

Supplementary Materials

The association between body roundness index and low body mass index-adjusted appendicular lean mass: a cross-sectional analysis of the NHANES 2011–2018 analytic sample

References cited below refer to the numbered list in the main article.

Supplementary methods

Study population and ethics

The National Health and Nutrition Examination Survey (NHANES) is coordinated by the U.S. Centers for Disease Control and Prevention and uses a complex, multistage probability design. We combined the 2011–2018 cycles. Of 39,156 participants, 16,539 were aged < 20 years, 11,896 did not have the data required to define low BMI-adjusted ALM, and 80 lacked BRI data. The final sample included 10,641 adults aged 20–59 years (Supplementary Figure S1). The absence of body-composition data includes age-related examination ineligibility and should not be interpreted solely as item nonresponse. NHANES protocols were approved by the National Center for Health Statistics Research Ethics Review Board; participants provided written informed consent. The study was conducted in accordance with the Declaration of Helsinki. Analyses did not incorporate sampling weights, strata, or primary sampling units, and the results are not nationally representative.

Exposure and outcome definitions

BRI was calculated from waist circumference (WC) and height (h), using the same units for both measurements, according to Thomas *et al.* [3]:

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

BRI is dimensionless and should not be interpreted as a direct measurement of visceral fat. BMI is weight in kilograms divided by height in metres squared (kg/m²). ALM is the sum of bone-free lean mass in both arms and both legs measured by dual-energy X-ray absorptiometry. The Foundation for the National Institutes of Health (FNIH) ratio cutoffs use ALM in kilograms: ALM/BMI < 0.789 in men and < 0.512 in women. The alternative absolute ALM cutoffs are < 19.75 kg in men and < 15.02 kg in women [5]. Neither outcome definition includes muscle strength or physical performance, so neither establishes clinically confirmed sarcopenia.

Covariates

Covariates assessed included sex, age (continuous), race/ethnicity (Mexican American, non-Hispanic White, non-Hispanic Black, or other), marital status (married/living with a partner,

widowed/divorced/separated, or never married), education (less than high school, high school graduate or equivalent, or college graduate or higher), smoking history (≥ 100 cigarettes during the lifetime), hypertension, diabetes, cancer, and physical activity. Hypertension, diabetes, and cancer were based on self-reported physician diagnoses. Physical activity was calculated from the NHANES Physical Activity Questionnaire as metabolic equivalent of task (MET)-minutes per week and classified as insufficient (< 600 MET-min/week), sufficient (≥ 600 MET-min/week), or missing. The 52 participants with missing physical-activity data were retained as a separate indicator category in multivariable models. Sex was included as a covariate in both primary multivariable models (Models 2 and 3) despite the use of sex-specific outcome cutoffs, because such thresholds do not eliminate potential confounding by sex. BMI was not included in the primary models because BMI is the denominator of ALM/BMI and additional adjustment could intensify mathematical coupling or overadjustment. In the sensitivity analysis based on absolute ALM, sex was likewise included, and BMI was additionally adjusted for because it was not part of the outcome definition.

Statistical analyses

Continuous variables are reported as median (interquartile range) in Table I of the main article, and categorical variables as n (%). Normality was assessed using the Shapiro–Wilk test, and continuous variables were compared using Student’s t test or the Mann–Whitney U test, as appropriate. Categorical variables were compared using χ^2 tests, with Yates’ continuity correction for 2×2 tables and Pearson χ^2 tests for larger tables. P -values are rounded to three decimal places, with values below 0.001 reported as < 0.001 . Percentages may not sum to 100 because of rounding.

Model 1 was unadjusted. Model 2 adjusted for sex, race/ethnicity, hypertension, diabetes, cancer, marital status, and education. Model 3 additionally adjusted for age and physical activity. Each primary model included 10,641 participants. BRI was analyzed continuously and in quartiles; sex was retained despite the sex-specific outcome thresholds. Restricted cubic splines assessed nonlinearity using the same model covariates. The sensitivity model for absolute ALM adjusted for age, sex, BMI, physical activity, race/ethnicity, hypertension, diabetes, cancer, marital status, and education. These analyses were unweighted.

Exploratory ROC analyses described apparent in-sample discrimination. DeLong tests compared BRI with age, BMI, and physical activity. No internal or external validation was performed, and data-derived cutoffs, sensitivity, specificity, and Youden indices are not reported. BRI is a strictly increasing transformation of waist-to-height ratio, so the indices have identical rank-based ROC statistics when evaluated in the same participants. Waist circumference and waist-to-hip ratio were not separately compared.

