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Prognostic effect of body roundness index on all-cause mortality among US older adults

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The Body Rounds Index (BRI) is an anthropometric indicator specifically developed to evaluate an individual's obesity level, particularly emphasizing central or abdominal obesity. This study aimed to explore the relationship between BRI and all-cause mortality in older U.S. adults. The research sample comprised individuals aged 65 and older from the National Health and Nutrition Examination Survey (NHANES), eligible for mortality analyses between 1999 and 2018. We utilized Cox regression analyses, restricted cubic spline (RCS), threshold effects analysis, Kaplan–Meier curves, and subgroup analyses were conducted to assess how the BRI correlates with all-cause mortality among older adults in the U.S. To further ensure the robustness of our findings, we conducted sensitivity analyses. Among 5371 U.S. older adults (age ≥ 65), with an average age of 72.45 (standard deviation [SD]:5.65) years, 2884 (60%) were women. During the follow-up period, there were 2781 deaths from all causes among the 5371 participants. After adjusting for all covariates, a U-shaped association was identified between BRI and the all cause mortality. Compared to a BRI of less than 4.457, a BRI between 4.457 and 5.538 was associated with a 19% reduction in the likelihood of mortality from any cause (HR = 0.81, 95% CI = 0.69–0.95). A BRI between 5.538 and 6.888 was linked to a 8% reduction in mortality risk (HR = 0.92, 95% CI = 0.79–1.07), while a BRI exceeding 6.888 showed a 1% increase in this risk (HR = 1.01, 95% CI = 0.87–1.17). RCS analysis indicated a U-shaped relationship between BRI and all-cause mortality. The turning point was located at 4.546, with correlations observed both before and after this point. This NHANES-based study highlights the U-shaped relationship between BRI and all-cause mortality among U.S. older adults, suggesting that the BRI has predictive value for mortality outcomes. The findings offer compelling support for utilizing BRI as a non-invasive mortality risk screening tool.

Keywords Body roundness index, All-cause mortality, Mortality risk, Older adults, Anthropometric indicators, NHANES

It is well established that among public health issues, obesity is a persistent and escalating problem. According to WHO statistics in 2020, out of 2.5 billion overweight adults, 890 million are classified as obese[1]. This condition has been strongly associated with an increased risk of all-cause mortality. A study of 21,399 adults in the National Health and Nutrition Examination Survey (NHANES) between 2011–2018 by Liu et al. found that obesity and adiposity were on the rise, but there were differences between racial or ethnic groups[2]. With the demographic shift towards older adults, comprehending the effects of obesity on older individuals becomes increasingly critical. A substantial body of research has explored the connection between obesity and various diseases, along with strategies for treatment, especially the report by Perdomo et al. 2023 on obesity therapeutics[3].

Many previous studies on obesity have utilized Body Mass Index (BMI) to assess obesity. However, BMI does not fully reflect the heterogeneity of obesity and fails to adequately represent the distribution of visceral fat[4]. Visceral fat is strongly associated with various diseases and Lee et al. have shown that the distribution of body fat serves as a more accurate predictor of all-cause mortality compared to overall adiposity[5]. To address this limitation, we introduced the body roundness index (BRI), a novel anthropometric indicator developed by Thomas et al., which integrates waist circumference, height, and weight to model body shape as an ellipse,

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offering superior sensitivity to visceral adiposity compared to traditional measures like BMI or waist-to-height ratio (WHtR)[6,7]. In addition to this,BRI outperforms WHtR and A Body Shape Index (ABSI) in predicting unfavourable health outcomes such as cardiovascular diseases[8,9], metabolic syndrome[10,11], hypertension[7,12] and cancer[13].

To the best of our knowledge, there is an absence of prior studies examining the association between BRI and mortality in older U.S. populations. To fill this gap, our objective was to describe the relationship between BRI and all-cause mortality in a nationally representative cohort of the U.S. individuals who are 65 years of age or older, covering data from 1999 to 2018.

Methods

The data utilized in this study were obtained from the NHANES database, a stratified, multistage sample survey conducted by the National Center for Health Statistics (NCHS) to assess the nutritional and health status of both adults and children in the United States. Mortality data were sourced from the National Death Index (NDI) records, with death information collected up until 31 December 2019.

Study participants

The study encompassed a total of 59,064 individuals from NHANES who met all the criteria for mortality analysis eligibility between 1999 and 2018. After excluding the individuals younger than 65 years (N = 45,038), there were 14,026 individuals left. Additional, we exclude individuals with missing BRI data (N = 11,570), excluded individuals with a prior diagnosis of myocardial infarction (N = 1294), stroke (N = 788), congestive heart failure (N = 478) and cancer (N = 1988), as well as individuals missing various covariates (N = 1651). Ultimately, the analysis incorporated data from 5371 participants (Fig. 1).

BRI: a novel anthropometric measure

The body roundness index (BRI) was proposed by Thomas et al. in 2013 as a metric for assessing individual fat distribution, particularly visceral fat. Unlike the Body Mass Index (BMI), which is limited in its ability to differentiate between adipose and muscle tissue, BRI models the human body as an ellipse, thereby providing a more accurate representation of body shape. Higher BRI values are indicative of rounder body shapes, which are often associated with increased amounts of body fat, particularly visceral fat—a recognized contributor to various chronic diseases. The calculation of BRI is based on individual measurements, waist circumference (Wc) and height (Height) were sourced from the NHANES database's body measurements dataset, and BRI values was computed by applying the corresponding formula[6]:

$$BRI = 364.2 - 365.5 \times \sqrt{1 - \left(\frac{Wc}{2\pi}\right)^2 / \left(\frac{Height}{2}\right)^2}$$

Covariates

Covariates considered were age, gender, race, education level, poverty income ratio(PIR), diabetes, hypertension, cigarette smoking and alcohol drinking. Diabetes status was ascertained from participants' replies to the questionnaire item, 'Doctor told you have diabetes'. Similarly, hypertension status was assessed using the questionnaire item 'Ever told you had high blood pressure'. To further categorize smoking and drinking behaviors among participants, we employed the questionnaire item 'Smoked at least 100 cigarettes in life' to ascertain smoking status, while the item 'Had at least 12 alcohol drinks/1 yr?' was used to determine alcohol consumption.

