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ORIGINAL RESEARCH

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Body Mass Index and Age-Adjusted Body Mass Index in Older Individuals: Clinical and Functional Correlations across Categories. Study from 30 904 Older Adults Living in the Community

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ABSTRACT

Body Mass Index (BMI) use in older adults has been questioned as it does not account for the loss of height with age, overestimating weight status. We explored age-height loss adjusted BMI (BMI-A) correlation with health variables, the significance of these associations for each BMI category, and concordance between BMI and BMI-A. This is a secondary analysis of three different population studies of older adults: SABE Ecuador 2009, SABE Colombia 2015, and MHAS 2015 (total $n = 30{,}904$). BMI-A was based on expected physiological loss, adding centimeters based on patient's age range. A descriptive analysis was performed, and concordance and correlation between models was tested. The correlation of each model divided by anthropometrical categories was tested with outcomes. Mean age was 69.8 (SD 7.59) years, 54.24% were females. BMI-A value was lower. For BMI-A the most common category was normal weight, compared to BMI where overweight was the most common. Correlation and agreement between models were good. For the general sample, all correlations were statistically significant, except for albumin. However, for the different categories,

KEYWORDS

Body mass index; geriatrics; population; body height

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significance was reduced, and specifically in people with low weight any relationship was significant. Relying exclusively on BMI for clinical decisions in older adults may not be optimal.

Introduction

Introduced in 1835 by Quetelet, the Body Mass Index (BMI) is a widely used anthropometric tool in medicine.[1] Traditionally, BMI has served as an approximation of adiposity and nutritional status, as well as a predictor of chronic diseases and health outcomes. Consequently, it has been widely incorporated into clinical practice and the development of health policies[2].

Even when there is evidence supporting the association of BMI with mortality and poor outcomes[3], the usefulness of this measurement is currently questioned due to some limitations. In older adults a major concern arises from the fact that BMI does not account for the morphophysiological changes associated with aging, such as the progressive loss of skeletal muscle mass and the increase in body fat[4,5]. Therefore, patients with a high fat-to-muscle ratio, which is associated with metabolic disorders[6], may be misclassified as healthy. Additionally, a less-discussed limitation in interpreting BMI for older adults is the loss of height that occurs as part of the aging process. This height loss is associated with outcomes such as sarcopenia and frailty[7], cognitive impairment[8], cardiovascular disease and mortality[9] and all-cause mortality[10]. A longitudinal follow-up of Spanish older adults (≥65 years), conducted by Moradell et al.[4], revealed that the mean height loss over an 8-year period is approximately 0.8 cm in men and 1.1 cm in women. Despite maintaining a stable weight, this height loss alone can result in an increase in BMI, impacting its accuracy in older individuals. Consequently, BMI may overestimate weight status, mask underweight and weight loss while overestimating overweight and obesity prevalence[11,12].

In addition, due to its inability to distinguish between lean mass and fat mass, BMI could potentially provide misleading assessments of health risks and nutritional status. As a result, patients with high lean body reserves are often misclassified as obese, while individuals with a high percentage of body fat but low muscle mass (sarcopenic obesity) are categorized as normal[13,14], with obvious different health consequences for these scenarios. Additionally, as it was not designed for this purpose, BMI fails to account for the distribution of body fat, which is a crucial cardiometabolic risk factor, especially when fat accumulates centrally (visceral pattern)[15,16].

Given the above scenario, several questions arise about the misclassification rate in the anthropometric assessment of older adults. In this sense, mainly considering the age-related height changes, previous studies have tried to design variants of the BMI. However, evidence is scarce, and proposals vary between adjustments based on the adult height[17,18] and longitudinal follow-ups to estimate the height loss[19,20], primarily from North American cohorts. Evidence is even more limited in Latin-American populations. In this study, we aimed to explore age-height loss adjusted BMI (BMI-A), assessing the concordance between standard BMI and BMI-A, and their correlation with clinically and functionally relevant variables in older adults, considering each BMI category.

Materials and methods

We conducted an analysis using data from three different population studies of older adults aged over 60 years, designed to determine the factors characterizing aging in their respective countries: the Salud, Bienestar y Envejecimiento (SABE) study in Ecuador 2009, SABE Colombia 2015, and the Mexican Health and Aging Study (MHAS) 2015. These cross-sectional studies collectively included a total of 30,904 participants (20,439 from Colombia, 3,614 from Ecuador, and 7,027 from Mexico), all aged 60 years or older, residing in both rural and urban areas. These Latin-American populations share sociodemographic risk profiles that shape health and aging processes, influencing significant health outcomes in older adults. Therefore, they were selected for this research.