Exploratory subgroup analyses evaluated age, sex, race/ethnicity, hypertension, diabetes, cancer, smoking, marital status, education, and physical activity. The 52 participants with missing physical activity were retained as a separate indicator category in multivariable models but were not analyzed as a separate physical-activity subgroup. Tests were two-sided, with $p < 0.05$ considered statistically significant. Analyses used SPSS Statistics 26 and R 4.3.3.

Supplementary results

Baseline characteristics are shown in Table I of the main article. The median age was 39.0 years, and 49.6% of participants were male. Participants with low BMI-adjusted ALM had higher median age, BMI, and BRI.

Apparent ROC results are presented in Supplementary Table SII and Figure 1 of the main article. DeLong comparisons favored BRI over age, BMI, and physical activity (all $p < 0.001$). These comparisons are unvalidated and do not establish superiority to other anthropometric measures or clinical screening utility. In the absolute ALM sensitivity analysis, the adjusted OR per one-unit increase in BRI was 5.25 (95% CI: 4.54–6.09), and the Q4-versus-Q1 OR was 72.65 (42.25–124.93; Supplementary Table SIII). These estimates are sensitive to outcome scaling and body-size adjustment.

Exploratory subgroup associations are shown in Supplementary Table SIV. Interactions were reported for sex ($p < 0.001$), hypertension ($p = 0.004$), diabetes ($p < 0.001$), and physical activity ($p < 0.001$). Other interactions were not statistically significant. The overall OR of 1.50 (1.46–1.54) shown in this table matches the unadjusted primary estimate in Supplementary Table SI. These exploratory comparisons involved multiple tests and do not support subgroup-specific clinical thresholds.

Supplementary Table SI. Associations of BRI with low BMI-adjusted appendicular lean mass

BRI exposure	Model 1 OR (95% CI)	Model 2 OR (95% CI)	Model 3 OR (95% CI)
Per one-unit increase	1.50 (1.46–1.54)	1.61 (1.56–1.67)	1.62 (1.56–1.67)
Quartile 1	Reference	Reference	Reference
Quartile 2	4.73 (2.75–8.14)	4.16 (2.41–7.17)	3.62 (2.09–6.25)
Quartile 3	16.54 (9.94–27.51)	14.32 (8.56–23.95)	12.20 (7.29–20.43)
Quartile 4	47.08 (28.56–77.60)	50.06 (30.09–83.29)	43.76 (26.27–72.88)
P for trend	< 0.001	< 0.001	< 0.001

BRI – body roundness index, BMI – body mass index, OR – odds ratio, CI – confidence interval. $N = 10,641$ in each model. Model 1: unadjusted. Model 2: adjusted for sex, race/ethnicity, hypertension, diabetes, cancer, marital status, and education. Model 3: additionally adjusted for age and physical activity. BMI was excluded from primary models. All analyses were unweighted. $P < 0.001$ for each continuous BRI estimate.

Supplementary Table SII. Exploratory in-sample discrimination for low BMI-adjusted ALM

Indicator	Apparent AUC	95% CI
Age	0.619	0.599–0.638
BMI	0.729	0.712–0.745
BRI	0.806	0.793–0.819
Waist-to-height ratio	0.806	0.793–0.819
Hypertension	0.543	0.527–0.558
Diabetes	0.548	0.536–0.560
Physical activity	0.570	0.553–0.587

ALM – appendicular lean mass, BMI – body mass index, BRI – body roundness index, AUC – area under the receiver operating characteristic curve, CI – confidence interval. Apparent AUCs were not internally or externally validated. The waist-to-height ratio entry follows from its identical rank ordering to BRI in the same sample. These results do not establish clinical screening performance.

Supplementary Table SIII. Sensitivity analysis using the FNIH absolute ALM definition

BRI exposure	Adjusted OR (95% CI)
Per one-unit increase	5.25 (4.54–6.09)
Quartile 1	Reference
Quartile 2	4.50 (3.55–5.70)
Quartile 3	15.78 (11.09–22.46)
Quartile 4	72.65 (42.25–124.93)
P for trend	< 0.001

ALM – appendicular lean mass, BMI – body mass index, BRI – body roundness index, FNIH – Foundation for the National Institutes of Health, OR – odds ratio, CI – confidence interval. N = 10,641. Low ALM: < 19.75 kg in men and < 15.02 kg in women. The model adjusted for age, sex, BMI, physical activity, race/ethnicity, hypertension, diabetes, cancer, marital status, and education. $P < 0.001$ for continuous BRI. All estimates were unweighted and are sensitive to outcome scaling and body-size adjustment.