Statistical analysis

This study's analyses were performed utilizing R (version 4.4.1). To ensure the study was broadly representative of all older adults aged 65 years and above in the United States, we weighted the data according to the NHANES database analysis guidelines. The association between BRI and the risk of all-cause mortality was analysed by multivariate Cox regression models. We used three different Cox regression models to estimate hazard ratios (HR) and 95% confidence intervals (CI): Model 1 did not adjust for covariates, Model 2 was adjusted for some basic demographic information such as age, gender and race, and Model 3 was incorporated adjusts for all baseline variables showing $p < 0.1$ in univariate analysis, including age, gender, race, education level, PIR, alcohol drinking, hypertension and diabetes. We also conducted a test for multicollinearity among all variables included in the analysis. Across fully adjusted Cox regression models (Model 3), VIF values ranged from 0.33 to 5.11 (Supplementary Table S1), with all values below the threshold of 10, indicating no significant multicollinearity.

We employed a dual modeling strategy for the BRI to ensure comprehensive evaluation of its relationship with all-cause mortality. The BRI was treated both as a categorical variable and as a continuous variable. Specifically, when analyzed categorically, BRI was divided into quartiles, with Quartile 1 (Q1) serving as the reference category for comparison with higher quartiles (Q2, Q3, Q4). This approach aligns with prior studies that validated quartile-based thresholds for BRI in mortality risk stratification[10,14]. Quartiles enable comparisons across heterogeneous populations while capturing non-linear trends, as demonstrated in large epidemiological cohorts[15]. Simultaneously, we modeled BRI as a continuous variable to capture the precision of mortality risk changes across its entire range. This approach allowed us to assess both the distinct effects among quartile groups and the broader trends observed across all levels of BRI, thereby providing a robust analysis of its impact on mortality outcomes. The relationship between BRI and all-cause mortality was examined using a dose–response approach, employing restricted cubic spline (RCS). To rigorously evaluate the non-linear relationship between BRI and all-cause mortality, we first fitted a linear Cox regression model and compared it to a restricted cubic

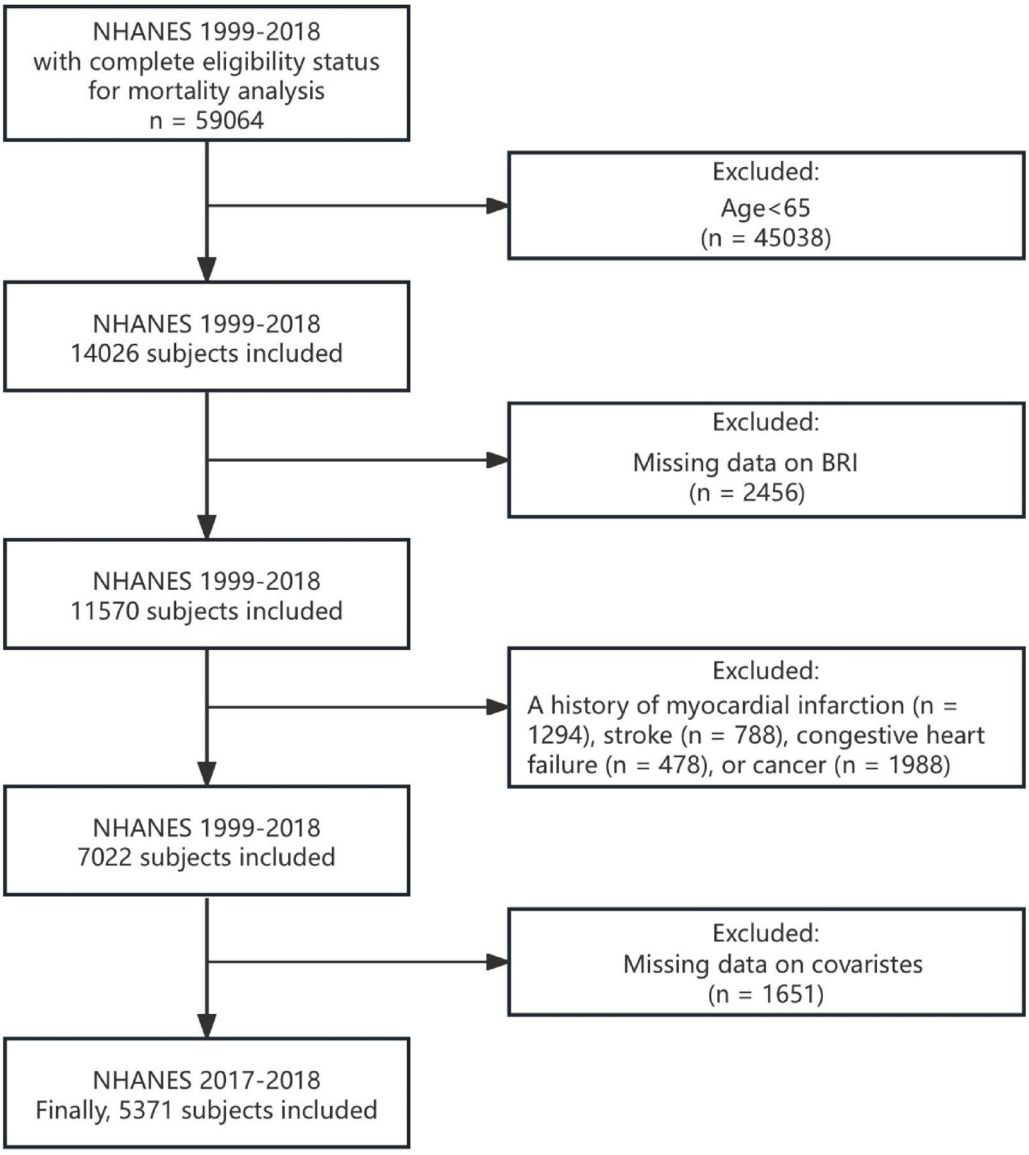

Fig. 1. NHANES 1999–2018 participant selection flowchart.

spline (RCS) model using a likelihood ratio test (LRT). The LRT tested the null hypothesis that the linear model adequately captured the association, with a significant result ($P < 0.001$) confirming the necessity of non-linear terms. To delve deeper into the threshold effect of BRI on all-cause mortality risk, a two-stage linear regression model was employed for analysis. The Kaplan–Meier method was employed to analyse the probability of survival of older Americans over time according to BRI categories.