The SABE Ecuador study was conducted by the Instituto Nacional de Estadística y Censos (INEC) Department of Sociodemographic Statistics and funded by the Ministry of Social and Economic Inclusion of Ecuador. In SABE Colombia, the University of Caldas and the University of Valle performed the study in collaboration with other academic institutions, government agencies, and international partners. The SABE studies used an instrument derived from the international instrument designed for the original SABE study conducted in five Latin American capital cities, and more details of the survey are available elsewhere[21,22]. Moreover, as of 2018, SABE Colombia was the largest database available for Latin American older adults.

On the other hand, The MHAS is a cohort study with several waves. It was conducted by researchers and institutions in Mexico, primarily coordinated by the Instituto Nacional de Estadística y Geografía (INEGI, or Mexico's National Institute of statistics and Geography). The data included in this study was obtained during the fourth wave of the study

in 2015. MHAS is a prospective, nationally representative panel study, containing a representative sample of community-dwelling Mexican adults.

The three studies covered a wide range of topics, including socio-demographic characteristics, cognitive status, health-related factors such as cognitive and physical function, medication usage, and healthcare services utilization. Additionally, they examined social network and family support, work and income history, housing conditions, physical performance, and exposure to violence and abuse[22]. The selection of the sample and final number of subjects included can be seen in Supplementary Figure 1.

Regarding SABE Colombia, approval was received from the ethics and scientific committee of the Aging Institute at Hospital Universitario San Ignacio and the Pontificia Universidad Javeriana. SABE Ecuador was authorized by the Ecuadoran ministry of health authorities. MHAS approval was sought and obtained from the Institutional Review Board of the University of Texas Medical Branch, and the Mexican Instituto Nacional de Estadística y Geografía and Instituto Nacional de Salud Pública. All subjects signed an informed consent for each study, and ethical guidelines of the Declaration of Helsinki were followed.

Variables

In the three studies, BMI was determined using anthropometric data, with body weight and height measured while the participant wore light indoor clothing. Weight was measured using an electronic portable scale accurate to the nearest 0.1 kg, and height was measured using a stadiometer accurate to the nearest 0.1 cm. BMI was then calculated using the formula BMI = weight (kg)/height (m^2). Participants were categorized into four weight status categories: underweight (<18.5 kg/m^2), normal (18.5 – 24.9 kg/m^2), overweight (25 – 29.9 kg/m^2), and obese (≥30 kg/m^2)[23].

Due to the inability to reliably determine the youth height of the participants, we decided to calculate the BMI-A by adjusting height based on the expected physiological loss for each age group. This adjustment was informed by the longitudinal findings from the study conducted by Moradell and colleagues in Spanish-speaking older adults[4]. Specifically, we added 0.7 cm for men and 1.0 cm for women between the ages of 60 to 69; 0.9 cm for men and 1.2 cm for women between the ages of 70 to 74; and 0.9 cm for men and 1.4 cm for women in those aged 75 years and older[4]. Following this adjusted height, the BMI was calculated in the same manner as the standard method.

The Mini-Nutritional Assessment Short Form (MNA-SF) was calculated in all participants. The MNA-SF score of 12-14 points was considered as "normal nutritional status", a score between 8 and 11 was categorized as "at risk of malnutrition" and a score between 0 and 7 points was

considered "malnourished". However, for the main analysis, MNA score was used as a continuous variable[24]. The version used was the version without BMI to avoid collinearity.

Other variables assessed included cognition, measured using the abbreviated version of the Mini-Mental State Examination (MMSE) in SABE which has been validated in several SABE studies[25]. For the MHAS a modified version of the cross-cultural Cognitive Examination (CCCE) was used to establish cases of cognitive impairment, with previously reported methodology on processing sub-tests and cutoff values (according to age and years in school categories). Additionally, we examined handgrip strength (measured in kilograms) in the 3 studies. The same methodology was used also for gait speed.

Measurements of albumin and lymphocytes were taken in a subgroup of participants, as part of a complete blood count, and their counts were obtained using automated hematology analyses in a subsample of 1635 subjects form Ecuador.

Variables were chosen not only for their availability in the data but also for their clinical significance. These variables act as important indicators of nutritional, functional, and cognitive status, helping to identify geriatric syndromes like malnutrition, cognitive decline, and sarcopenia[26,27], which are strongly related to disability and mortality[28,29]. Additionally, albumin and lymphocyte count are included in the nutritional risk assessment, as outlined by the Prognostic Nutritional Index[30].

