

## OBESITY AND RELATED DISORDERS

# Modified body adiposity index for body fat estimation in severe obesity

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### Keywords

bioelectrical impedance analysis, body adiposity index, body composition, severe obesity, waist-hip ratio.

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### Abstract

**Background:** The body adiposity index (BAI) comprises a simple method for estimating body fat (BF) that needs to be validated in patients with severe obesity. The present study aimed to determine BAI accuracy with respect to the determination BF in patients with severe obesity.

**Methods:** A cross-sectional prospective study comparing two methods for BF estimation was conducted in 433 patients with severe obesity between August 2012 to December 2014. BF was estimated by bioelectrical impedance analysis (BIA) with specific equations developed for BF estimation in patients with severe obesity and BAI. The BF estimation in 240 patients with severe obesity (Group 1: G1) was used to evaluate BAI limitations and to develop a specific equation in this population. The new equation proposed was validated in another 158 patients with severe obesity (Group 2: G2).

**Results:** There was a significant difference between BF determination by BIA and BAI ( $P = 0.039$ ). The mean (SD) BF in G1 was 52.3% (6.1%) determined by BIA and 51.6% (8.1%) determined by BAI. Sex, waist-hip ratio (WHR) and obesity grade determined significant errors on BF estimation by BAI. A new equation (modified body adiposity index; MBAI) was developed by linear regression to minimise these errors [MBAI % =  $23.6 + 0.5 \times (\text{BAI})$ ; add 2.2 if body mass index  $\geq 50 \text{ kg m}^{-2}$  and 2.4 if WHR  $\geq 1.05$ ]. The new equation reduced the difference [1.2% (5.9%),  $P < 0.001$  to 0.4% (4.12%),  $P = 0.315$ ] and improved the correlation (0.6–0.7) between methods.

**Conclusions:** BAI present significant limitations in severe obesity and MBIAI was effective for BF estimation in this population.

### Introduction

Obesity rates are growing worldwide <sup>(1)</sup> and, in the USA, approximately 35.7% of the adult population is considered to be obese. Obesity is directly responsible for 112 000–365 000 deaths annually, with an estimated cost of 139 billion dollars <sup>(2–4)</sup>. Body fat (BF) assessment in patients with severe obesity is important with respect to treatment (clinical and surgical) evaluation because a loss of lean mass may be associated with deleterious health effects <sup>(5)</sup>. The maintenance of lean mass contributes to improving quality of life by maintaining the functional capacity <sup>(6)</sup>.

Severe obesity is characterised by excessive body fat deposition, increased total body water and a reduction of lean mass <sup>(7–9)</sup>. The hydration state could affect the values of fat free mass in body composition assessments <sup>(9)</sup>. These changes determine several limitations related to methods commonly used for evaluating body composition in normal weight, overweight or moderately obese subjects <sup>(8)</sup>. Furthermore, there are also physical limitations with respect to the equipment, as well as the ability to perform the manoeuvres required for body composition evaluation <sup>(7,8)</sup>.

Bioelectrical impedance analysis (BIA) significantly underestimates BF in morbid obese subjects <sup>(7,10–15)</sup>

because the equations developed to calculate BF using BIA resistance are population specific<sup>(16)</sup> and are considered inappropriate for patients with severe obesity<sup>(7,10,13,15,17)</sup>. Nevertheless, specific equations for BF estimation in severe obesity were developed and validated by Horie-Waitzberg using BIA data, with a high specificity and sensitivity compared with plethysmography<sup>(18)</sup>.

Anthropometry data also presents several limitations in patients with severe obesity<sup>(19)</sup>. However, Bergman *et al.*<sup>(20)</sup> developed the body adiposity index (BAI) using only two anthropometric measurements (hip circumference and height) and suggested that it could be an effective method for BF estimation even in patients with severe obesity. It was developed and validated in non-Caucasian subjects and might be adequate in populations of Central and South America<sup>(20)</sup>.