Stratified analyses were also conducted by gender (male, female), ethnicity (Non-Hispanic White, Non-Hispanic Black, Mexican American, Other Hispanic, Other Race-including Multi-Racial), education level (Less than 9th grade, 9–11th grade, High school graduate, Some college or AA degree, College graduate or above), diabetes status (Yes, No, Borderline), hypertension status (Yes, No), PRI ($<1.3, >=3.5$, $1.3 \sim 3.5$), cigarette smoking (Yes, No), alcohol drinking(Yes, No). To formally assess effect modification, we included interaction terms between BRI (as a continuous variable) and each stratification variable in the fully adjusted Cox regression models. Interaction significance was evaluated using likelihood ratio tests comparing models with and without the interaction terms. Finally, several sensitivity analyses were performed to test the robustness of our findings.

In all analyses, weights from the NHANES survey were used to account for the survey's multistage stratified sampling design. These weights correct for potential bias due to oversampling and nonresponse to certain subgroups, thereby ensuring that the survey results are representative of the broader U.S. older population. Survey weights were applied consistently in Cox regression models, RCS analyses, and KM survival curves.

Results

The weighted baseline characteristics of participants

From 1999 to 2018, a total of 5371 older adults (age ≥ 65) in the United States were engaged in the study. After survey weighting, the mean age of participants was 72.449 years, women (60%) of the whole study population as a higher percentage than men (40%). Non-Hispanic white had the highest representation (79%). Majority of the participants possessed an education level of high school or above (76%). Additionally, 16% of participants had diabetes, and 2.6% were at the borderline, and 55% suffered from hypertension. Furthermore, 45% had a PIR between 1.3 and 3.5, 48% smoked and 63% had a history of drinking alcohol. In this study, the BRI was divided by quartiles into Q1 (1.194, 4.457), Q2 (4.457, 5.538), Q3 (5.538, 6.888), Q4 (6.888, 17.738), of which Q3 has the highest number of participants (N = 1411). Significant differences were observed for all variables ($P < 0.05$) except smoking ($P = 0.609$, Table1).

Association between BRI and the risk of all-cause mortality among U.S. older adults

We used three different Cox regression models to calculate hazard ratios (HR) along with 95% confidence intervals (CI). In the unadjusted model, using the lowest quartile of the BRI (Q1) as a baseline reference, the rate of all-cause mortality was significantly reduced in Q2 (HR = 0.76, 95% CI = 0.65–0.89, $P < 0.001$). This downward trend persisted in the partially adjusted models (HR = 0.83, 95% CI = 0.70–0.97, $P = 0.02$) and fully adjusted models (HR = 0.81, 95% CI = 0.69–0.95, $P = 0.011$). There was no statistically significant difference detected in the comparisons of Q3 and Q4 with Q1 across all three models ($P > 0.05$). In Model3, when compared to the all-cause mortality risk associated with a BRI below 4.457, the risk of a BRI between 4.457 and 5.538 showed

Characteristic	Overall (N = 5371)	Q1 (N = 1294)	Q2 (N = 1323)	Q3 (N = 1411)	Q4 (N = 1343)	*p*-value[1]
Age (years), Mean(SD)	72.449 (5.651)	72.879 (5.891)	72.344 (5.633)	72.650 (5.567)	71.923 (5.466)	0.022
Gender, n(%)						< 0.001
Male	2,487 (40%)	640 (38%)	706 (45%)	675 (43%)	466 (32%)	
Female	2,884 (60%)	654 (62%)	617 (55%)	736 (57%)	877 (68%)	
Race/ethnicity, n(%)						< 0.001
Non-hispanic white	2846 (79%)	729 (80%)	705 (80%)	718 (78%)	694 (79%)	
Non-hispanic black	971 (8.5%)	262 (8.4%)	241 (8.2%)	231 (8.3%)	237 (9.1%)	
Mexican American	870 (4.2%)	131 (2.5%)	200 (3.6%)	272 (5.3%)	267 (5.6%)	
Other hispanic	403 (4.0%)	64 (2.9%)	95 (3.7%)	135 (5.2%)	109 (4.2%)	
Other race–including multi-racial	281 (4.0%)	108 (5.9%)	82 (4.7%)	55 (3.1%)	36 (2.1%)	
Education level, n(%)						0.021
Less than 9th grade	1158 (11%)	240 (11%)	254 (9.6%)	335 (13%)	329 (12%)	
9–11th grade	849 (13%)	190 (12%)	203 (14%)	227 (14%)	229 (14%)	
High school graduate/GED or equivalent	1280 (27%)	308 (26%)	319 (27%)	331 (26%)	322 (29%)	
Some college or AA degree	1154 (26%)	291 (26%)	279 (25%)	299 (25%)	285 (27%)	
College graduate or above	930 (23%)	265 (26%)	268 (26%)	219 (21%)	178 (18%)	
Diabetes, n(%)						< 0.001
Yes	1008 (16%)	134 (7.3%)	196 (12%)	309 (19%)	369 (24%)	
No	4206 (82%)	1136 (91%)	1095 (86%)	1060 (78%)	915 (72%)	
Borderline	157 (2.6%)	24 (1.5%)	32 (2.0%)	42 (3.1%)	59 (3.9%)	
Hypertension, n(%)						
Yes	3016 (55%)	554 (41%)	679 (49%)	852 (60%)	931 (70%)	< 0.001
No	2355 (45%)	740 (59%)	644 (51%)	559 (40%)	412 (30%)	
PIR, n(%)						< 0.001
< 1.3	1643 (20%)	366 (19%)	353 (17%)	466 (23%)	458 (23%)	
> = 3.5	1345 (34%)	366 (37%)	382 (39%)	318 (29%)	279 (31%)	
1.3 ~ 3.5	2383 (45%)	562 (43%)	588 (44%)	627 (48%)	606 (46%)	
Cigarette smoking, n(%)						
Yes	2613 (48%)	643 (46%)	656 (49%)	673 (48%)	641 (48%)	0.609
No	2758 (52%)	651 (54%)	667 (51%)	738 (52%)	702 (52%)	
Alcohol drinking, n(%)						
Yes	3293 (63%)	831 (64%)	875 (68%)	854 (63%)	733 (58%)	0.002
No	2078 (37%)	463 (36%)	448 (32%)	557 (37%)	610 (42%)	

