Clinical Nutrition Open Science 46 (2022) 20–28

Contents lists available at ScienceDirect

Clinical Nutrition Open Science

journal homepage: www.clinicalnutritionopenscience.com

Original Article

Impedance change during intentional weight loss in Thai obese patients

Sornwichate Rattanachaiwong [a, *], Veeradej Pisprasert [a], Pranithi Hongsprabhas [a], Uthumporn Panitanarak [b], Peerakong Larphun [c]

[a] Division of Clinical Nutrition, Department of Medicine, Faculty of Medicine, Khon Kaen University, Khon Kaen, Thailand
[b] Department of Biostatistics, Faculty of Public Health, Mahidol University, Bangkok, Thailand
[c] Department of Medicine, Loei Hospital, Loei, Thailand

ARTICLE INFO

Article history:
Received 28 August 2022
Accepted 6 November 2022
Available online 11 November 2022

Keywords:
Bioelectrical impedance analysis
BIA
Impedance
Body composition
Obesity
Weight reduction

SUMMARY

Background & aims: Longitudinal measurements of raw bioelectrical impedance analysis (BIA) parameters suggested a worsening of the nutritional status in obese patients during weight loss after bariatric surgery. The effects of weight reduction through dietary intervention on raw BIA parameters is rarely described.
Methods: A retrospective observational study was conducted on obese patients who were in a weight-loss program. Dietary counseling, exercise, and lifestyle modification were suggested as the main approach to lose weight. Then longitudinal follow-up visits were scheduled every 1–3 months for up to 2 years. On each visit, body weight, waist, and hip circumferences were recorded along with BIA measurements. Repeated measures correlation (r_{rm}) was used to assess the relationship between BIA-derived impedance and body weight.
Results: A total of 116 obese patients were recruited. Participants had lost their weight from 113.47 ± 26.73 kg at the first visit to 103.69 ± 23.97 kg at the last visit ($P < 0.001$). A significant decrease of percentage of body fat was observed by −3.30 ± 4.33% from baseline. Total body water and fat-free mass were also significantly decreased. There was an increase in impedance from 483.55 ± 78.38 ohm at baseline to 496.11 ± 82.30 ohm at the last

Abbreviations: BIA, bioelectrical impedance analysis; BMI, body mass index; FFM, fat-free mass; FFMI, fat-free mass index; FM, fat mass; IQR, interquartile range; r_{rm}, repeated measures correlation; SD, standard deviation; TBW, total body water.

* Corresponding author. Division of Clinical Nutrition, Department of Medicine, Faculty of Medicine, Khon Kaen University, Mitraparp Highway Road, Nai Muang, Maung, Khon Kaen, 40002, Thailand.
E-mail addresses: srattanamd@gmail.com, sornra@kku.ac.th (S. Rattanachaiwong).

https://doi.org/10.1016/j.nutos.2022.11.004

visit ($P < 0.001$). The r_{rm} between impedance and body weight was −0.31 (95% CI −0.37 to −0.25, $P < 0.001$).
Conclusions: Impedance had a significant negative correlation on body weight in obese patients during intentional weight loss, which might be due to decreased total body water and fat-free mass. Further study is required to explore the clinical meaning of these changes.

Introduction

Bioelectrical impedance analysis (BIA) is a method used to quantitate body composition by applying low-voltage electrical current through the body, in order to differentiate the body into compartments according to their electrical properties. Currently, BIA is a practical tool recommended for body composition assessment in various settings, including obesity [1]. However, the body composition measurement by BIA also has limitations in regards to obese subjects, particularly for those whose body mass index (BMI) beyond 34 kg/m^2 [2]. An extreme percentage of body fat can ruin the validity of BIA regression equation which was developed from healthy subjects, hence further validation on obesity as a subgroup is still required.