The present study aimed to evaluate BAI for BF determination in patients with severe obesity.

## Materials and methods

### Sampling procedure

A cross-sectional study comparing two methods for BF estimation was conducted in 433 patients with severe obesity undergoing bariatric surgery between August 2012 and December 2014 in the Bariatric and Metabolic Surgical Unit, Hospital das Clínicas, University of São Paulo Medical School. Patients with a pacemaker ( $n = 1$ ), acute or chronic disease (congestive heart failure, chronic renal failure, liver failure) associated with excessive water retention ( $n = 25$ ) or subjects who did not agree to participate ( $n = 9$ ) were excluded, leaving 398 patients in the study.

The present study was performed in accordance with the ethical recommendations of the Declaration of Helsinki and was approved by the Hospital das Clínicas Ethical Committee. All persons involved provided their informed consent prior to study enrollment. The sample was calculated using GPOWER, version 3.1 (<http://www.gpower.hhu.de>), with 5% of significance and 95% statistical power. Data were collected during the first nutritional interview in our ambulatory unit. Body weight was measured to the nearest 0.1 kg with a high precision electronic balance (model W 300A; Welmy, Santa Bárbara D'Oeste, Brazil) and height was measured with a stadiometer coupled to the balance to the nearest 0.5 cm. The circumferences were measured by using a flexible plastic tape with graduated scale. Waist circumference (WC) was measured between the last rib and the iliac crest (at the umbilical level) and hip circumference (HC) was measured in the largest circumference of the buttocks. Body fat was estimated by BAI and BIA.

## Measures

### Body adiposity index

Body fat was determined by BAI as described by Bergmann *et al.*<sup>(20)</sup>. This index comprises the use of two anthropometrics measurements to estimate body fat:

$$\text{BF}(\%) = \left[ \frac{\text{hip circumference (cm)}}{\text{height (m)}^{1.5}} \right] - 18.$$

### Bioelectrical impedance analysis

A single-frequency BIA (Model 310; Biodynamics, Seattle, WA, USA) was used to perform the analysis. Patients were in supine position with arms and legs lying parallel and separated, so that the thighs were not touching. Two electrodes were placed on the hand and wrist, and two others were positioned on the foot and ankle of the right side of the body. An electrical current of 50 kHz was introduced into the subject, and resistance and reactance were measured. BF was calculated using the Horie-Waitzberg<sup>(18)</sup> equation: Body fat (kg) = 23.25 + (0.09 × resistance in ohms) + (1.00 × weight kg) – (0.08 × height in meters) + (0.13 × age in years). The results were transformed into BF% using the formula:

$$\text{BF}\% = \frac{\text{BF (kg)}}{\text{weight (kg)}} \times 100.$$

### Statistical analysis

All statistical analyses were performed in R, version 3.0.2 (R Foundation for Statistical Computing, Vienna, Austria). The statistical methods of the present study were reviewed by of Epidemiology and Statistics Laboratory, Gastroenterology Department, University of São Paulo Medical School. Results are expressed as the mean (SD). A *t*-test and intraclass correlation were used to compare BAI with BIA. We used the Lausen<sup>(21)</sup> method to determine the cut-off points to waist-hip ratio (WHR) that might interfere with the BAI. Multiple linear regression analysis was used to develop a new equation for BF determination. In all of the analyses, the percentage of body fat estimated by BIA (Horie-Waitzberg equation) was used as the reference method.  $P < 0.05$  was considered statistically significant.

## Results

The BF determination in 240 patients with severe obesity (Group 1: G1) was used to determine the BAI limitations and to develop a specific correction equation (G1). The new equation proposed was validated in 158 subjects (Group 2: G2). There was no significant difference in subject characteristics between the two groups (Table 1).