Table 1. Weighted baseline characteristics of participants. Categorical variables are presented as unweighted counts (weighted percentage); continuous data are presented as mean (SD). *BRI* body roundness index, PIR: income to poverty ratio. [1]Design-based KruskalWallis test; Pearson's X^2: Rao & Scott adjustment.

HR(95%CI), *P*-value			
	Model1	**Model2**	**Model3**
BRI	1.01 (0.98, 1.04) 0.561	1.04 (1.02,1.07) 0.002	1.01 (0.99,1.04) 0.326
BRI quartiles			
Q1, [1.194,4.457]	1(Reference)	1(Reference)	1(Reference)
Q2, [4.457, 5.538]	0.76 (0.65,0.89) < 0.001	0.83 (0.70,0.97) 0.02	0.81 (0.69,0.95) 0.011
Q3, [5.538, 6.888]	0.96 (0.83,1.11) 0.576	1.01 (0.86,1.18) 0.932	0.92 (0.79, 1.07) 0.281
Q4, [6.888, 17.738]	0.95 (0.82,1.10) 0.490	1.14 (0.99,1.32) 0.075	1.01 (0.87, 1.17) 0.898
P for trend	0.755	0.012	0.518

Table 2. Weighted association between body roundness index (BRI) and mortality. Model 1: no covariates were adjusted; Model 2: age, gender, and race were adjusted; Model 3: age, gender, race, education level, *PIR*, cigarette smoking, alcohol drinking, hypertension, diabetes were adjusted; *BRI:* body roundness index; *PIR:* income to poverty ratio; *HR:* hazard ratio; *Q:* quantile.

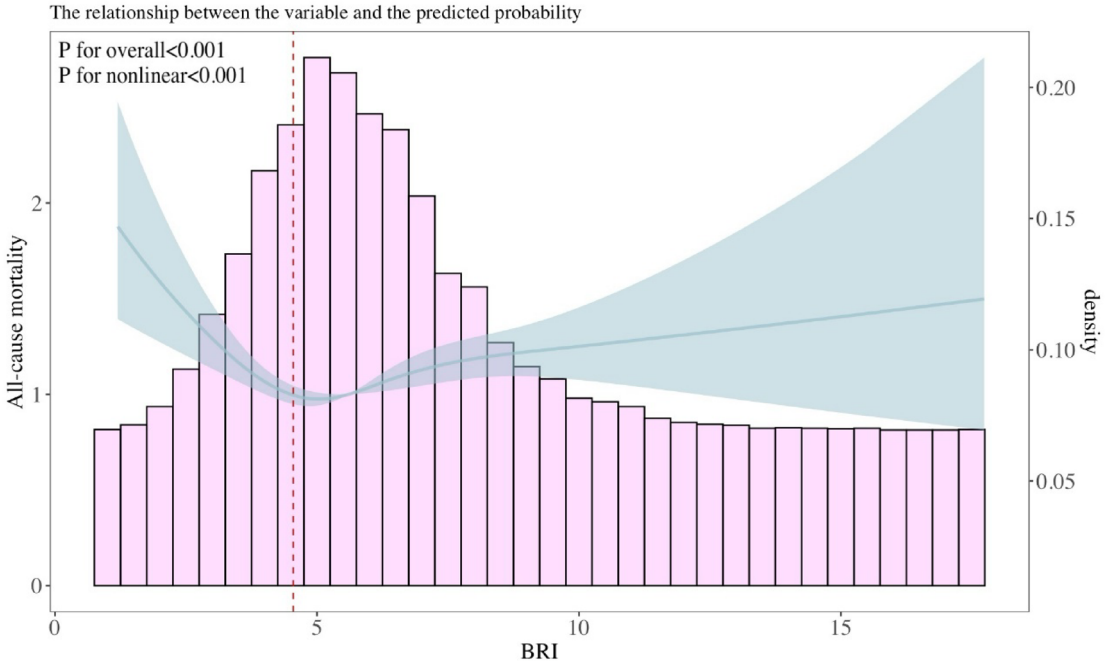

Fig. 2. RCS analysis of the association between body roundness index (BRI) and all-cause mortality risk.

a 19% reduction (HR = 0.81; 95% CI = 0.69–0.95). However, the mortality risk reductions observed for BRI between 5.538 and 6.888 (HR = 0.92, 95% CI = 0.79–1.07) and the nominal increase for BRI > 6.888 (HR = 1.01, 95% CI = 0.87–1.17) were not statistically significant. While the point estimates suggest a potential non-linear trend, definitive conclusions cannot be drawn for these ranges due to the lack of statistical precision (Table2).