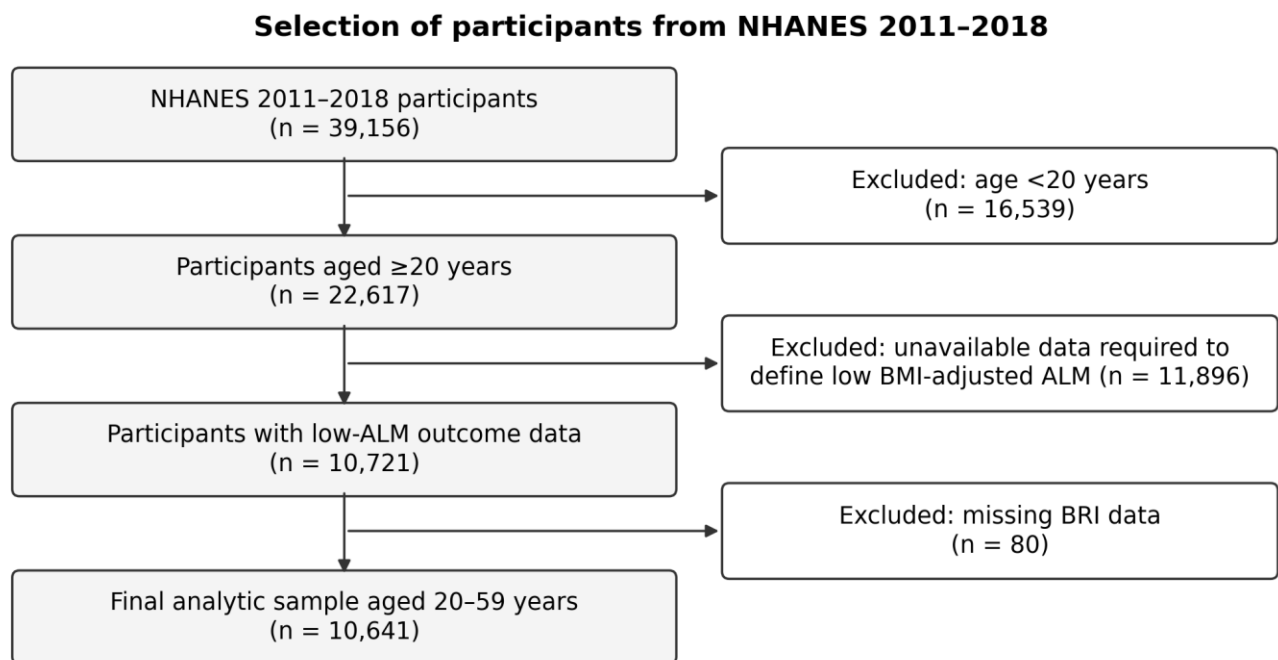
Supplementary Table SIV. Exploratory subgroup associations of BRI with low BMI-adjusted ALM

Subgroup	<i>n</i> (%)	OR (95% CI)	<i>P</i> -value	<i>P</i> for interaction
Overall	10,641 (100.00)	1.50 (1.46–1.54)	< 0.001	
Sex				< 0.001
Male	5,278 (49.60)	1.69 (1.62–1.77)	< 0.001	
Female	5,363 (50.40)	1.43 (1.38–1.49)	< 0.001	
Race/ethnicity				0.946
Mexican American	1,582 (14.87)	1.61 (1.51–1.72)	< 0.001	
Non-Hispanic White	3,656 (34.36)	1.58 (1.50–1.67)	< 0.001	
Non-Hispanic Black	2,268 (21.31)	1.60 (1.47–1.75)	< 0.001	
Other races	3,135 (29.46)	1.57 (1.48–1.66)	< 0.001	
Hypertension				0.004
Yes	2,489 (23.39)	1.42 (1.36–1.49)	< 0.001	
No	8,152 (76.61)	1.55 (1.50–1.61)	< 0.001	
Diabetes				< 0.001
Yes	857 (8.05)	1.32 (1.23–1.41)	< 0.001	
No	9,784 (91.95)	1.52 (1.48–1.57)	< 0.001	
Cancer				0.688
Yes	400 (3.76)	1.54 (1.36–1.73)	< 0.001	
No	10,241 (96.24)	1.50 (1.46–1.54)	< 0.001	
Smoking history				0.067
Yes	4,158 (39.08)	1.55 (1.48–1.62)	< 0.001	
No	6,483 (60.92)	1.47 (1.42–1.52)	< 0.001	
Marital status				0.104
Married/living with partner	6,352 (59.69)	1.52 (1.47–1.58)	< 0.001	
Widowed/divorced/separated	1,483 (13.94)	1.54 (1.43–1.65)	< 0.001	
Never married	2,806 (26.37)	1.43 (1.36–1.50)	< 0.001	
Education				0.782
Less than high school	1,148 (10.79)	1.51 (1.40–1.63)	< 0.001	
High school graduate/equivalent	7,489 (70.38)	1.49 (1.44–1.54)	< 0.001	