Inter- and intra-observer variability coefficients for BIA and BAI evaluations were calculated (Table 2). There was a significant difference ( $P < 0.05$ ) between BF determination by BIA and BAI [0.6% (5.1%)]. The mean (SD) BF in G1 determined by BIA and BAI was 52.3% (6.1%) and

51.6% (8.1%), respectively. The two methods were similar according to the intraclass correlation (0.74; 95% confidence interval = 0.68–0.79) (Table 3). In patients with excessive abdominal fat accumulation (android obesity), BAI may underestimate BF. We determined a WHR cut-

**Table 1** Characteristics of the 398 patients with severe obesity evaluated before bariatric surgery (Group 1 and Group 2)

Characteristics	Group 1			Group 2		
	Total ( <i>n</i> = 240)	Female ( <i>n</i> = 190)	Male ( <i>n</i> = 50)	Total ( <i>n</i> = 158)	Female ( <i>n</i> = 136)	Male ( <i>n</i> = 22)
Age (years)	44.1 ± 11.1	44.5 ± 10.8	42.8 ± 12.2	44.1 ± 12.1	43.6 ± 12.2	43.4 ± 12.7
Weight (kg)	128.8 ± 23.8	122.6 ± 18.8	149.3 ± 27.1	128.5 ± 25.5	122.6 ± 19.8	156.1 ± 29.9
Height (m)	1.6 ± 0.1	1.6 ± 0.1	1.7 ± 0.1	1.6 ± 0.1	1.6 ± 0.1	1.7 ± 0.1
BMI (kg m <sup>-2</sup> )	49.2 ± 7.4	48.7 ± 7.1	50.9 ± 8.0	49.1 ± 7.6	48.3 ± 7.2	52.8 ± 7.4
WC (cm)	139.6 ± 18.5	136.8 ± 18.7	148.9 ± 14.6	135.2 ± 17.0	131.3 ± 14.4	152.6 ± 16.7
HC (cm)	142.5 ± 14.0	141.5 ± 13.3	145.5 ± 15.9	142.1 ± 14.8	140.5 ± 14.3	149.1 ± 14.0
WHR	1.0 ± 0.1	0.9 ± 0.1	1.0 ± 0.1	1.0 ± 0.1	0.9 ± 0.1	1.0 ± 0.1

Results are expressed as the mean (SD).

BAI, body adiposity index; BF, body fat; BIA, bioelectrical impedance analysis; BMI, body mass index; WHR, waist-hip ratio.

**Table 2** Inter- and intra-observer variability coefficients for bioelectrical impedance analysis (BIA) and body adiposity index (BAI) evaluations according to body mass index (BMI) in patients with severe obesity (*n* = 240): Group 1 (G1)

Variable	BMI	Male (M)	Female (F)	Q1 (M/F)	Median (M/F)	Q3 (M/F)	Min (M/F)	Max (M/F)	CV(%) (M/F)
BF % BAI	40–45	43.9 ± 2.9	43.8 ± 4.0	43.5/42.0	43.3/44.1	42.0/44.2	41.6/42.1	44.9/44.8	15.1/9.1
	45–50	46.4 ± 4.7	47.5 ± 4.6	43.5/44.0	45.3/47.2	47.3/49.2	46.1/45.2	48.2/49.7	10.1/9.7
	50–55	49.4 ± 8.0	52.1 ± 5.0	43.7/48.8	48.2/51.8	51.2/55.3	50.1/50.2	54.6/54.1	16.2/9.7
	55–60	52.7 ± 4.3	55.9 ± 5.7	48.4/51.9	54.0/55.2	56.9/60.3	55.9/56.9	57.6/59.8	8.2/10.2
	60–65	61.5 ± 7.5	63.6 ± 3.5	60.6/61.6	64.9/63.8	65.8/65.5	60.3/60.0	64.8/65.0	12.3/5.5
BF % BIA	40–45	43.7 ± 0.5	43.1 ± 1.3	43.5/42.9	43.7/43.3	44.1/44.1	42.8/40.4	44.4/44.6	1.2/3.0
	45–50	47.4 ± 1.1	48.0 ± 1.3	46.5/47.2	47.4/48.2	48.5/49.2	46.0/45.1	48.8/49.9	2.4/2.7
	50–55	52.0 ± 1.5	52.4 ± 1.4	50.7/51.2	51.8/52.2	53.0/53.6	50.2/50.1	54.5/54.9	3.0/2.7
	55–60	56.2 ± 0.9	57.1 ± 1.4	55.6/55.8	55.9/57.3	56.6/58.2	55.2/55.3	57.7/59.8	1.6/2.4
	60–65	62.5 ± 1.1	61.7 ± 1.1	61.9/61.1	62.4/61.6	63.1/62.2	60.7/60.0	64.6/64.4	2.6/1.8

