip circumference can hide the status of abdominal obesity.[10]

Recently, a new anthropometric measure, a body shape index (ABSI), has been introduced.[11] ABSI is based on WC, but is independent of height, weight and BMI. Therefore, being independent of BMI, ABSI could shed light on elucidating the predictive ability of abdominal obesity that cannot be attributed to BMI alone. This new measure has been suggested by Krakauer *et al* to predict mortality independently from BMI in the US population,[11] and recently in a European population.[12] However, use of ABSI as a predictor of total and cause-specific mortality has not yet been validated in an elderly population, where the predictive ability of traditional risk factors in prediction declines.[13 14] We, therefore, sought to examine the predictive ability of ABSI in association with total and cause-specific (including cardiovascular disease (CVD) and cancer) mortality in the population-based Rotterdam Study (RS). We also aimed to compare the predictive performance of ABSI in association with total and cause-specific mortality with those from BMI, WC, WHtR and WHR.

METHODS

Study population

The RS is a prospective population-based cohort study in the city of Rotterdam in the Netherlands. The original RS cohort (RS-I) started in 1990 when all inhabitants aged 55 and over residing in the Ommoord district of Rotterdam were invited to participate and 7983 (78.1%) were enrolled. For the present analysis, we excluded all participants without data for weight, height, waist or hip circumference, and those who did not provide informed consent for follow-up data collection. This left a total of 6366 persons (2626 men and 3740 women) eligible for the analysis. A more detailed description of the RS can be found elsewhere.[15]

Assessment of anthropometric measurements

Anthropometrics were measured in the research centre by trained staff. Height and weight were measured with the participants standing without shoes and heavy outer garments. WC was measured at the level midway between the lower rib margin and the iliac crest, with participants in standing position without heavy outer garments and with

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emptied out pockets, breathing out gently. Hip circumference was recorded as the maximum circumference over the buttocks. BMI was calculated as weight divided by height squared (kg/m^2), whereas WHtR and WHR were calculated as WC divided by height, and as WC divided by hip circumference, respectively. ABSI was defined as WC/(BMI$^{2/3}$×height$^{1/2}$) expressing WC and height in metre.[11] Information regarding the measurement of other risk factors is provided as online supplementary material.

Assessment of mortality

Data on total and cause-specific mortality were collected using an automated follow-up system until 1 January 2011. Cardiovascular mortality was defined as mortality as a consequence of coronary heart disease, cerebrovascular disease, or other atherosclerotic disease.[16] Cancer mortality was defined as mortality attributed to malignant neoplasms (International Classification of Diseases, Tenth Revision, (ICD-10): C00–C97). The median follow-up for the analyses was 15.93 years (IQR 8.74–18.01).

Statistical analysis

Correlation between anthropometric variables was evaluated with Pearson correlation analysis. Cox proportional hazards regression models were used to estimate the HRs and 95% CIs for the association between anthropometric measures and mortality, separately for men and women.[17] We initially adjusted the models for age among men and women. For the main analysis, all models were adjusted for traditional risk factors including age, total and high-density lipoprotein (HDL) cholesterol, systolic blood pressure, treatment for hypertension, current smoking, and diabetes mellitus. Adjustments for confounders were performed based on prior knowledge in published literature.[11] We additionally adjusted the models for education, activities of daily living (as a proxy for physical activity), and marital status (living or not living with a partner).

To assess the performance of anthropometric measures in prediction of mortality, we developed several prediction models. Our base model included traditional risk factors. We then developed several extended models by adding each anthropometric measure to the base model (base model+ABSI, base model+BMI, base model+WC, base model+WHR, base model+WHtR) for prediction of different mortality outcomes. First, we computed the informativeness for each model. The informativeness of an anthropometric measure is meant to capture how well it predicts the outcome. Informativeness is calculated as the difference in twice the log-likelihood of a Cox model with and without that anthropometric measure. This difference between these log-likelihoods follows a χ^2-distribution, and the greater the difference, the more 'informative' that anthropometric measure is. We then test whether this difference is statistically significant, which is similar to the likelihood ratio test between the two models.[18] Second, we calculated the c-statistic based on the Cox proportional hazard regression models to assess discrimination.[19] Discrimination is the ability of a prediction model to assign a higher risk to the individuals who will develop an event compared with those who will not develop an event. The c-statistic was calculated independently for the base model and for each extended model. The comparison between c-statistic of the base and each extended model was based on their respective estimates and CIs. Third, to assess the change in the predictive power of the base model in prediction of different mortality outcomes on addition of the anthropometric measures, we calculated the 15-year risk for all-cause and cause-specific mortality for each participant—first based on the base model and then using each extended model. To compare the predicted probabilities from the base model and each extended model, we computed the integrated discrimination improvement (IDI),[20] and the net reclassification improvement (NRI).[21] Since well-established cut-off points for calculation of NRI across different risk categories for mortality are lacking, we calculated the continuous NRI (cNRI) for each participant. The cNRI only takes into account the correct upward and downward reclassifications for individuals with and without an event (ie, mortality) and does not require risk stratification into categories.