Despite these limitations, BIA continues to provide interesting results from its raw parameters. BIA measurement yields raw electrical properties from the body including resistance, reactance, impedance, and phase angle. These raw parameters are measured directly from the body without any regression equations applied, hence they can be used in conditions where BIA assumptions on body composition analysis are not valid [3]. Many studies have explored the clinical values of raw BIA parameters and found that they can be used to assess tissue hydration status, cell membrane function, nutritional status, and even prognosis [4–8]. Regarding obesity, raw BIA parameters have been studied widely and shown to have some correlations with various clinical aspects e.g. physical fitness [9], prediction of degree of weight loss after bariatric surgery [10], and inflammation [11].

The prevalence of obesity has been increasing globally for decades [12]. Obviously, weight reduction is a key treatment for it. Clinical practice guidelines have recommended evidence-based weight loss interventions such as lifestyle modification, behavioral and cognitive therapy, pharmacotherapy, and bariatric surgery [13]. There is also an increasing number of obese patients who have received bariatric surgery for weight reduction [14]. The amount of weight loss after a bariatric surgery is substantial and durable enough to bring about the resolution of obesity-related diseases in many cases [15–17]. On the other hand, rapid weight loss after bariatric surgery can lead to concerns regarding nutritional health. Studies on body composition changes after bariatric surgery showed a significant amount of fat-free mass (FFM) loss and a worsening of raw BIA parameters that might reflect malnutrition [18,19]. While longitudinal changes of raw BIA parameters during weight loss after bariatric surgery are well described [19], the effect of dietary intervention and lifestyle modification on these parameters in obesity is rarely documented. Therefore, the primary objective of this study was to determine the change of BIA-derived impedance and correlation between impedance and body weight during intentional weight loss by lifestyle modification for obesity.

Materials & methods

A retrospective observational study was performed on obese patients at an obesity clinic, outpatient department, Srinagarind hospital, Khon Kaen University, Thailand. Medical records of the patients in the obesity clinic who had visits between January 1, 2015 and December 31, 2019 were reviewed. According to inclusion criteria, subjects were age ≥ 18 years, body mass index (before weight reduction) ≥ 30 kg/m^2, and had longitudinal measurement of body weight and impedance ≥ 2 measurements by the same BIA device. As we were interested in the effect of weight reduction by lifestyle intervention, the patients who were prescribed anti-obesity drugs or underwent bariatric surgery were excluded. Also, patients with a serious comorbidity that might influence weight loss (e.g. liver cirrhosis, chronic kidney disease of more than stage 3, end stage renal disease with or without renal replacement therapy, chronic heart failure, active cancer, autoimmune disease, HIV infection) were not recruited. The study protocol was approved by the Khon Kaen University Ethics Committee for Human Research.

Our obesity clinic provided comprehensive clinical evaluation, counseling, and treatment for weight reduction. Physicians specialized in clinical nutrition evaluated patients for severity of obesity and comorbidities related to it. They also provided individualized counseling on diet control and lifestyle modification for weight reduction. Nutritional management was mainly based on a balanced-diet pattern, and caloric restriction emphasizing on adequate protein intake. Physical activity was encouraged according to standard recommendations [13,20,21]. Obesity-related complications were screened as indicated and treated if needed. A registered dietitian was available for provision of dietary programs according to the physician's suggestion. Patients were scheduled to revisit the clinic at intervals of 1–3 months depending on physician and patient's agreement. Anthropometric measurements and body composition analysis were measured and recorded during each visit. Waist and hip circumference were measured in centimeters using a measuring tape. Height was measured in centimeters using a stadiometer.

For BIA measurement, patients were asked to wear only light clothing and remove all the metallic accessories before stepping on a single, non-phase sensitive, 50 kHz-frequency, 8-electrodes BIA device with a built-in weighing scale (Tanita® Body Composition Analyzer BC-418, Japan). Data input included patient's age, sex, and height. Weight of clothing was set at 0.3 kg. Patients were asked to step on the device in cleaned bare feet, place their feet on the right and left feet-electrodes, grasp the electrode grips in their hands firmly while standing on the device, separated their arms from their trunk until the measurement finished. The data obtained from BIA device were body weight, percentage of body fat, fat mass (FM), fat-free mass (FFM), total body water (TBW), and impedance. Impedance-height ratio was calculated by impedance divided by height in meter. The measurement was performed around the same time of the day in every visit, 1.00–2.00 PM, as it was the beginning of operating hour of our clinic.