Results are expressed as the mean (SD).

BF, body fat; CV %, variability coefficients; F, female; M, male; Max, maximum value; Min, minimum value; Q1, quantile 1; Q3, quantile 3.

**Table 3** Body fat determined by bioelectrical impedance analysis (BIA) and body adiposity index (BAI), percentage differences between methods and intraclass correlation in patients with severe obesity: Group 1 (*n* = 240)

Characteristics	BIA (BF%)	BAI (BF%)	Difference % (BIA-BAI)	<i>P</i> value	Minimum error	Maximum error	Intraclass correlation (95% CI)
Females	52.8 ± 5.8	52.7 ± 7.6	0.2 ± 4.8	0.664	-11.5	10.2	0.75 (0.68–0.81)
Males	50.1 ± 6.7	47.6 ± 8.9	2.5 ± 5.9	0.004*	-14.2	14.1	0.68 (0.50–0.80)
BMI 35–49.99 kg m <sup>-2</sup>	49.4 ± 5.2	48.0 ± 6.1	1.4 ± 4.7	0.001*	-10.8	14.1	0.63 (0.52–0.72)
BMI ≥ 50 kg m <sup>-2</sup>	56.5 ± 4.7	56.9 ± 7.9	-0.5 ± 5.5	0.569	-14.2	13.0	0.64 (0.50–0.74)
WHR < 1.05	52.2 ± 6.0	52.3 ± 7.7	0.0 ± 4.8	0.899	-14.2	12.1	0.76 (0.69–0.81)
WHR ≥ 1.05	52.3 ± 6.6	47.3 ± 9.2	5.0 ± 4.7	0.002*	-7.2	14.1	0.67 (0.43–0.82)
Total	52.3 ± 6.1	51.6 ± 8.1	0.6 ± 5.1	0.039*	-14.2	14.1	0.74 (0.68–0.79)

Results are expressed as the mean (SD).

BMI, body mass index; CI, confidence interval; WHR, waist-hip ratio.

\* $P < 0.05$ .

off point of 1.05 where the difference between the methods was  $\geq 5\%$  for the same subject. Therefore, when  $\text{WHR} \geq 1.05$ , BAI underestimates BF in 5.0% (4.7%) ( $P = 0.002$ ). BAI also underestimates BF in males [2.5% (5.9%);  $P = 0.004$ ] and in patients with a body mass index (BMI) between 35 and 49.99  $\text{kg m}^{-2}$  [1.4% (4.7%);  $P = 0.001$ ] (Table 3). Multiple linear regression analysis (Table 4) with variable selection using the model reduction method (Backward) gave the following correction equation (modified body adiposity index; MBAI) with a coefficient of determination ( $r^2$ ) of 0.65:  $\text{MBAI} = 23.6 + 0.5 \times \text{BAI}\%$  Add 2.2 if  $\text{BMI} \geq 50 \text{ kg m}^{-2}$  and 2.4 if  $\text{WHR} \geq 1.05$ .

The final model was chosen when all variables were significant. In addition, the good performance of the model was ratified by a residual analysis. It was performed by the envelope method in generalised linear models.