Confounding variables

We included demographic factors such as age, sex and years of schooling. Also, a medical conditions index was created with the sum of the presence of comorbidities: diabetes mellitus, depression, chronic obstructive pulmonary disease (COPD), joint disorders, osteoporosis, cancer, cerebrovascular events, visual problems, and heart disease.

Statistical analysis

First, a descriptive analysis was conducted on the variables included in the analysis disaggregated by country. Following this, Kappa statistics were performed to compare the agreement between the categories of the traditional BMI with the BMI-A. Also, Bland-Altman plots were constructed to evaluate and communicate the concordance and differences between of the traditional BMI with the BMI-A, including the mean of the differences, the bias, individual observations and a correlation analysis using Spearman's Rho coefficient. Finally, linear regression models were fitted to explore the association of the traditional BMI and BMI-A with each of the outcomes of interest:

MNA, MMSE, CCCE, Handgrip strength (Kg), Gait Speed (m/s), Lymphocytes (cells/μL) and Albumin (g/dL). These models were adjusted for sex, age, years of schooling, and comorbidities. During the diagnostic phase of the adjusted models, observations considered as outliers were removed using Cook's Distance. A significance level of 0.05 was set for hypothesis testing. R software version 4.2.1 was used to carry out statistical analyses.

To handle missing data, a complete case analysis approach was used. That is, each multiple linear regression model included only participants with complete information for both dependent and independent variables. No imputation of missing data was performed.

Results

Population characteristics and descriptive results

General characteristic of the sample can be found in Table 1. 54.24% of the population were females, and data divided by sex is available in Supplementary Table 1. More males had normal weight (30.5% in women and 42.6% in men), and BMI (27.5 for women and 25.7 for men), as well as BMI-A (27.0 for women and 25.3 for men) were higher in females.

BMI-A provided a lower value, compared to the standard BMI, in all categories. Also, for the overall sample, in the BMI-A the most common

Table 1. Population characteristics by country.

Characteristics	Colombia (*n* = 20,439)	Ecuador (*n* = 3,614)	Mexico (*n* = 7,027)	Overall (*n* = 31,080)
Age, mean (SD)	70.0 (7.68)	70.2 (7.98)	69.0 (7.05)	69.8 (7.59)
Sex, *n* (%)				
Female	11420 (55.9%)	1770 (49.0%)	3669 (52.2%)	16859 (54.2%)
Male	9019 (44.1%)	1844 (51.0%)	3358 (47.8%)	14221 (45.8%)
Education, (%)				
Elementary school	4274 (20.9%)	176 (4.9%)	3677 (52.3%)	8127 (26.1%)
Middle school	11744 (57.5%)	2772 (76.7%)	2641 (37.6%)	17157 (55.2%)
High school	3084 (15.1%)	470 (13.0%)	280 (4.0%)	3834 (12.3%)
College/ University	1337 (6.5%)	196 (5.4%)	429 (6.1%)	1962 (6.3%)
Mini mental State Examination (MMSE), mean (SD)	23.9 (7.08)	15.4 (2.95)	–	22.6 (7.28)
Missing, (%)	0 (0%)	99 (2.7%)	–	7126 (22.9%)
Cross Cultural Cognitive Examination (CCCE), mean (SD)	–	–	55.6 (17.7)	55.6 (17.7)
Mini Nutritional Assessment (MNA), mean (SD)	10.5 (1.80)	12.1 (1.56)	12.6 (1.53)	11.0 (1.93)
Missing, (%)	3338 (16.3%)	97 (2.7%)	4315 (61.4%)	7750 (24.9%)
Number of comorbidities, mean (SD)	1.44 (1.29)	1.57 (1.46)	1.04 (0.965)	1.36 (1.26)
Handgrip strength (Kg), mean (SD)	23.0 (8.80)	24.1 (9.51)	25.0 (8.65)	23.8 (9.17)
Missing, (%)	17917 (87.7%)	95 (2.6%)	6098 (86.8%)	24110 (77.6%)
Gait Speed, mean (SD)	0.734 (0.274)	–	0.642 (0.229)	0.729 (0.273)
Missing, (%)	604 (3.0%)	–	6102 (86.8%)	10320 (33.2%)
Lymphocytes (cells/μL), mean (SD)	–	2420 (776)	–	2420 (776)
Missing, (%)	–	1900 (52.6%)	–	29366 (94.5%)
Albumin (g/dL), mean (SD)	–	4.36 (0.317)	–	4.36 (0.317)

Missing variables "-" refers that those elements were not available for that specific survey.

Table 2. BMI classification of the population using the standard BMI and the BMI-A.