To deal with missing values for the covariates, we used multiple imputation (n=5 imputations) with the Expectation Maximization method in SPSS. For the informativeness, c-statistic, IDI and NRI we used single imputed data set. Analyses were conducted by using SPSS software V.20 (IBM SPSS Statistics for Windows, Armonk, New York: IBM Corp) and the R statistical software (http://www.r-project.org), V.3.0.1 and its libraries "survcomp", "nricens", and "Hmisc".

RESULTS

Baseline characteristics

Table 1 presents the baseline characteristics of the study population. Compared with men, women were slightly older, had higher mean values of total and HDL cholesterol, BMI and WHtR; however, the mean values for ABSI, WC and WHR were lower among women. A larger proportion of women were receiving antihypertensive treatment whereas a smaller proportion were current smokers. In our study, ABSI was not significantly correlated with BMI but strongly correlated with WC, WHtR, and WHR. The correlation coefficients of ABSI with BMI, WC, WHtR, and WHR were: 0.002 (p=0.9), 0.600 (p<0.01), 0.600 (p<0.01) and 0.650 (p<0.01) in men and −0.018 (p=0.268), 0.637 (p<0.01), 0.630 (p<0.01) and 0.804 (p<0.01) in women, respectively.

Associations with total mortality

Table 2 shows the association between anthropometric measures and all-cause and cause-specific mortality for men and women in multivariable adjusted models. Per 1 SD increase in ABSI, the

Table 1 Baseline characteristics of the study population (N=6366)

Characteristic	Values* Men (n=2626)	Women (n=3740)
Age (years)	68.2 (8.2)†	69.5 (9.2)
Systolic blood pressure (mm Hg)	139 (21.9)	140 (23)
Treatment for hypertension (N, %)	393 (15)†	734 (20)
Diabetes mellitus (N, %)	262 (10)	385 (10)
Total cholesterol (mg/dL)	244.0 (45.6)†	264.5 (46.7)
HDL cholesterol (mg/dL)	47.1 (12.7)†	55.6 (14.3)
Use of serum lipid reducing agents (N, %)	70 (2.7)	84 (2.2)
Current smoking (N, %)	762 (29)†	699 (19)
Weight loss (N, %)	253 (9.6)	416 (11)
ABSI (m$^{11/6}$/kg$^{2/3}$)	0.0821 (0.0050)†	0.0776 (0.0068)
BMI (m/kg^2)	25.7 (3.0)†	26.7 (4.1)
WC (m)	0.94 (0.09)†	0.88 (0.11)
WHR	0.96 (0.07)†	0.87 (0.09)
WHtR	0.54 (0.06)†	0.55 (0.07)

*Values are means (SDs) or numbers (percentages).
†The difference between men and women is significant at p≤0.05 at two sides.
ABSI, a body shape index; BMI, body mass index; WC, waist circumference; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio.