Statistical analyses

Demographic data were analyzed using descriptive statistics. Categorical variables were presented as numbers and percentages. Continuous variables were expressed in mean and standard deviation (SD) or median and interquartile range (IQR) where appropriate. Anthropometric and BIA parameters of the first visit and that of the last visit were compared using paired *t*-tests. Correlation between impedance and body weight of each visit were assessed by repeated measures correlation (r_{rm}), stratified by sex, pre-defined age group (age < 60 and ≥60), and the presence of comorbidities. We used R program and SPSS Version 26.0 to analyze this dataset. P value < 0.05 was considered statistically significant.

Sample size

Sample size was calculated based on a formula for correlation sample size. We used α as 0.05, β as 0.100, and we assumed that impedance and body weight have a weak to moderate correlation ($r = 0.4$). The adequate sample size was 62.

Results

There were 184 patients who had at least 2 BIA records during the study period. Sixty-eight patients were excluded by our exclusion criteria. A total of 116 participants were recruited, 66 (56.9%) were females and 50 (44.1%) were males, who contributed to a total of 1009 visits. A mean age of participants was 38.92 ± 15.02 years old. The averages of weight and BMI at first visit were 113.47 ± 26.73 kg and

42.09 ± 8.12 kg/m^2 respectively. Median (IQR) of the follow-up period was 12 (6–23) months with a median (IQR) of 7 (4–11) visits. The prevalence of obesity-related comorbidities among participants were described in Table 1.

The anthropometric measurements and the BIA results of the first and the last visit were shown in Table 2. After lifestyle modification, patient body weights of their last visit were significantly less than that of their first visit (103.69 ± 23.97 kg versus 113.47 ± 26.73 kg respectively, $P < 0.001$). Mean of weight loss was −9.78 ± 11.78 kg. Waist and hip circumferences showed a significant decrease accordingly, −8.03 ± 9.16 and −6.54 ± 7.70 cm respectively. Body composition analyses revealed significant decrease in FM, FFM, and TBW where the biggest change was seen in FM, −7.99 ± 9.85 kg, followed by FFM, −1.98 ± 3.72 kg, and TBW, −1.39 ± 5.02 kg respectively. A significant decrease of percentage of body fat was observed by −3.30 ± 4.33% from baseline.

Mean impedance and impedance-height ratio were 483.55 ± 78.38 ohm and 297.34 ± 5.26 ohm/m respectively at baseline. In the last visit, there were significant increases of both impedance and impedance-height ratio (496.11 ± 82.30 ohm and 305.11 ± 5.52 ohm/m respectively, $P < 0.001$ for both as compared to their baselines) (Table 2). Repeated measures correlation (r_{rm}) between impedance and body weight was −0.31 (95% CI −0.37 to −0.25, $P < 0.001$) (Table 3, Figure 1A). The r_{rm} between impedance-height ratio and body weight was −0.30 (95%CI −0.36 to −0.24, $P < 0.001$) (Table 4, Figure 1B). Subgroup analyses showed that impedance and impedance-height ratio had significant correlations with body weight across sex, age, and the presence or absence of underlying disease (Tables 3 and 4). The r_{rm} was more prominent in the elderly subgroup (age ≥ 60) than the other groups (r_{rm} −0.47 (95%CI −0.64 to −0.26, $P < 0.001$) for impedance and −0.47 (95%CI −0.64 to −0.26, $P < 0.001$) for impedance-height ratio. The weaker r_{rm} between impedance, impedance-height ratio, and body weight was observed among the participants without any underlying diseases (r_{rm} −0.24, 95%CI −0.34 to −0.13, $P < 0.001$, for impedance and −0.23, 95%CI −0.34 to −0.12, $P < 0.001$, for impedance-height ratio).