In our restricted cubic spline (RCS) regression analysis, we rigorously compared linear and non-linear models to evaluate the association between BRI and mortality. The likelihood ratio test (LRT) demonstrated a significant improvement in model fit when non-linear terms were incorporated (design-adjusted 2logLR = 16.06, $P = 0.0001$). This confirmed a robust U-shaped relationship between BRI and all-cause mortality (P for overall trend < 0.001, P for non-linearity < 0.001, Fig. 2). Both low and high BRI values were associated with elevated mortality risks compared to moderate levels. Threshold effect analysis further localized the inflection point at BRI = 4.546 (*P* for likelihood ratio test < 0.001). Below this threshold, each 1-unit increase in BRI was associated with a 17.4% reduction in mortality risk (HR = 0.826, 95% CI = 0.742–0.919, $P < 0.001$). Conversely, above BRI = 4.546, each additional unit increase in BRI correlated with a 5.3% elevation in mortality risk (HR = 1.053, 95% CI = 1.01–1.09, $P = 0.04$, Table 3). This non-linear pattern underscores the dual risks of undernutrition and visceral adiposity in older adults.

Incidence rate of all-cause mortality by BRI quartile among U.S. older adults

The Kaplan–Meier survival curves illustrate a notable variation in all-cause mortality among the four quartile groups classified by the BRI (log-rank test, $\chi^2 = 8.08$, df = 3, $P = 0.044$, Fig. 3). The log-rank test was performed using data from the entire follow-up period, ensuring that the analysis accounts for all observed time points. The

All-cause mortality	HR (95% CI)
BRI	
Fitting by standard linear model	1.008 (0.98–1.038)
Fitting by two-piecewise linear model	
Inflection point	4.546
< 4.546	0.826 (0.742–0.919)
> 4.546	1.053 (1.017–1.09)
P for likelihood ratio test	< 0.001

Table 3. Threshold effect analysis of body roundness index (BRI) and all-cause mortality using a two-piecewise linear regression model. Unadjusted for covariates.

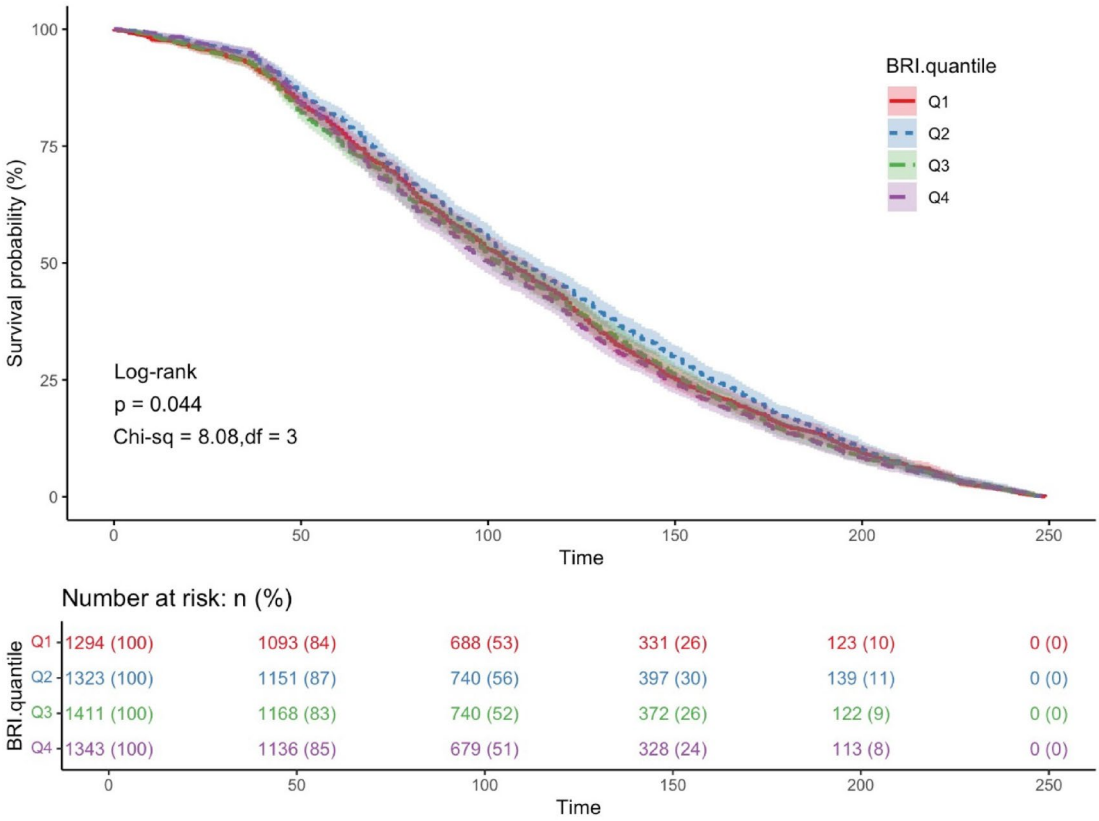

Fig. 3. Kaplan–Meier survival curves for all-cause mortality by body roundness index (BRI) quartiles. The survival probability is plotted against time, with each line representing a different BRI quartile: Q1 (1.194, 4.457), Q2 (4.457, 5.538), Q3 (5.538, 6.888), Q4 (6.888, 17.738).

highest probability of survival for all-cause mortality was found when the BRI between 4.496 and 5.565(Q2), while the lowest survival probability for all-cause mortality was found in individuals when the BRI greater than 6.888(Q4).

Stratified analysis of all-cause mortality

Subgroup analyses stratified by gender, race, education level, diabetes, hypertension, poverty-income ratio (PIR), smoking, and alcohol consumption revealed that the association between BRI and all-cause mortality was largely consistent across most subgroups in older U.S. adults. However, a significant interaction was observed between BRI and hypertension (P for interaction = 0.015), with hypertensive individuals experiencing a 4% increased mortality risk per unit rise in BRI (HR = 1.04, 95% CI = 1.00–1.08), compared to a non-significant inverse trend in non-hypertensive participants (HR = 0.97, 95% CI = 0.93–1.01). This highlights hypertension as a critical modifier of BRI-related mortality risks. No significant interactions were detected for other variables, including gender (P = 0.097), race (P = 0.822), education (P = 0.377), diabetes (P = 0.601), PIR (P = 0.943), smoking (P = 0.476), or alcohol consumption (P = 0.638). Notably, the "Other Race-Including Multi-Racial" subgroup showed a suggestive elevation in mortality risk (HR = 1.18, 95% CI = 1.02–1.37), potentially reflecting unmeasured factors such as genetic or body composition differences, though this finding requires further