Characteristics	Colombia ($n = 20,439$)	Ecuador ($n = 3,614$)	Mexico ($n = 7,027$)	Overall ($n = 31,080$)
BMI (kg/m^2), mean (SD)	26.5 (4.93)	26.3 (4.66)	27.3 (4.84)	26.6 (4.89)
BMI classification (kg/m^2), (%)				
Underweight	715 (3.5%)	96 (2.7%)	102 (1.5%)	913 (2.9%)
Normal	7524 (36.8%)	1383 (38.3%)	2295 (32.7%)	11202 (36.0%)
Overweight	7758 (38.0%)	1468 (40.6%)	2903 (41.3%)	12129 (39.0%)
Obese	4442 (21.7%)	667 (18.5%)	1727 (24.6%)	6836 (22.0%)
BMI-A (kg/m^2), mean (SD)	26.1 (4.86)	25.9 (4.59)	26.9 (4.76)	26.2 (4.82)
BMI-A classification (kg/m^2), (%)				
Underweight	853 (4.2%)	117 (3.2%)	121 (1.7%)	1091 (3.5%)
Normal	8111 (39.7%)	1511 (41.8%)	2489 (35.4%)	12111 (39.0%)
Overweight	7562 (37.0%)	1398 (38.7%)	2895 (41.2%)	11855 (38.1%)
Obese	3913 (19.1%)	588 (16.3%)	1522 (21.7%)	6023 (19.4%)
Weight, mean (SD)	64.8 (13.1)	62.0 (12.3)	69.7 (13.5)	65.6 (13.3)
Height, mean (SD)	156 (8.88)	154 (9.00)	160 (9.84)	157 (9.30)
Adjusted height, mean (SD)	159 (8.66)	156 (8.77)	162 (9.64)	159 (9.08)

category was normal weight, which was also seen in the sample from Ecuador and Colombia, compared to the standard BMI where overweight was the most common category (Table 2).

Agreement between models

Based on Kappa statistics, the agreement between BMI and BMI-A was almost perfect, both for the overall group (Kappa 0.924) and when divided by sex (Female Kappa 0.932, Male Kappa 0.875)[31] (Supplementary Table 2).

Concordance and correlation between models

In general, models showed no concordance between the BMI and the BMI-A. The smallest bias was for males with low weight (bias = 0.26), and the largest was for males with obesity (bias = 0.56) (Figure 1).

Correlation between models was statistically significant for all categories. The largest magnitude of the association was for the overall females (estimate = 0.702, $p < 0.001$), and the lowest was for females with overweight (estimate = 0.311, $p < 0.001$) (Figure 1). The models for people with normal weight can be found in Supplementary Figure 2.

Linear regression models

In general, for the overall samples, all correlations were statistically significant, except for the albumin in females and in the whole sample. In people with normal weight, the MNA (BMI: estimate = 0.541, $p < 0.001$; BMI-A: estimate = 0.556, $p < 0.001$), MMSE (BMI: estimate = 0.266, $p < 0.001$; BMI-A: estimate = 0.278, $p < 0.001$), handgrip strength (BMI: estimate = 0.335, $p < 0.001$; BMI-A: estimate = 0.556, $p < 0.001$), and