Discussion

The benefits of weight reduction through dietary intervention on obesity have been well established [22–25]. Lifestyle and behavioral interventions are recommended as the first line therapy for weight reduction in obesity(20). Obese patients should be encouraged to lose at least 5–10% of their body weight

Table 1
Baseline characteristics

Variables	All (N = 116)
Age-year (mean ± SD)	38.92 ± 15.02
Female-n (%)	66 (56.90)
Body weight-kg (mean ± SD)	113.47 ± 26.73
Height-m (mean ± SD)	1.64 ± 0.10
BMI-kg/m^2 (mean ± SD)	42.09 ± 8.12
Number of visits (median, IQR)	7 (4–11)
Follow-up interval-days (median, IQR)	42 (35–63)
Duration of follow-up-months (median, IQR)	12 (6–23)
Comorbidities- n(%)	
• Obstructive sleep apnea	54 (46.55)
• Hypertension	30 (25.86)
• Non-alcoholic steatohepatitis	22 (18.97)
• Diabetes mellitus type 2	16 (13.79)
• Dyslipidemia	12 (10.34)
• Gastroesophageal reflux disease	10 (8.62)
• Obesity hypoventilation syndromes	8 (6.90)
• Polycystic ovary syndrome	7 (6.03)
• Others[a]	12 (10.34)
• None	43 (37.07)

SD standard deviation, IQR interquartile range.
[a] Stroke, atrial fibrillation, peripheral arterial disease, osteoarthritis.

Table 2
Comparison of anthropometric and BIA parameters between first and last visit

	First visit	Last visit	Change after weight loss	*P*-value[a]
Anthropometry				
• Body weight (kg), mean ± SD	113.47 ± 26.73	103.69 ± 23.97	−9.78 ± 11.78	<0.001
• Waist circumference (cm), mean ± SD	118.45 ± 1.47	110.42 ± 1.40	−8.03 ± 9.16	<0.001
• Hip circumference (cm), mean ± SD	128.00 ± 1.47	121.46 ± 1.35	−6.54 ± 7.70	<0.001
BIA parameters				
• Percentage of body fat (%), mean ± SD	47.56 ± 0.92	44.26 ± 0.93	−3.30 ± 4.33	<0.001
• Fat mass (kg), mean ± SD	54.24 ± 1.69	46.25 ± 1.51	−7.99 ± 9.85	<0.001
• Fat-free mass (kg), mean ± SD	59.23 ± 1.62	57.25 ± 1.50	−1.98 ± 3.72	<0.001
• Total body water (kg), mean ± SD	44.54 ± 1.14	43.13 ± 1.09	−1.39 ± 5.02	0.003
• Impedance (ohm), mean ± SD	483.55 ± 78.38	496.11 ± 82.30	12.56 ± 36.65	<0.001
• Impedance-height ratio (ohm/m), mean ± SD	297.34 ± 5.26	305.11 ± 5.52	7.74 ± 24.59	<0.001

SD standard deviation.
[a] First visit versus last visit by paired *t*-test.

Table 3
Repeated measures correlation between impedance and body weight stratified by sex and age group

Group	r_{rm} (95% CI)	*P*-value
All (N = 116)	−0.31 (−0.37, −0.25)	<0.001
Subgroup by sex		
• Female (N = 66)	−0.31 (−0.38, −0.26)	<0.001
• Male (N = 50)	−0.32 (−0.41, −0.23)	<0.001
Subgroup by age group		
• Age < 60 (N = 105)	−0.31 (−0.37, −0.25)	<0.001
• Age ≥ 60 (N = 11)	−0.47 (−0.64, −0.26)	<0.001
Subgroup by presence of comorbidities		
• Presence (N = 73)	−0.34 (−0.41, −0.27)	<0.001
• Absence (N = 43)	−0.24 (−0.34, −0.13)	<0.001

r_{rm} repeated measure correlation, CI confidence interval.