The new equation was used for BF estimation on data collected from G2 and the results were compared with the BF provided by BIA (Horie-Waitzberg equation).

The same BAI limitations found in G1 were also observed in G2. The mean (SD) BF determined by BIA

and BAI was 52.4% (5.7%) and 51.2% (7.9%), respectively [mean (SD) difference = 1.2% (5.9%),  $P < 0.001$ ]. BAI also underestimated BF in males [3.1% (4.8%);  $P = 0.007$ ], as well as in patients with a  $\text{WHR} > 1.05$  [7.2 (6.1);  $P < 0.001$ ] or with a BMI between 35 and 49.99  $\text{kg m}^{-2}$  [2.3% (5.5%);  $P < 0.001$ ] (Table 5). MBAI corrected these limitations (Figs 1 and 2) and improved the correlation between methods (from 0.61 to 0.70). BF determined by MBAI and BIA was 52.0% (4.8%) and 52.4% (5.7%) [mean (SD) difference of 0.4% (4.12%),  $P = 0.315$ ], respectively (Table 5).

There was a positive and linear correlation between methods (BIA and BAI) with a significant improvement with MBAI (Fig 1).

## Discussion

Traditional methods present several limitations to estimating BF in patients with severe obesity<sup>(10–12)</sup>. BIA is a simple and non-invasive method<sup>(22)</sup> for estimating BF via specific equations in these population patients<sup>(23)</sup>.

In recent studies, BAI presented positive correlations with other methods for body composition analysis with small significant differences compared to dual energy X-ray absorptiometry (DXA)<sup>(24–26)</sup>. The major advantage of the test is its low cost and simplicity<sup>(27)</sup>.

In our population ( $n = 398$ ), the mean differences between BAI and BIA were small [0.6% (5.1%) in G1 and 1.2% (5.9%) in G2] but significant ( $P = 0.039$  in G1 and  $P < 0.001$  in G2) and the maximum and minimum errors were high (−11.9% and 20.3%). The BF underestimation in our series was also observed in studies with BAI in women with severe obesity (1.7%<sup>(27)</sup> and 1.2%<sup>(28)</sup>) with similar maximum and minimum errors (−13.63 and 11.13)<sup>(29)</sup>.

**Table 4** Multiple linear regression analysis in patients with severe obesity ( $n = 240$ ): Group 1 (G1)

Variable	Estimate	<i>P</i>
(Intercept)	23.6 ± 1.8	<0.001
BAI	0.5 ± 0.0	<0.001
BMI ≥ 50 $\text{kg m}^{-2}$	2.2 ± 0.6	<0.001
WHR ≥ 1.05	2.4 ± 0.7	<0.001

Results are expressed as the mean (SD).

BAI, body adiposity index; BMI, body mass index; WHR, waist–hip ratio.