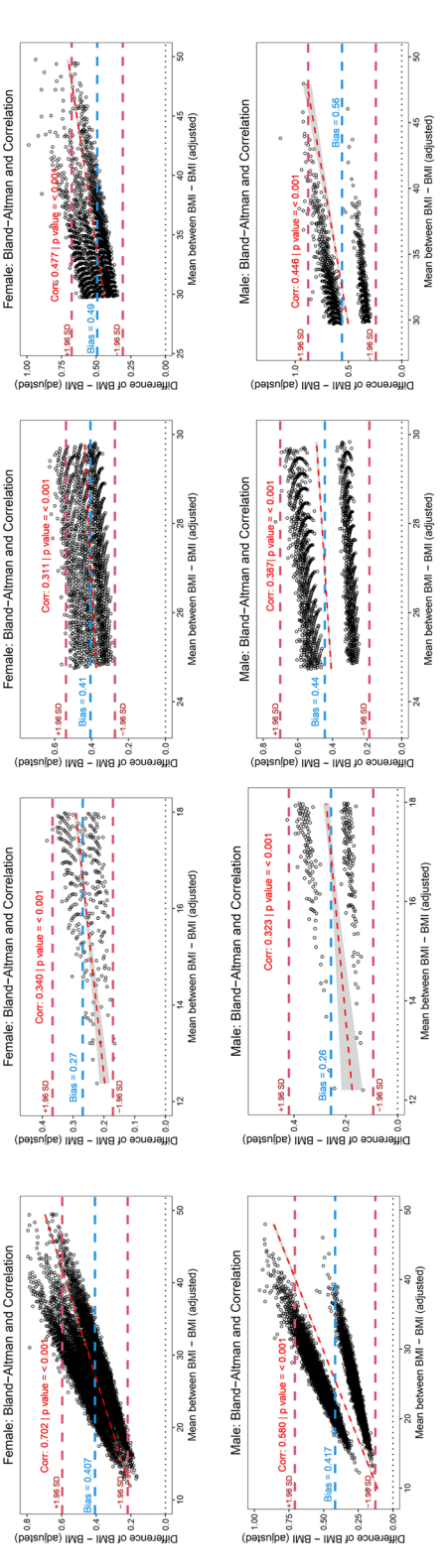


Figure 1. Concordance and correlation between models for the overall sample, people with overweight and people with underweight.

Bland-Altman plots reflect the concordance between BMI and BMI-A in the overall sample and for each nutritional category. The Y-axis shows the differences between the methods against the mean of both methods (X-axis). The blue central line represents the mean of differences, while the upper and lower red lines indicate the limits of agreement.

lymphocytes (BMI: estimate = 35.123, $p = 0.036$; BMI-A: estimate = 36.477, $p = 0.031$), had an statiscally significant association. However, for the different categories, significance was lost for certain outcomes. For people with low weight, any relationship was significant. In people with overweight, the MMSE had a significant relationship for the overall sample (BMI: estimate = 0.118, $p = 0.014$; BMI-A: estimate = 0.143, $p = 0.003$). For people with obesity, a significant relationship was found only for gait speed (BMI: estimate = −0.007, $p < 0.001$; BMI-A: estimate = −0.008, $p < 0.001$) and albumin (BMI: estimate = −0.013, $p = 0.035$; BMI-A: estimate = −0.013, $p = 0.037$) (Table 3).

Table 3. Linear regression models divided by nutritional status.

Overall sample						
	Exposure variables*					
	BMI			BMI-A		
Dependent variable	Estimate	Std. Error	*P* value	Estimate	Std. Error	*P* value
Mini Nutritional Assessment Short Form (MNA-SF)	0.1275	0.0026	**<0.001**	0.1294	0.0026	**<0.001**
Mini mental State Examination (MMSE)[a]	0.1210	0.0092	**<0.001**	0.1248	0.0093	**<0.001**
Cross Cultural Cognitive Examination (CCCE)[a]	0.1850	0.0400	**<0.001**	0.1908	0.0406	**<0.001**
Handgrip strength (Kg)	0.1747	0.0175	**<0.001**	0.1755	0.0178	**<0.001**
Gait Speed, mean (SD)	−0.0028	0.0004	**<0.001**	−0.0029	0.0004	**<0.001**
Lymphocytes (cells/μL), mean (SD)[a]	17.2530	4.2510	**<0.001**	17.7060	4.3180	**<0.001**
Albumin (g/dL)[a]	0.0001	0.0017	0.944	0.0002	0.0018	0.928
Underweight						
	Exposure variables*					
	BMI			BMI-A		
Dependent variable	Estimate	Std. Error	*P* value	Estimate	Std. Error	*P* value
Mini Nutritional Assessment Short Form (MNA-SF)	−0.0162	0.0495	0.744	−0.0168	0.0501	0.738
Mini mental State Examination (MMSE)[a]	0.0945	0.1836	0.607	0.1071	0.1863	0.566
Cross Cultural Cognitive Examination (CCCE)[a]	2.5778	1.9964	0.201	2.7849	2.0154	0.172
Handgrip strength (Kg)	−0.2449	0.2375	0.304	−0.2474	0.2411	0.306
Gait Speed, mean (SD)	−0.0027	0.0090	0.768	−0.0024	0.0091	0.792
Lymphocytes (cells/μL), mean (SD)[a]	86.1300	60.0000	0.161	88.8600	60.8100	0.154
Albumin (g/dL)[a]	0.0100	0.0241	0.681	0.0094	0.0245	0.705
Normal						
	Exposure variables*					
	BMI			BMI-A		
Dependent variable	Estimate	Std. Error	*P* value	Estimate	Std. Error	*P* value
Mini Nutritional Assessment Short Form (MNA-SF)	0.5331	0.0114	**<0.001**	0.5392	0.0116	**<0.001**
Mini mental State Examination (MMSE)[a]	0.3013	0.0429	**<0.001**	0.3208	0.0435	**<0.001**
Cross Cultural Cognitive Examination (CCCE)[a]	0.3844	0.2104	0.068	0.3918	0.2135	0.067
Handgrip strength (Kg)	0.3031	0.0811	**<0.001**	0.2914	0.0823	**<0.001**

(*Continued*)

Table 3. Continued.