Table 2 Multivariable adjusted HRs* for the association of anthropometric measures with total and cause-specific mortality

	Total mortality		CVD mortality†		Cancer mortality	
	Men (n=1679/2626)	Women (n=1996/3740)	Men (n=564/2626)	Women (n=631/3740)	Men (n=450/2626)	Women (n=423/3740)
ABSI	1.15 (1.09 to 1.21)	1.09 (1.04 to 1.14)	1.18 (1.08 to 1.29)	1.04 (0.96 to 1.12)	1.10 (0.99 to 1.22)	1.18 (1.07 to 1.30)
BMI	0.93 (0.89 to 0.99)	0.96 (0.92 to 1.01)	0.90 (0.82 to 0.99)	1.01 (0.94 to 1.09)	0.99 (0.90 to 1.10)	0.96 (0.86 to 1.06)
WC	1.02 (0.97 to 1.07)	1.02 (0.98 to 1.07)	1.02 (0.93 to 1.10)	1.03 (0.95 to 1.12)	1.05 (0.95 to 1.16)	1.10 (0.99 to 1.21)
WHR	1.07 (1.01 to 1.12)	1.02 (0.98 to 1.07)	1.04 (0.95 to 1.13)	1.00 (0.92 to 1.09)	1.08 (0.98 to 1.19)	1.07 (0.99 to 1.18)
WHtR	1.03 (0.98 to 1.08)	1.02 (0.98 to 1.06)	1.00 (0.91 to 1.08)	1.03 (0.97 to 1.10)	1.03 (0.94 to 1.14)	1.06 (0.98 to 1.14)

*HRs (95% CIs) are presented per 1 unit SD increase in each anthropometric measure and are adjusted for age, current smoking, systolic blood pressure, medication for hypertension, diabetes mellitus, total cholesterol and high-density lipoprotein cholesterol.
†Additionally adjusted for prevalent CVD at baseline.
ABSI, a body shape index; BMI, body mass index; CVD, cardiovascular disease; WC, waist circumference; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio.

risk for total mortality increased by 15% (HR 1.15 (95% CI 1.09 to 1.21)) among men and by 9% (HR 1.09 (95% CI 1.04 to 1.14)) among women. Among men, BMI and WHR were significantly associated with total mortality: HRs and (95% CI) were 0.93 (0.89 to 0.99) and 1.07 (1.01 to 1.12), respectively. These results were not significant among women. The association between WC and WHtR with total mortality did not reach statistical significance.

Associations with CVD mortality

Among men, the HRs and (95% CI) were 1.18 (1.08 to 1.29) and 0.90 (0.82 to 0.99) per 1 SD increases in ABSI and BMI, respectively. In women, the associations between anthropometric measures and CVD mortality did not reach statistical significance (table 2).

Associations with cancer mortality

Among men, none of anthropometric measures were associated with cancer mortality, whereas in women only ABSI (HR 1.18, (95% CI 1.07 to 1.30) per 1 SD increase) was associated with cancer mortality (table 2).

Online supplementary tables S1 and S2 show the associations of anthropometric measures with total and cause-specific mortality in models adjusted only for age and per tertiles in the multivariable adjusted models, respectively. Associations between anthropometric measures and total and cause-specific mortality in age-adjusted models were generally similar with multivariable models. Compared with the first tertile, the third tertile of ABSI clearly showed a significant association with total and CVD mortality among men. The graded significant associations were less evident among women and CIs largely overlapped. We additionally adjusted the models for education, activities of daily living (as a proxy for physical activity), and marital status (living or not living with a partner). This additional adjustment did not substantially change the effect estimates (see online supplementary table S3). All women in our study were postmenopausal. In an additional analysis, we further adjusted the multivariable models for hormone replacement therapy among women. The results for this analysis were not substantially different from the original analysis (data not shown).

Sensitivity analysis

Table S3 (see online supplementary material) shows multivariable adjusted HRs for anthropometric measures, and the risk for total and cause-specific mortality stratified by age group. By using homogeneity statistical test, we observed that WHR had a stronger association with total and CVD mortality in men of age 55–65 years, whereas the association of other anthropometric measures with the mortality outcomes were generally similar across the age subgroups. The results for the analyses excluding events during the first 5 years of follow-up (798 (407 men and 391 women) of all cause deaths) or excluding the participants who lost more than 3 kg weight in the past 12 months prior to the study (664 (252 men and 412 women)) did not deviate substantially from our original analysis regarding the associations of ABSI with total and cause-specific mortality. For BMI, the associations with total mortality did not change substantially, but some associations were no longer statistically significant.