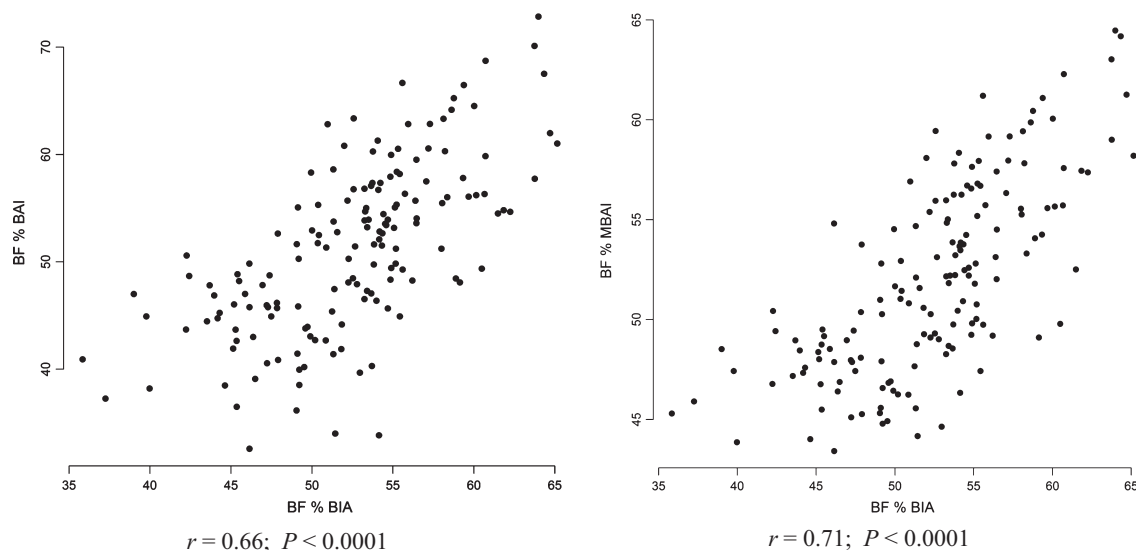
**Table 5** Body fat determined by bioelectrical impedance analysis (BIA), body adiposity index (BAI) and modified body adiposity index (MBAI), differences between BIA and BAI and between BIA and MBAI, and intraclass correlation in patients with severe obesity: Group 2 ( $n = 158$ )

Characteristics	BIA (BF%)	BAI (BF%)	MBAI (BF%)	Difference % (BIA-BAI)		Difference % (BIA-MBAI)		Intraclass correlation (95% CI)	
				Difference %	<i>P</i> value	Difference %	<i>P</i> value	BIA x BAI	BIA x MBAI
Females	52.6 ± 5.6	51.6 ± 8.1	52.1 ± 4.9	0.9 ± 6.1	0.078	0.4 ± 4.1	0.246	0.6 (0.5–0.7)	0.7 (0.6–0.8)
Males	51.5 ± 6.2	48.5 ± 6.6	51.2 ± 4.2	3.1 ± 4.8	0.007*	0.3 ± 3.5	0.672	0.6 (0.3–0.8)	0.8 (0.6–0.9)
BMI 35–49.99 $\text{kg m}^{-2}$	49.8 ± 5.1	47.5 ± 6.0	49.0 ± 2.9	2.3 ± 5.5	<0.001*	0.7 ± 4.4	0.112	0.4 (0.3–0.6)	0.4 (0.2–0.6)
BMI ≥ 50 $\text{kg m}^{-2}$	56.4 ± 4.0	56.8 ± 7.2	56.5 ± 3.5	−0.4 ± 6.2	0.605	−0.1 ± 3.4	0.833	0.4 (0.2–0.6)	0.6 (0.4–0.7)
WHR < 1.05	52.4 ± 5.3	52.2 ± 7.2	52.1 ± 4.6	0.2 ± 5.3	0.664	0.3 ± 4.0	0.438	0.7 (0.6–0.7)	0.7 (0.6–0.8)
WHR ≥ 1.05	52.7 ± 7.5	45.5 ± 9.6	51.5 ± 5.9	7.2 ± 6.1	<0.001*	1.2 ± 4.4	0.211	0.5 (0.1–0.8)	0.8 (0.6–0.8)
Total	52.4 ± 5.7	51.2 ± 7.9	52.0 ± 4.8	1.2 ± 5.9	<0.001*	0.4 ± 4.0	0.315	0.6 (0.5–0.7)	0.7 (0.6–0.8)

Results are expressed as the mean (SD).

BF, Body Fat; BMI, body mass index; WHR, waist–hip ratio.

\* $P < 0.05$ .



**Figure 1** Relationship between bioelectrical impedance analysis (BIA) and body adiposity index (BAI) and between BIA and modified body adiposity index (MBAI) in patients with severe obesity: Group 2 ( $n = 158$ ).

BAI underestimates BF in 8.2% and 10% of women and in 2.6–4.3% of patients with severe obesity<sup>(15,28,29)</sup> and in 7.6% of overweight post-menopausal women using DXA as the reference method<sup>(30)</sup>. BAI also underestimates BF in 5% and 5.5% of severely obese women compared to plethysmography<sup>(29,31)</sup>.