Gait Speed, mean (SD)	−0.0011	0.0017	0.535	−0.0010	0.0017	0.573
Lymphocytes (cells/μL), mean (SD)[a]	35.1230	16.7070	**0.036**	36.4770	16.9140	**0.031**
Albumin (g/dL)[a]	0.0039	0.0075	0.602	0.0046	0.0076	0.548
Overweight						
	Exposure variables*					
	BMI			BMI-A		
Dependent variable	Estimate	Std. Error	*P* value	Estimate	Std. Error	*P* value
Mini Nutritional Assessment Short Form (MNA-SF)	0.0192	0.0125	0.124	0.0190	0.0127	0.133
Mini mental State Examination (MMSE)[a]	0.1176	0.0477	**0.014**	0.1433	0.0483	**0.003**
Cross Cultural Cognitive Examination (CCCE)[a]	−0.1580	0.2049	0.441	−0.1192	0.2080	0.567
Handgrip strength (Kg)	0.1546	0.0956	0.106	0.1473	0.0969	0.129
Gait Speed, mean (SD)	−0.0004	0.0020	0.829	−0.0004	0.0020	0.857
Lymphocytes (cells/μL), mean (SD)[a]	9.4560	23.0690	0.682	13.5440	23.3780	0.563
Albumin (g/dL)[a]	0.0067	0.0082	0.414	0.0073	0.0083	0.383
Obese						
	Exposure variables*					
	BMI			BMI-A		
Dependent variable	Estimate	Std. Error	*P* value	Estimate	Std. Error	*P* value
Mini Nutritional Assessment Short Form (MNA-SF)	−0.0017	0.0069	0.800077	−0.0016	0.0070	0.814247
Mini mental State Examination (MMSE)[a]	−0.0070	0.0261	0.788	−0.0040	0.0265	0.879
Cross Cultural Cognitive Examination (CCCE)[a]	0.0780	0.0967	0.420	0.0853	0.0985	0.387
Handgrip strength (Kg)	0.0243	0.0467	0.603	0.0200	0.0474	0.673
Gait Speed, mean (SD)	−0.0074	0.0010	**<0.001**	−0.0075	0.0011	**<0.001**
Lymphocytes (cells/μL), mean (SD)[a]	−4.4560	13.6980	0.745	−5.0390	13.8880	0.717
Albumin (g/dL)[a]	−0.0130	0.0062	**0.035**	−0.0131	0.0062	**0.037**

Statistically significant results are bolded. For analysis divided by sex please see Supporting Information.
*Adjusted with sex, age, years of schooling and comorbidities.
[a]Not available in all surveys.

When addressing the specific differences between the standard BMI and BMI-A version, they behave similarly, with only one exception for the MMSE in males with overweight, which showed an association with BMI-A but not with BMI (BMI: estimate = 0.135, $p = 0.059$; BMI-A: estimate = 0.162, $p = 0.025$) (Supplementary Table 3).

Discussion

In this study, the models between BMI and BMI-A showed good correlation. Based on the Bland-Altman plots, a quantitative analysis showed no concordance between the models, but as the Kappa statistics evidenced an almost perfect agreement, the classification per categories of the patients was similar. Additionally, there were no differences in their association with relevant clinical outcomes in older adults such as cognition, nutritional

status, functionality, or biochemical parameters. As BMI measurements lose concordance within higher weight categories, probably due to the loss of height that increases the traditional BMI, using the BMI-A provides a better anthropometrical knowledge and decrease the overestimation of overweight, but with the same uncertainty to determine whether the weight is due to fat or muscle. It has been shown that older adults with obesity may have a larger muscle volume[32] providing a limitation to establish a unique pattern of body composition. Moreover, it is difficult to know where people with a high BMI can have a phenotype more oriented to sarcopenic obesity or 'healthy obesity' and, in these cases, other variables, such as physical activity and caloric intake, should be considered, as they can affect body composition, oxidative stress, inflammation and anabolic resistance[32].