To show the independence of ABSI over BMI, we conducted a multivariable model that included both ABSI and BMI. When additionally adjusted for each other, the HRs for ABSI and BMI did not change; that is, the direction and the magnitude of association for both ABSI and BMI were comparable to the multivariate adjusted models containing each measure alone. This pattern was the same for cause-specific mortality (online supplementary table S4). When we included BMI and WC in the same multivariable model, the HRs for BMI and WC in association with total mortality became stronger. After controlling for WC, the HR of BMI in association with total mortality decreased by 11% for men and 8% for women; new HRs (95% CIs) for BMI were 0.82 (0.75 to 0.89) and 0.88 (0.83 to 0.95), respectively, for men and women. After controlling for BMI, the HR of WC in relation to total mortality became significant and increased by 17% for men and 9% for women; new HRs (95% CIs) for WC were 1.19 (1.10 to 1.28) and 1.11 (1.04 to 1.19), respectively, for men and women. We observed the same pattern with the cause-specific mortality (online supplementary table S4).

Informativeness, discrimination and reclassification

Table 3 shows the informativeness which is the difference in twice the log-likelihood between the base multivariable model and the extended models for each anthropometric measure as a continuous variable. Among all anthropometric measures, ABSI was the most informative measure for predicting total and cause-specific mortality for men and women. The χ^2 of likelihood ratio test for ABSI in association with total, CVD and cancer mortality were 26.4, 12.2 and 3.9 in men, and 15.1, 0.9 and 10.6 in women, respectively. BMI and WHR offered a small improvement in model fit. The χ^2 of likelihood ratio test for BMI in association with total mortality was 6.5 in men and 3.9 in women, and with CVD mortality it was 5.1 in men. The χ^2 of likelihood ratio test for WHR in association with total mortality was 6.0 in men.

Table 4 shows the c-statistic for the models containing different anthropometric measures in prediction of total and cause-specific mortality. The c-statistics of the models including ABSI were higher compared with the models including other anthropometric measures in prediction of total and cause-specific mortality.

Table 3 Informativeness of different models in association with total and cause-specific mortality among men and women

	Total mortality		CVD mortality*		Cancer mortality	
	Men	Women	Men	Women	Men	Women
ABSI	26.4†	15.1†	12.2†	0.9	3.9	10.6†
BMI	6.5†	3.9†	5.1†	0.2	0.2	1.2
WC	0.6	0.7	0.1	0.6	0.5	2.8
WHR	6.0†	1.0	0.7	0.02	1.9	1.6
WHtR	1.3	1.3	0.1	1.3	0.8	1.0

The presented values are $\chi 2$ which is the difference in twice log-likelihood of a multivariate model (base model) including age, current smoking, systolic blood pressure, medication for hypertension, diabetes mellitus, total cholesterol and high-density lipoprotein cholesterol, with multivariable models additionally including each anthropometric measure (ie, base model+ABSI, base model+BMI, base model +WC, base model+WHR, base model+WHtR) in prediction of different mortality outcomes.
*Additionally adjusted for prevalent CVD at baseline.
†Significant at $p \leq 0.05$.
ABSI, a body shape index; BMI, body mass index; CVD, cardiovascular disease; WC, waist circumference; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio.

However, considering the large overlap in the CIs of the c-statistics, the increase of c-statistic were not statistically significant. In prediction of total mortality, the c-statistic (95% CI) for ABSI was 0.746 (0.734 to 0.757) for men and 0.784 (0.774 to 0.794) for women. In prediction of CVD mortality, the c-statistic (95% CI) for ABSI was 0.792 (0.775 to 0.810) for men and 0.819 (0.803 to 0.835) for women. In prediction of cancer mortality, the c-statistic for ABSI (95% CI) was 0.668 (0.643 to 0.692) for men and 0.644 (0.618 to 0.670) for women (table 4).

Table 5 shows the IDI and cNRI in prediction of total and cause-specific mortality. Among men, ABSI offered most improvement in model performance compared with other anthropometric measures for prediction of total mortality: IDI 0.003 (95% CI 0.001 to 0.005) and cNRI 0.13 (95% CI 0.06 to 0.21), followed by WHR (cNRI 0.09 (95% CI 0.01 to 0.16)). ABSI also lead to a cNRI of 0.16 (95% CI 0.06 to 0.25) in prediction of CVD mortality among men. However, among women, none of the anthropometric measures led to improvements in risk predictions for total and cause-specific mortality.