In the present study, BAI has a positive linear relationship and a strong intraclass correlation (0.74) with BIA. Gibson *et al.*<sup>(28)</sup> and Geliebter *et al.*<sup>(29)</sup> also found significant correlations between BIA and BAI in women with severe obesity (0.86<sup>(28)</sup> and 0.87<sup>(29)</sup>). The correlation between methods was higher in females (0.75 versus 0.68), as observed in other studies (BMI 17–55 kg m<sup>-2</sup>; correlation of 0.82 versus 0.74)<sup>(25)</sup>. BAI underestimated BF by 2.5% only in males ( $P = 0.04$ ).

BAI also underestimated BF when the WHR was above 1.05. After linear regression analysis, sex lost significance, suggesting that fat distribution affects BAI accuracy. A recent Chinese study (BMI = 28 kg m<sup>-2</sup>) demonstrated a higher correlation between DXA-BF and WC than with HC in men (0.85 versus 0.81)<sup>(25)</sup>.

In the present study, we did not compare BAI with a gold-standard method of body fat estimation such as DXA. However, our results were closely similar to other studies<sup>(24–26,28–30)</sup> that used DXA and plethysmography to assess BAI accuracy in patients with severe obesity. BAI was a good method for population assessment, although it presents some limitations in these populations. We also did not consider the effects of nutraceuticals and diet in body composition analysis by BIA<sup>(32)</sup>.

The new equation (MBAI) proposed for BF estimation in severe obesity corrects the limitations observed with

BAI. The method remained simple (requiring only WC, HC, height and weight) and the variables included were able to explain 65% of the BF variation. The mean difference between BAI and BIA was reduced from 1.2% ( $P = 0.029$ ) to 0.4% ( $P = 0.18$ ) with MBAI.