Subgroup	<i>n</i> (%)	OR (95% CI)	<i>P</i> -value	<i>P</i> for interaction
College graduate or above	2,004 (18.83)	1.54 (1.42–1.66)	< 0.001	
Age				0.927
<40 years	5,393 (50.68)	1.49 (1.43–1.56)	< 0.001	
≥40 years	5,248 (49.32)	1.49 (1.44–1.55)	< 0.001	
Physical activity				< 0.001
Insufficient	3,345 (31.44)	1.40 (1.35–1.46)	< 0.001	
Sufficient	7,244 (68.08)	1.55 (1.50–1.61)	< 0.001	

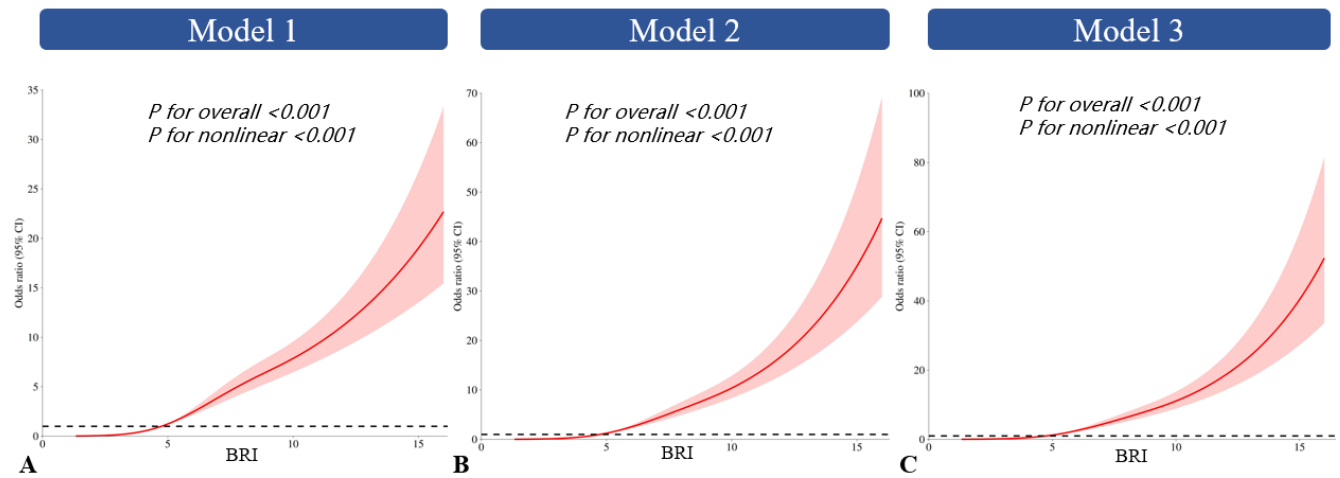
ALM, appendicular lean mass; BMI, body mass index; BRI, body roundness index; OR, odds ratio; CI, confidence interval. ORs are per one-unit increase in BRI. Estimates are exploratory and unweighted. The overall estimate corresponds to the unadjusted primary OR. Percentages use the total analytic sample as the denominator. The 52 participants with missing physical activity were not included as a separate subgroup.

Supplementary Figure S1. Participant selection from NHANES 2011–2018



ALM – appendicular lean mass, BMI – body mass index, BRI – body roundness index, NHANES – National Health and Nutrition Examination Survey. The outcome-data exclusion includes participants without the measurements required for ALM/BMI, including those outside the age range eligible for the body-composition examination. The final sample is unweighted.

Supplementary Figure S2. Restricted cubic spline analyses of BRI and low BMI-adjusted appendicular lean mass



Panels A–C correspond to Models 1–3 in Supplementary Table SI. Red lines show odds ratios; shaded areas show 95% confidence intervals. Dashed lines indicate an odds ratio of 1. All analyses were unweighted. BRI – body roundness index; BMI – body mass index.