DISCUSSION

In this population-based cohort study, among the presented anthropometric measures, ABSI had a stronger association with death from any cause in men and women, from CVD in men, and from cancer in women. However, addition of ABSI to the traditional risk factors did not improve the c-statistic and provided only a modest improvement in model fit and had a small impact on risk stratification in prediction of total mortality among men.

ABSI is a new anthropometric measure, recently introduced by Krakauer *et al*,[11] which takes into consideration WC and BMI concurrently and is, therefore, considered to be more comprehensive than other traditional anthropometric measures. Our findings regarding the association of ABSI with total mortality confirm the previous results.[11 12 22] Furthermore, we showed that increase in ABSI was associated with a higher risk for cardiovascular mortality in men and cancer mortality in women in populations over the age of 55 years.[23] In line with the previous findings, we observed linear associations between ABSI with total and cause-specific mortality; however, these linear associations in our study were more clearly demonstrated among men.[22] The association of ABSI with the risk of mortality can be addressed through its components. At a given height and weight, high ABSI may correspond to a greater fraction of visceral fat compared with peripheral tissue,[11] to a smaller fraction of limb muscle mass,[11] and to a lower fat-free mass index.[24] Excess visceral fat is associated with a variety of adverse metabolic outcomes. Similarly, lean tissue mass and limb circumference[25 26] as well as fat-free mass index[27] have been shown to be negatively associated with mortality risk. Therefore, lifestyle interventions that lead to a reduction in ABSI, such as exercise to increase skeletal muscle mass or weight loss to reduce WC and BMI, could potentially yield favourable health effects followed by an increase in the quality of life. However, to this end, replication of ABSI in different population-based settings to establish appropriate cut-off values followed by large randomised controlled trials would be necessary.

In our study, the association of ABSI with mortality was not attenuated when BMI was added in the multivariable model and therefore, confirms the independence of ABSI from BMI in the association with mortality.[11] Our results indicate that the association of ABSI with total mortality does not differ between the younger and the older age groups, as reported previously.[11] In our study, ABSI continued to be a significant predictor for mortality when deaths during the first 5 years of follow-up were excluded. This finding suggests that the association of ABSI with mortality is not confounded by the presence of life-threatening disease at the baseline.[11]

The present study demonstrated that increase in BMI was associated with a lower risk for total and cardiovascular mortality among men. While most prospective studies indicate overweight and obesity as risk factors for mortality, the inverse relationship between BMI and total mortality has been reported in studies comprising elderly subjects (eg, above the age of 65 years) with acute or chronic illnesses.[17 28] In our study, when

Table 4 C-statistic for the models containing different anthropometric measures in prediction of total and cause-specific mortality

	Total mortality		CVD mortality†		Cancer mortality	
	Men	Women	Men	Women	Men	Women
Base model*	0.744 (0.732 to 0.755)	0.783 (0.773 to 0.793)	0.789 (0.771 to 0.807)	0.819 (0.803 to 0.834)	0.667 (0.643 to 0.691)	0.637 (0.610 to 0.663)
+ABSI	0.746 (0.734 to 0.757)	0.784 (0.774 to 0.794)	0.792 (0.775 to 0.810)	0.819 (0.803 to 0.835)	0.668 (0.643 to 0.692)	0.644 (0.618 to 0.670)
+BMI	0.744 (0.733 to 0.755)	0.783 (0.773 to 0.793)	0.790 (0.773 to 0.808)	0.819 (0.803 to 0.834)	0.667 (0.643 to 0.692)	0.637 (0.611 to 0.663)
+WC	0.744 (0.732 to 0.755)	0.783 (0.773 to 0.794)	0.789 (0.772 to 0.807)	0.819 (0.803 to 0.834)	0.667 (0.642 to 0.691)	0.638 (0.612 to 0.664)
+WHR	0.745 (0.733 to 0.756)	0.784 (0.773 to 0.794)	0.790 (0.772 to 0.807)	0.819 (0.803 to 0.834)	0.668 (0.644 to 0.692)	0.638 (0.612 to 0.665)
+WHtR	0.743 (0.732 to 0.755)	0.784 (0.773 to 0.793)	0.789 (0.772 to 0.807)	0.819 (0.803 to 0.834)	0.670 (0.646 to 0.694)	0.642 (0.616 to 0.668)

*Base model includes age, current smoking, systolic blood pressure, medication for hypertension, diabetes mellitus, total cholesterol and high-density lipoprotein cholesterol. Each anthropometric measure was added alone to the base model (ie, base model+ABSI, base model+BMI, base model+WC and base model+WHR).
†Additionally adjusted for prevalent CVD at baseline.
ABSI, a body shape index; BMI, body mass index; CVD, cardiovascular disease; WC, waist circumference; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio.