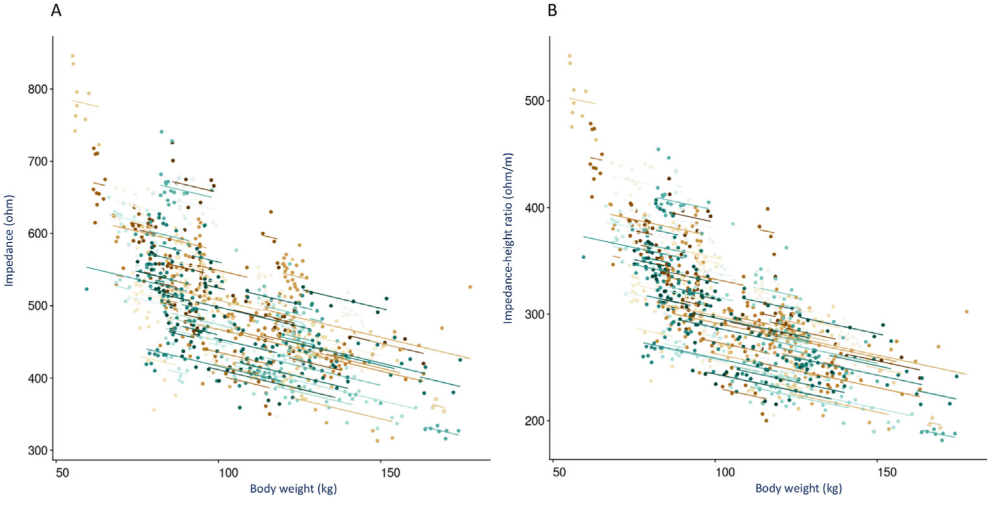

Figure 1. Repeated measures correlations between A. impedance and body weight, and B. impedance-height ratio and body weight. Each dot represents each measurement, and the same color indicates the measurements from the same patient.

Table 4
Repeated measures correlation between impedance-height ratio and body weight stratified by sex and age group

Group	r_{rm} (95% CI)	*P*-value
All (N = 116)	−0.30 (−0.36, −0.24)	<0.001
Subgroup by sex		
• Female (N = 66)	−0.31 (−0.38, −0.23)	<0.001
• Male (N = 50)	−0.32 (−0.41, −0.23)	<0.001
Subgroup by age group		
• Age < 60 (N = 105)	−0.31 (−0.37, −0.24)	<0.001
• Age ≥ 60 (N = 11)	−0.47 (−0.64, −0.26)	<0.001
Subgroup by presence of comorbidities		
• Presence (N = 73)	−0.34 (−0.41, −0.26)	<0.001
• Absence (N = 43)	−0.23 (−0.34, −0.12)	<0.001

r_{rm} repeated measure correlation, CI confidence interval.

by aiming at an improvement of their metabolic risks and obesity-related complications [1,13,20,23]. The patients in our study lost significant weight as shown during their follow-up period. The average weight loss was about 8% from their initial body weight (data not shown). Despite the large bias and wide limits of agreement in cross-sectional body composition assessment by a single-frequency BIA have been reported in obese subjects, in terms of measuring changes during weight loss, it provided accurate assessments, with little bias and narrow limits of agreement [26,27]. The body composition results in our study showed that the loss of body weight was mainly attributed by the loss of FM. Therefore, the health benefits from intentional weight loss were anticipated in our participants. We expected to see the improvement of their health status after weight reduction as quantified by impedance-derived BIA.

Longitudinal measurement of BIA in our participants showed that impedance and impedance-height ratio increased significantly after weight reduction. Brunani *et al.* performed BIA measurement in patients with various degree of obesity and found significant a decrease in resistance, reactance, and therefore impedance, as BMI increased beyond 30 kg/m^2 [28]. So we speculated that the increment of impedance seen after weight reduction might be a change toward a healthier status.