The BMI-A version classified a larger percentage of people with normal weight, compared to the standard version, where overweight was the most common category in this group. This underscores the importance of considering normal age-related height loss when assessing BMI. Failure to account for this can lead to an overestimation of the prevalence of excess weight. This observation may help explain recent findings indicating that older adults with overweight status exhibit better health statuses and outcomes compared to older adults with normal BMI[33]. In this sense, a recent study in older patients at a hospital in Italy suggests that among patients older than 60 years old, having moderate overweight may confer a lower risk of developing comorbidities such as cardiovascular diseases[34]. Moreover, recent evidence suggests that later-life obesity may be a protective factor for dementia, and dementia-related mortality[35]. This trend has been described as the obesity paradox in aging and is mainly due to a lack of consideration of other variables such as fitness, body composition, visceral adiposity or sarcopenic obesity[36], underscoring the importance of not solely considering BMI without other anthropometrical or cardiometabolic context. Therefore, it could be posited a natural increase in BMI during aging, attributed to changes in height, may result in an underestimation of individuals with malnutrition, a predominant risk factor for frailty, delirium, muscle wasting, cognitive decline, depression, lower quality of life, osteoporosis and premature mortality in older adults[37].

Changes in the proportion of individuals classified in a pathological weight category have been previously examined. A longitudinal study conducted in 2006, using a large Norwegian sample, demonstrated that the observed increase in the proportion of overweight and obese individuals may be attributed to a decline in height during follow-up, particularly among the oldest age groups[11]. Therefore, alternative approaches could be used, such as employing age-specific cutoff points. In this regard, the Spanish Society of Clinical Nutrition and Metabolism (SENPE) proposes a broader range for classifying normal body weight in the elderly

population, based on studies that demonstrated an increased mortality risk associated with a BMI <22kg/m^2–[38]. According to SENPE criteria, BMI <22kg/m^2 is categorized as underweight, 22-27kg/m^2 as normal, 27.1–29.9 kg/m^2 as overweight and ≥30kg/m^2 as obese[38]. Other studies suggest that a normal BMI range for optimal longevity could be considered between 23 and 29.9 kg/m^2–[39].

Moreover, a review from 1999 stated that the BMI is associated with minimal increases in mortality with age, possibly due to undernutrition being masked by height loss[20]. BMI can be more reliable in severe cases of malnutrition, however, in the early stages of malnutrition, or where the diagnosis is not clear, it could be useful to complement clinical evaluation with other tools. In fact, a report from a secondary analysis of MHAS, evidenced that in frail older adults, measuring calf circumference better predicts mortality. Also, BMI was not associated with mortality in this study[40].

In our study, in the linear regression models, irrespective of whether it was BMI or BMI-A, being obese was associated with lower albumin levels and slower gait speed. Normal status showed a protective association with cognition and nutritional status, and overweight status showed a protective association with cognition. Being underweight according to BMI or BMI-A did not show significant correlations. However, when assessing BMI and BMI-A without the categories, it exhibited significant associations with most of the assessed variables. This highlights the need of more tailored tools for the assessment of anthropometry in older adults, especially in those who already have underweight and may have a larger risk of poorer outcomes. This can help support the use of BMI as a possible entry tool for the initial nutritional assessment of patients. However, as mentioned, in a second assessment it is important to add other tools that can, for example, identify sarcopenic obesity or the presence of muscle mass with low fat mass index. In addition, the adjustment (BMI-A) did not modify the outcomes, which is consistent with the high agreement and correlation between models. Also, from a clinical point of view, BMI and BMI-A did not display relevant differences when assessing their association with the dependent variables. Therefore, this might suggest that there are no substantial advantages in using BMI-A. However, a previous study reports that using BMI-A provides an advantage related to its association with cardiovascular and metabolic outcomes[17]. Not considering age-related heigh loss substantially underestimate health status, and this change itself can affect health due to declines in muscle mass and bone density[41]. Moreover, height loss has been described as a marker of excess mortality in women, particularly related to cardiovascular diseases[10].

Widely used instruments like MNA and other nutritional risk scores incorporate BMI categories as a crucial element. However, as mentioned, BMI reliability as age increases has been an important topic for

gerontological research[12]. Several studies have attempted to employ other tools as a replacement, such as calf or mid-arm circumference for a modified MNA[42]. Also, hematological variables such as neutrophil-to-lymphocyte ratio, which has previously been associated with nutritional status, were recently proposed by our group as an alternative to BMI in the MNA-SF, finding fair agreement and varying associations with functional, cognitive and physical assessment variables[43]. In this sense, it is important to propose and develop new clinical assessment tools, as well as update the already stablished ones.