Table 5 Risk reclassification improvement* for total and cause-specific mortality with addition of anthropometric measures to the base model

	Total mortality				CVD mortality†			
	Men		Women		Men		Women	
Anthropometric measures	IDI	NRI	IDI	NRI	IDI	NRI	IDI	NRI
ABSI	0.003 (0.001 to 0.005)	0.13 (0.06 to 0.21)	0.001 (−0.001 to 0.001)	0.05 (−0.01 to 0.12)	0.000 (−0.003 to 0.003)	0.16 (0.06 to 0.25)	0.000 (0.000 to 0.000)	0.05 (−0.04 to 0.14)
BMI	0.001 (−0.001 to 0.003)	0.04 (−0.04 to 0.12)	0.000 (0.000 to 0.000)	−0.02 (−0.09 to 0.04)	0.003 (0.000 to 0.007)	0.07 (−0.03 to 0.16)	0.000 (0.000 to 0.000)	−0.10 (−0.19 to −0.01)
WC	0.000 (0.000 to 0.000)	−0.04 (−0.12 to 0.04)	0.000 (0.000 to 0.000)	0.05 (−0.02 to 0.11)	0.000 (−0.000 to 0.001)	−0.09 (−0.19 to 0.01)	0.000 (0.000 to 0.000)	0.05 (−0.04 to 0.14)
WHR	0.001 (0.000 to 0.001)	0.09 (0.01 to 0.16)	0.000 (0.000 to 0.000)	0.03 (−0.04 to 0.09)	0.000 (0.000 to 0.001)	−0.04 (−0.14 to 0.06)	0.000 (0.000 to 0.000)	−0.01 (−0.10 to 0.085)
WHtR	0.000 (0.000 to 0.000)	0.04 (−0.03 0.11)	0.000 (0.000 to 0.000)	0.04 (−0.02 to 0.10)	0.001 (−0.001 to 0.002)	−0.03 (−0.13 0.06)	0.000 (0.000 to 0.000)	0.07 (−0.01 0.17)

	Cancer mortality			
	Men		Women	
Anthropometric measures	IDI	NRI	IDI	NRI
ABSI	0.000 (−0.001 to 0.000)	−0.02 (−0.13 to 0.09)	0.002 (0.000 0.004)	0.06 (−0.05 to 0.17)
BMI	0.000 (−0.001 to 0.001)	0.01 (−0.09 to 0.12)	0.000 (0.000 to 0.000)	0.07 (−0.05 to 0.18)
WC	0.000 (0.000 to 0.000)	0.09 (−0.01 to 0.20)	0.001 (−0.001 to 0.002)	0.07 (−0.04 to 0.18)
WHR	0.000 (0.000 to 0.000)	−0.05 (−0.15 to 0.06)	0.000 (−0.001 to 0.002)	0.07 (−0.05 to 0.19)
WHtR	0.000 (0.000 to 0.000)	0.02 (−0.08 0.13)	0.000 (−0.001 to 0.002)	0.03 (−0.08 to 0.14

*NRI and IDI present improvement in risk predictions between the based model: including age, current smoking, systolic blood pressure, medication for hypertension, diabetes mellitus, total cholesterol and HDI cholesterol, and the extended models additionally including each anthropometric measure.
†Base model additionally includes prevalent CVD at baseline.
ABSI, a body shape index; BMI, body mass index; CVD, cardiovascular disease; HDI, high-density lipoprotein; IDI, integrated discrimination improvement; NRI, continues net reclassification improvement; WC, waist circumference; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio.

we excluded subjects who died during the first 5 years of follow-up, the inverse association of BMI with total mortality did not change substantially, but was no longer statistically significant. Although the loss of statistical significance might be due to lower power after excluding deaths during the first 5 years of follow-up, such an observation might suggest that the association of BMI with mortality might be distorted by the presence of a group of subjects with life-threatening diseases at baseline for whom an increase in BMI actually improves the outcome.