As impedance is a vector addition between reactance and resistance obtained from the BIA measurement, the increment of impedance can be either caused by increase of resistance or increase of reactance, or both. According to the cylinder model for the relationship between resistance and any geometric forms, the increase of resistance can be caused by a decrease of the cross-sectional area [29]. To relate this with weight the reduction process, the increase in resistance might reflect the decrease of limb or truncal cross-sectional area from weight loss, i.e. decrease of mid-arm or waist circumference. The other reason for the increase of resistance might be due to loss of TBW and FFM accompanied weight loss [30]. We also found significant decreases of TBW and FFM in our study as well (Table 2). The worsening of lean body mass during weight reduction was described in other studies as well, particularly in those with substantial weight loss e.g. post bariatric patients [10,15]. Considering obesity as a state of inflammation [31], weight reduction by lifestyle modification can lead to a measurably lesser degree of inflammation [32,33], improve integrity of cell membrane [34], which could result in an increase of reactance and,therefore, impedance is increased.

From repeated measures correlation analyses, we observed a weak to moderate degree, yet significant, of negative correlation between impedance and body weight in obesity patients during intentional weight loss. A similar correlation was also found with impedance-height ratio. Subgroup analyses showed that the correlation between body weight and impedance was more prominent in the elderly group than in the non-elderly. This finding might support that TBW and FFM losses are the explanation behind the increase of impedance. The studies in elderly showed that the higher impedances were found among sarcopenic older adults as compared to their non-sarcopenic counterpart [35,36]. We found that the correlation between body weight and impedance was stronger in those with underlying disease(s) than those without. We had 2 hypotheses for this finding. First, the group with comorbidities were older than those without comorbidity so that they suffered from loss of FFM during weight loss as we discussed above regarding the elderly subgroup. Second, this finding pointed out that impedance change during weight loss was influenced by the presence of disease(s). Weight reduction might lead to improvement of diseases, lessen inflammation, which helps to restore cell membrane integrity, increase reactance, and hence impedance.

Other studies with sequential BIA measurements in obese subjects during weight loss showed that the direction of changes in BIA parameters might depend on how the patients lost their weight. Many studies in post bariatric patients found that BIA-derived phase angle decreased by 11–20% after weight loss [15,37–39]. Some authors proposed that this finding might indicate a worsening of nutritional status [30,37]. On the other hand, the patients who lost their weight by nonsurgical intervention showed an increase of phase angle and changes of some body composition parameters that might point to a better nutritional status [30]. The clinical meanings of the changes in raw BIA parameters might depend not only on the direction of their changes but also the clinical setting. In critically ill patients, the increase of impedance was reported to relate with lower severity, clinical improvement, and lower mortality [6,8]. The higher impedance in the elderly was associated with sarcopenia [36]. Our study has proved that the change of BIA-derived body impedance after weight reduction by lifestyle modification is significant. We postulated that the increase of impedance might indicate a healthier status in this setting. If it does, BIA measurement will be a potential point-of-care testing to distinguish between healthy weight loss and weight-losing associated with malnutrition. However, at this point of time, further study is needed before we can propose its clinical value in practice.

The strength of our study is the long follow-up period, up to 2 years, with more than one thousand BIA records. However, there are some limitations in our study. Firstly, we did not assess the compliance of the diet and exercise regimen in our participants during the follow-up period. Secondly, we did not assess body composition change by the gold standard method, such as dual-energy X-ray absorptiometry (DXA). An over-estimation of lean mass was reported when applying BIA in an obese population [40,41]. Due to a retrospective design, we did not plan for a regular calibration of the BIA device during data collection process. The standardization of BIA results among different devices is still debated. Hence, we could not make a strong conclusion that the increase of impedance during weight loss was driven by changes in body composition. Thirdly, the BIA-derived resistance, reactance, phase angle and bioelectrical impedance vector analysis (BIVA), the commonly used BIA parameters to indicate a healthy status and its change, were not reported by the device we used at that time when data were collected.

Conclusion

There was a correlation between impedance and body weight. We reported a significant increase of impedance during intentional weight loss in obese patients. Further study is required to explore the clinical meaning of these changes.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

CRediT author statement

Sornwichate Rattanachaiwong: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Project administration; Resources; Supervision; Validation; Visualization; Roles/Writing – original draft; Writing – review & editing. Veeradej Pisprasert: Data curation; Investigation. Pranithi Hongsprabhas: Data curation; Investigation. Uthumporn Panitanarak: Formal analysis; Methodology; Software. Peerakong Larphun: Conceptualization; Data curation; Investigation; Methodology; Project administration; Roles/Writing – original draft.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors appreciate the support of the obesity clinic team, Srinagarind hospital, Khon Kaen, Thailand, for data collection. The authors thanks Thomas Edward Grogan for the English editing.