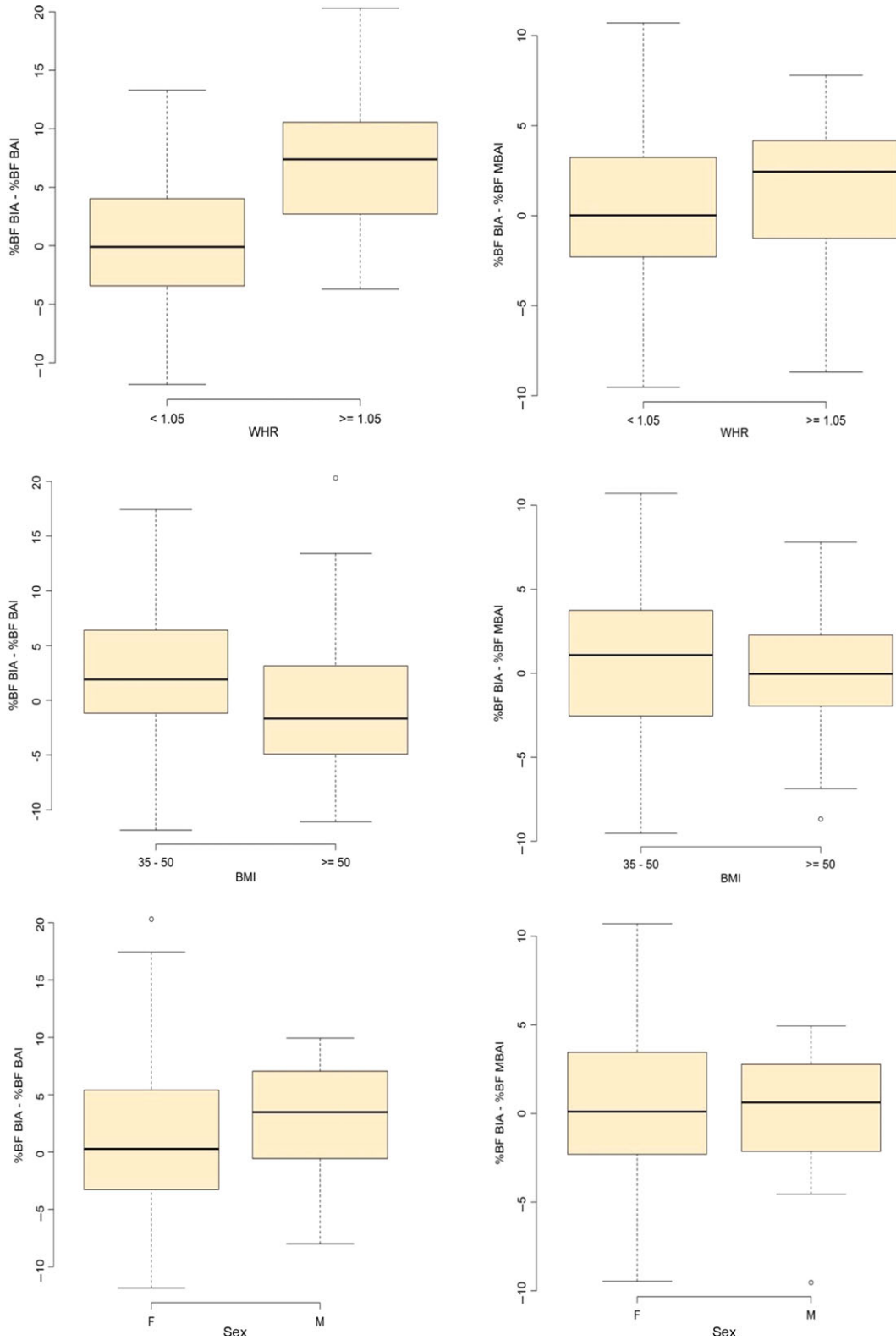
MBAI eliminated limitations previously observed in BAI. The differences were reduced in males [from 3.1% (4.8%) to 0.3% (3.5%)], in individuals with WHR  $\geq 1.05$  [from 7.2% (6.15) to 1.2% (4.4%)] and in patients with a BMI between 35 and 49.99 kg m<sup>-2</sup> [from 2.3 (5.5) to 0.7 (4.4)]. The correlations were strengthened in males (0.6–0.8), in the group with BMI  $> 50$  kg m<sup>-2</sup> (0.4–0.6) and when the WHR  $\geq 1.05$  (0.4–0.8).

We emphasise the importance of a simple and inexpensive method for BF estimation in countries where the availability of sophisticated equipment is not wide.

In conclusion, BAI had limitations with respect to estimating BF in patients with severe obesity, especially with respect to WHR and obesity grade. The new equation proposed (MBAI) correctly determines BF in this population and can be widely used in clinical practice.

### Transparency declaration

The lead author affirms that this manuscript is an honest, accurate, and transparent account of the study being reported, that no important aspects of the study have been omitted and that any discrepancies from the study as planned (and registered with) have been explained. The reporting of this work is compliant with STROBE guidelines.



**Figure 2** Differences between bioelectrical impedance analysis (BIA) and body adiposity index (BAI) and between BIA and modified body adiposity index (MBAI) in patients with severe obesity (Group 2) according to waist-hip ratio (WHR), body mass index (BMI) and sex ( $n = 158$ ). BF, body fat; F, female; M, male.

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## Conflict of interests, source of funding and authorship

The authors declare that they have no conflicts of interest.

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RC and MAS contributed equally to this work. RC and MAS were responsible for the study conception and design, and also drafted and critically revised the manuscript. ABB, VMS, MPS and DP were responsible for the measurement of body circumferences, body adiposity index calculations and bioelectrical impedance analysis in all patients. All authors participated in the analysis and interpretation of data. All authors contributed to and have approved the final manuscript submitted for publication. All authors take public responsibility for its content.

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