Another aspect that BMI does not directly consider is body composition. In addition to height loss, aging leads to a redistribution of adiposity. Moreover, when weight loss occurs in older adults, it typically involves decreases in both fat mass index and fat-free mass index, which may be not adequately reflected by BMI alone[4]. Furthermore, for sarcopenic obesity, described as a unique condition distinct from obesity or sarcopenia alone, the use of BMI, while recognizing its limitations[44], should be reserved for screening purposes only when it is parallelly present with surrogate indicators of sarcopenia. Consequently, the diagnosis depends on skeletal muscle functional parameters and body composition analysis based on validated techniques as dual-energy X-ray absorptiometry, or bioelectrical impedance analysis[13]. Another measurement that could aid in identifying muscle mass is calf circumference. It has shown to predict mortality and incident disability; and might be a ready-available measurement for those clinicians with a busy office[45].

This study has some limitations. First, this is a cross-sectional study; therefore, causality cannot be determined. Second, we performed a secondary analysis which means that the variables were not collected for the specific purpose of this paper. Third, this study had missing data in several outcome variables; therefore, a complete case analysis approach was used without applying imputation techniques, which reduced the sample size in some models. It was not possible to determine whether the missing data was completely random, so the presence of selection bias cannot be ruled out. Nevertheless, statistically significant associations were identified in the models, suggesting that the analyses retained sufficient power to detect relevant associations, although the results should be interpreted with caution. Sample sizes are available in Figure 1.

Finally, our proposal for BMI-A faces certain challenges. On the one hand, it′s unrealistic to assume that all individuals will experience uniform height loss. Factors such as vertebral fractures, back muscles weakness and intervertebral disk degeneration contribute to this event[46], but their impact varies among different people, so within distinct subgroups of older adults with a similar age, height loss can significantly differ. Consequently, applying a global adjustment for all older adults, including

those who may not require it, could potentially underestimate or overestimate both the prevalence of overweight and underweight. On the other hand, in this study, BMI adjustment was derived from the results from a Spanish Cohort[4], which raises concerns about the external validity of the formulae, particularly for developing countries. This contradicts the rationale for using BMI-A, which aims to achieve greater accuracy in anthropometric classification. Other researchers have suggested alternative approaches, such as using youth height, recorded before the age 30–40, which marks the onset of height loss[17]. However, obtaining accurate historical height data from clinical practice is unlikely due to recall bias, and other approaches and cutoff points based on data from other cohorts may come from regions with a more different genetic ancestry such as Scandinavians countries[11], compared to Spain and Latin America[4].

Despite these challenges, we believe our proposal may prove valuable for patients with clinically apparent heigh loss or musculoskeletal conditions strongly related to height changes. Furthermore, rather than validate a new global adjustment for BMI, our scope is to explore alternative approaches that allow for improved accuracy in its classification but emphasizing that even BMI-A has limitations and, on its own, is not directly associated with clinically relevant outcomes (although a statistically significant association was demonstrated, the beta coefficients were quite small). Therefore, it should always be complemented by other health and nutrition markers.

Conclusion

Our results indicate that both BMI-A and BMI show similar correlations with key variables related to old age. Moreover, the BMI-A classified a larger percentage of people with normal weight, compared to the standard version. However, when comparing categories, these instruments appear to lack correlation with important health variables, particularly in cases of underweight conditions.

BMI is widely used and provides valuable insights into health-related outcomes, especially in cases of underweight or obesity. However, like most health measures, BMI has limitations, particularly when assessing older adults, where changes in the musculoskeletal system due to aging can affect accuracy. Therefore, it is advisable to conduct a comprehensive nutritional and anthropometric assessment and to propose new tools, as well as update the already established clinical assessment tools for this purpose in future studies. Relying solely on BMI and BMI-A categories for important clinical decisions in the treatment of older adults may not be optimal.

Author contributions

SSL: Investigation, Methodology, Validation, Visualization, Writing - original draft. MLP: Investigation, Methodology, Validation, Writing - original draft. AMM: Conceptualization, Methodology, Writing - original draft. JPB: Data curation, Formal analysis, Methodology, Software, Writing - review & editing. PLS: Investigation, Validation, Writing - review & editing. DA: Funding acquisition, Resources; Writing - review & editing. MUPZ: Supervision, Validation, Writing - review & editing. MGB: Conceptualization, Investigation, Methodology, Writing - original draft- FJTZ: Project administration, Resources; Supervision, Writing - review & editing.

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Data availability statement

Information related to surveys supporting this work are available at: https://www.ecuadorencifras.gob.ec/encuesta-de-salud-bienestar-del-adulto-mayor/, https://www.mhasweb.org/Home/index.aspx and https://www.minsalud.gov.co/sites/rid/lists/bibliotecaDigital/RIDE/VS/ED/GCFI/Resumen-ejecutivo-encuesta-SABE.pdf.

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