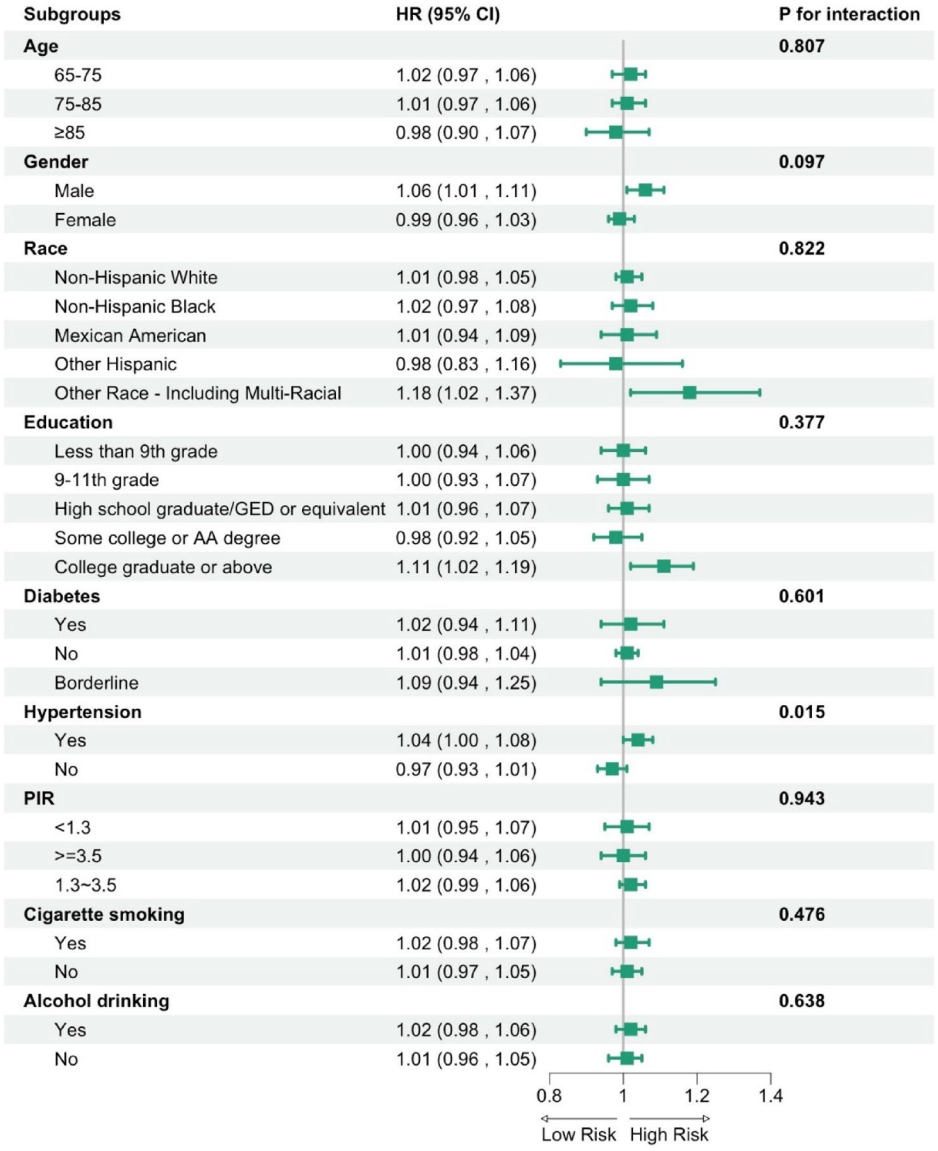

Fig. 4. Forest plot displaying the hazard ratios (HR) with 95% confidence intervals (CI) for all-cause mortality according to subgroup characteristics.

validation. Overall, these results emphasize the necessity of considering hypertension status when evaluating BRI-associated health risks, while underscoring the stability of the BRI-mortality relationship across diverse demographic strata (Fig. 4).

Sensitivity analysis

To assess the robustness of our findings, we conducted a sensitivity analysis by including participants with pre-existing myocardial infarction, stroke, congestive heart failure, or cancer. Cox regression models and RCS analyses were repeated under identical adjustment strategies. The U-shaped relationship between BRI and all-cause mortality persisted robustly, with only a marginal shift in the inflection point from 4.546 in the primary analysis to 4.478 in the sensitivity analysis (Supplementary Tables S2, S3). Sensitivity analyses adjusting for physical activity (MET-min/week) and dietary intake (HEI-2015 score) demonstrated that the U-shaped relationship between BRI and all-cause mortality remained robust, with nearly identical inflection points (4.55 vs. 4.546) and consistent hazard ratios across BRI quartiles (Supplementary Tables S4, S5). These findings suggest that BRI's prognostic value is largely independent of lifestyle factors, though residual confounding by unmeasured variables (e.g. genetic predisposition) cannot be ruled out.

Discussion

This study, which included older Americans from 1999 to 2018, enhances the comprehension of the relationship between BRI and all-cause mortality among U.S. older adults. Among these participants, a higher percentage

are female and Non-Hispanic Whites. Futhermore, BRI and all-cause mortality show a U-shaped relationship among U.S. older adults, with an inflection point of 4.546, highlighting the complex impact of how body fat distribution on health in older adults. Subgroup analysis indicated hypertension may exacerbate risks associated with elevated BRI and suggested a stronger inverse association between BRI and all-cause mortality among other race—including Multi-Racial.