The positive association between abdominal obesity, assessed by WC or WHtR, and abdominal girth, assessed by WHR, with total and cause-specific mortality has been well described before.[8 9 17 23] In the present study, we complement the evidence by comparing these three measures with ABSI. We showed that ABSI is strongly associated with total mortality among men and women, and with cancer mortality among women. Moreover, in contrast to a previous study,[23] we found that ABSI had a stronger association with CVD mortality among men compared with WC, WHtR and WHR. The inconsistency between the previous study with our results may be explained by different age groups of the two study populations. Our study comprises an older population (aged 55+) compared with the previous study (aged 29+),[23] and WC and WHR seem to be more strongly associated with cardiovascular mortality in younger adults compared with the elderly.[29] Moreover, in our population the association of WHR with total and CVD mortality was stronger in individuals aged 55–65 years compared with the elderly (aged 65+). Although it has been suggested that WC, due to its correlation with abdominal fat, may be informative for CVD mortality,[7] we found it less informative than other anthropometric measures. While we did not find an association between WC and WHtR with total mortality in our multivariable analysis, increase in WHR was associated with higher total mortality among men.

Although BMI and WC are strongly correlated, it has recently been recommended to use both of these anthropometric measures in clinical practice simultaneously, as these two measures reflect different aspects of obesity.[30] While BMI is an indication for non-abdominal fat and abdominal subcutaneous fat, WC is a reflection of the visceral fat.[30] When we included BMI and WC in one multivariable model in association with total and cause-specific mortality, the associations of BMI and WC with the outcome became stronger, compared with using each of these anthropometric measures alone. Our results, therefore, provide further evidence regarding simultaneous use of BMI and WC in assessing the risk of total and cause-specific mortality.[31–33]

The strengths of our study include availability of a long follow-up time with detailed and validated information on cause-specific mortality, access to comprehensive data on a number of anthropometric measures (height, weight, WC and hip circumference) that allowed for head-to-head comparisons of these measures, and availability of data to control for possible confounders. Nevertheless, our study has limitations. We did not have detailed data on life-threatening conditions at baseline (ie, cancer prevalence). However, as a proxy, we additionally adjusted our multivariable models for unintended weight loss over the last year before subjects entered the study. Moreover, as a sensitivity analyses, we repeated the analyses after excluding subjects who died during the first 5 years of follow-up. Although we developed several models where we adjusted for a wide range of potential confounders, residual confounding cannot be completely ruled out. Moreover, it should be noted that differences in the studies regarding the study population and its characteristics, definition of outcomes, and inclusion of different confounders might lead to discrepancy in the results between the studies. The mean age of our study population was 69 years and our study might, therefore, not be generalisable to younger populations. We examined the anthropometric measures only once, at the start of the study, for each subject. Thus, no conclusions can be drawn regarding the changes in the anthropometric measures over time.

To conclude, in our population-based study, ABSI as measure of body shape had a stronger association with mortality compared with other presented anthropometric measures. However, the added predictive value of ABSI in prediction of mortality was limited.

What is already known:

- Anthropometric measures are frequently used to assess the risk of morbidity and mortality. Studies on the assessment of body mass index (BMI) in relation to mortality have led to contradictory results.
- The contribution of different anthropometric measures in prediction of mortality among the elderly is not clear.

What this study adds:

- Among individuals 55 years and older, a new body shape index (ABSI) has a stronger association with total, cardiovascular and cancer mortality, compared to other anthropometric measures. However, the added predictive value of ABSI in prediction of mortality is limited.
- Among the elderly, where the predictive ability of other anthropometric measures declines, ABSI as a measure of body shape index, could provide a better assessment of the mortality risk.

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Competing interests None declared.

Patient consent Obtained.

Ethics approval The Rotterdam Study has been approved by the institutional review board (Medical Ethics Committee) of the Erasmus Medical Centre and by the medical ethics committee according to the Wet Bevolkingsonderzoek ERGO (Population Study Act Rotterdam Study) executed by the Ministry of Health, Welfare and Sports of the Netherlands.

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Data sharing statement Data can be obtained on request. Requests should be directed towards the management team of the Rotterdam Study (secretariat.epi@erasmusmc.nl), which has a protocol for approving data requests. Because of restrictions based on privacy regulations and informed consent of the participants, data cannot be made freely available in a public repository.

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