Our results indicate that individuals with either extremely low or high BRI values have an elevated risk of mortality, thereby reinforcing the need for a nuanced approach in assessing health risks in older adults. The fact that when BRI values are moderate, the risk of death and the risk of conditions such as hypertension and gallstones[16] are reduced highlights the potential for clinical interventions aimed at achieving optimal body size. The U-shaped association between BRI and all-cause mortality underscores the complex interplay between body composition, metabolic health, and physiological resilience in older adults. However, it is important to note that the risk estimates for higher BRI quartiles (Q3 and Q4) lacked statistical significance. These findings may reflect limitations in statistical power or residual confounding, particularly for extreme BRI values. At lower BRI levels (< 4.546), the elevated mortality risk may be attributed to sarcopenia, frailty, or malnutrition—conditions characterized by diminished muscle mass and inadequate energy reserves. Sarcopenia reduces metabolic flexibility and impairs immune function, increasing susceptibility to infections and functional decline[17]. Malnutrition further exacerbates these risks by compromising organ function and wound healing[18]. Notably, Chen et al. demonstrated that insufficient physical activity in vulnerable populations (e.g. short sleepers) accelerates muscle atrophy and insulin resistance, a pathway that may explain the metabolic fragility observed in low-BRI individuals[19]. Conversely, elevated BRI values (> 4.546) reflect visceral adiposity, which drives chronic inflammation through pro-inflammatory cytokines (e.g. TNF-α, IL-6) and ectopic fat deposition in organs such as the liver and heart[4]. This inflammatory milieu promotes insulin resistance, atherosclerosis, and hypertension, ultimately contributing to cardiovascular and metabolic mortality[7]. The inflection point at BRI ≈ 4.546 likely represents an equilibrium where sufficient fat and muscle mass support metabolic homeostasis without inducing pathological states. These dual mechanisms align with the "obesity paradox" in aging populations, where both undernutrition and overnutrition independently elevate mortality risk through divergent pathways[20]. Clinically, our findings emphasize the need for personalized interventions: nutritional support and resistance training for low-BRI individuals versus weight management and aerobic exercise for those with high BRI. Similarly, Wei et al. showed a 125% increase in the risk of gallstones per unit increase in BRI when BRI < 3.96 and a 13% increase in the risk of gallstones when BRI > 3.96[21]. Ding et al. showed that there is an inflection point of 9.5229 between BRI and total bone mineral density. Below this point, total bone mineral density decreased by 0.0298 g/cm^2 for every unit increase in BRI, and above this point, total bone mineral density decreased by 0.0363 g/cm^2 [22]. Chen et al. conducted a comprehensive analysis of rural health workers' job satisfaction and highlighted the intricate relationship between job satisfaction, burnout, and turnover intention, indicating that factors influencing these outcomes often vary across different populations and contexts. By comparing our results with those of Chen et al., it becomes evident that health indicators, whether related to job satisfaction or physical health, share underlying mechanisms that are essential for understanding the broader public health implications[23]. Physicians can tailor health promotion activities and lifestyle interventions to an individual's BRI value. For individuals above this threshold, clinical interventions may need to focus on exercise programs, weight loss, and improved fat distribution to reduce metabolic and cardiovascular risk. Whereas for individuals below this threshold, interventions may need to focus on individualized diets, nutritional supplementation, and muscle mass enhancement to avoid the health problems associated with low BRI. In summary, maintaining BRI in a moderate range has important clinical implications for promoting health and longevity in the elderly population.

Both Tao and Zhou's studies demonstrated a non-linear relationship between BRI and both cardiovascular disease (CVD) mortality and all-cause mortality[24,25]. A study by Zhang et al. found that an exceptionally low BRI correlates with a notable increase in all-cause mortality risk, particularly among individuals aged 65 and above. This study reinforces the U-shaped correlation between BRI and mortality within the general U.S. population, revealing a 25% higher mortality risk for those with a BRI below 3.4 and a 49% higher risk for those with a BRI of 6.9 or above, compared to the mid-range BRI category of 4.5 to 5.5[14]. A study by Wu et al. highlighted a non-linear relationship between elevated BRI levels and the incidence of Type 2 Diabetes Mellitus (T2DM), with the inflection point for BRI being 4.137 in females, which was greater than in males (3.146)[26]. Research led by Zhang et al. identified a positivecorrelation between BRI and the development of gallstones[16]. Xiong et al. reported that BRI levels was positively linked to the occurrence of lower urinary tract symptoms caused by benign prostatic hyperplasia[27]. Furthermore, both Lotfi and Zhang et al. showed that BRI levels were positively correlated with depression[28,29]. These fresults support the potential utility of BRI as a non-invasive screening technique for assessing mortality risk as well as prediction of multiple diseases. Given the increasing aging of the population and the fact that the relationship between the BRI and the elderly population in the United States is unknown, the present study fills this gap.

Obesity, marked by an overabundance of body fat storage, represents a global health issue closely linked with a heightened risk of all-cause mortality. Research by Flegal et al. and the Global BMI Mortality Collaboration have both found that individuals with obesity or overweight status exhibit a heightened association with increased all-cause mortality rates[20,30]. Additionally, a study by Calderón-García et al. demonstrated that a higher BRI correlates with a greater risk of developing hypertension and can serve as a predictive marker for this condition[7]. Tang et al. demonstrated a significant correlation between BRI and hypertension-induced organ damage (HMOD) among the elderly[31]. Feng et al. showed a U-shaped relationship between blood pressure and waist circumference. Women with a WC < 80 cm and a high percentage of subcutaneous fat receive a small amount of estrogen from the subcutaneous adipose tissue, and the presence of this estrogen provides a degree of protection for blood pressure stability. When the WC exceeds 80 cm, the negative effects of visceral adiposity become apparent, which in turn interferes with the normal regulatory mechanisms of blood pressure[32]. In

addition, a study by Seravalle et al. indicated that obesity in older men significantly increases cardiac load and often triggers diastolic dysfunction, which impairs the heart's ability to fill during diastole[33]. These findings suggest that an elevated BRI is associated with hypertension. Further, obesity and hypertension share common pathophysiological mechanisms, such as the sympathetic nervous system, renal and adrenal function, endothelial cells, adipokines, and insulin resistance, and are associated with target organ damage, requiring joint active intervention[33]. This reinforces our speculation that hypertension may also exacerbate elevated BRI, and that there is between hypertension and BRI that interacts to lead to an increase in all-cause mortality and associated morbidity, which may result in a '1 + 1 > 2' effect. The prevalence of obesity has been increasing globally, with a profound impact on public health and we must act on it.

In the elderly, obesity further complicates the management of age-related conditions, potentially leading to a vicious cycle of declining health and increased healthcare utilization. Previous studies have focused on various anthropometric measures such as waist circumference, body mass index, hip circumference, waist-to-hip ratio, waist-to-height ratio, weight, height and skinfold thickness, as well as advanced techniques such as 3D Optical Scanning and Digital Anthropometry, Bioelectrical Impedance Analysis (BIA), Dual X-ray Absorptiometry (DXA), Computed Tomography (CT) and Magnetic Resonance Imaging (MRI), which help to assess the degree of obesity and associated health risks in an individual of obesity. However, they have their limitations. For example, BMI does not provide a direct assessment of adiposity and does not reflect an individual's body fat distribution, which may be overestimated in athletes possessing substantial muscle mass or in patients with oedema, while potentially resulting in underestimations for elderly individuals with reduced muscle mass[15,34,35]. While traditional measures like the waist-to-hip ratio (WHR) have been widely used to evaluate body fat distribution and associated health risks, they primarily focus on linear dimensions and do not fully capture the volumetric and geometric complexities of body shape. WHR is limited in its utility for assessing central adiposity's health implications, as it fails to account for variations in body contour and overall adiposity distribution across different populations and age groups. In addition, previous studies have shown that the BRI is significantly better than the WHR in predicting diseases such as the metabolic syndrome, and it has also been shown that the WHR is a weaker indicator of visceral obesity[10,36]. The accuracy of BIA may be affected by water balance and may not be suitable for individuals with extreme BMI ranges or abnormal water balance[35,37]. DXA, CT, and MRI are more costly, require a technician to perform, and cannot be repeated as often due to radiation concerns. Instead, the BRI is an index based on waist circumference, weight and height that overcomes the limitations of BMI, WC, WHtR and ABSI in differentiating between the health effects of body shape (central and peripheral obesity) and body size (height and weight)[10,35]. Unlike ABSI, which primarily reflects abdominal adiposity adjusted for height and weight, BRI incorporates geometric modeling of body contours to better represent visceral fat distribution. This distinction may explain its stronger predictive value for mortality outcomes, as shown in comparative studies[7]. Furthermore, BRI avoids the over-simplification of linear ratios like WHtR by accounting for three-dimensional body geometry, making it more robust across diverse populations[10]. Consequently, in the context of obesity and its associated health risks, particularly among the elderly, it is crucial to intervene to lower the incidence of obesity-related diseases and all-cause mortality by managing the BRI within the range of 4.457 and 5.538. To achieve the desired outcomes, evidence-based strategies should focus on several key areas. Nutritional optimization involves developing tailored dietary plans that emphasize balanced caloric intake and reduced visceral fat accumulation, utilizing diets such as the Mediterranean or DASH diets, while also monitoring waist circumference to track progress. Physical activity should include resistance training to preserve muscle mass and aerobic exercise to reduce visceral adiposity, following WHO guidelines for older adults. Weight management is crucial, with regular monitoring of the BRI alongside BMI and waist circumference, particularly in individuals with hypertension or metabolic disorders. Although BRI is not yet part of formal clinical guidelines, its geometric basis aligns with emerging recommendations for a multidimensional assessment of obesity. Schweitzer et al. suggest that indices like BRI should complement BMI for risk stratification, especially in aging populations where sarcopenia and visceral adiposity coexist[38]. Despite the validity of the BRI as a non-invasive anthropometric measure for predicting disease and all-cause mortality, it remains crucial to consider the full spectrum of clinical information, rather than relying solely on a single numerical value, when assessing obesity and health risks. Future guidelines could potentially incorporate BRI thresholds to enhance personalized interventions for managing conditions like metabolic syndrome. This integrated approach reflects current research and anticipates future developments in obesity and metabolic syndrome management.

By concentrating on BRI, this study extends our understanding of its applications in older Americans, contributing to its potential clinical utility. However, this study has many shortcomings. Firstly, our study utilized listwise deletion for handling missing covariate data, which may introduce selection bias. Although the proportion of missing data was modest, future research should employ advanced methods such as multiple imputation to better account for missing values and validate the robustness of our findings. Additionally, the lack of statistical significance for certain BRI ranges (e.g. Q3 and Q4 in fully adjusted models) Therefore, a larger sample size is required to improve the accuracy of estimating the risk of death at extreme BRI levels. Secondly, the observational nature of NHANES limits the ability to determine causality. Future studies should explore longitudinal data to better determine causality and examine the relationship between changes in the BRI over time and mortality risk. The findings prompt several avenues for future research. Longitudinal studies examining the impact of lifestyle interventions on BRI and subsequent mortality outcomes could provide further evidence for the utility of BRI as a clinical tool. Future research could further explore the comparative performance of BRI, BMI, ABSI and other indices in different situations, including through meta-analyses[39]. Additionally, research should explore the mechanisms underlying the observed U-shaped relationship, including metabolic and inflammatory pathways that may mediate the effects of body roundness on health outcomes.

Conclusion

This study reveals a U-shaped relationship between BRI and all-cause mortality among older adults in the United States. This finding strongly supports the need to use the BRI as a noninvasive and easily obtainable screening anthropometric measure for assessing mortality risk in older adults, particularly for moderate BRI ranges where associations were statistically robust. highlights the necessity for more personalised health assessments in clinical settings. And as the population continues to age, this will enhance the well-being and overall life quality of older adults.

Data availability

The datasets generated and/or analyzed during the current study are available in the NHANES repository at https://www.cdc.gov/nchs/nhanes/index.htm and the National Center for Health Statistics (NCHS) at https://www.cdc.gov/nchs/data-linkage/mortality.htm.

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Declarations

Competing interests

The authors declare no competing interests.

Additional information

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