References

[1] Yumuk V, Tsigos C, Fried M, Schindler K, Busetto L, Micic D, et al. European Guidelines for Obesity Management in Adults. Obes Facts 2015;8(6):402–24.
[2] Kyle UG, Bosaeus I, De Lorenzo AD, Deurenberg P, Elia M, Manuel Gómez J, et al. Bioelectrical impedance analysis-part II: utilization in clinical practice. Clin Nutr 2004;23(6):1430–53.
[3] Barbosa-Silva MCG, Barros AJD. Bioelectrical impedance analysis in clinical practice: a new perspective on its use beyond body composition equations. Curr Opin Clin Nutr Metab Care 2005;8(3):311–7.
[4] Hise AC da R, Gonzalez MC. Assessment of hydration status using bioelectrical impedance vector analysis in critical patients with acute kidney injury. Clin Nutr 2018;37(2):695–700.
[5] Lukaski HC, Kyle UG, Kondrup J. Assessment of adult malnutrition and prognosis with bioelectrical impedance analysis: phase angle and impedance ratio. Curr Opin Clin Nutr Metab Care 2017;20(5):330–9.
[6] Azevedo ZMA, Moore DCBC, de Matos FAA, Fonseca VM, Peixoto MVM, Gaspar-Elsas MIC, et al. Bioelectrical impedance parameters in critically ill children: importance of reactance and resistance. Clin Nutr 2013;32(5):824–9.
[7] Sato M, Inai K, Shimizu M, Sugiyama H, Nakanishi T. Bioelectrical impedance analysis in the management of heart failure in adult patients with congenital heart disease. Congenit Heart Dis 2019;14(2):167–75.
[8] Lee YH, Lee JD, Kang DR, Hong J, Lee JM. Bioelectrical impedance analysis values as markers to predict severity in critically ill patients. J Crit Care 2017;40:103–7.
[9] Streb AR, Hansen F, Gabiatti MP, Tozetto WR, Del Duca GF. Phase angle associated with different indicators of health-related physical fitness in adults with obesity. Physiol Behav 2020;225:113104.
[10] Vassilev G, Hasenberg T, Krammer J, Kienle P, Ronellenfitsch U, Otto M. The Phase Angle of the Bioelectrical Impedance Analysis as Predictor of Post-Bariatric Weight Loss Outcome. Obes Surg 2017;27(3):665–9.
[11] Barrea L, Muscogiuri G, Laudisio D, Di Somma C, Salzano C, Pugliese G, et al. Phase Angle: A Possible Biomarker to Quantify Inflammation in Subjects with Obesity and 25(OH)D Deficiency. Nutrients 2019;11(8):E1747.
[12] GBD 2015 Obesity Collaborators, Afshin A, Forouzanfar MH, Reitsma MB, Sur P, Estep K, et al. Health Effects of Overweight and Obesity in 195 Countries over 25 Years. N Engl J Med 2017;377(1):13–27.
[13] Garvey WT, Mechanick JI, Brett EM, Garber AJ, Hurley DL, Jastreboff AM, et al. American Association of Clinical Endocrinologists and American College of Endocrinology Comprehensive Clinical Practice Guidelines For Medical Care of Patients with Obesity. Endocr Pract 2016;22(Suppl 3):1–203.
[14] Ohta M, Seki Y, Wong SKH, Wang C, Huang CK, Aly A, et al. Bariatric/Metabolic Surgery in the Asia-Pacific Region: APMBSS 2018 Survey. Obes Surg 2019;29(2):534–41.
[15] Golzarand M, Toolabi K, Djafarian K. Changes in Body Composition, Dietary Intake, and Substrate Oxidation in Patients Underwent Laparoscopic Roux-en-Y Gastric Bypass and Laparoscopic Sleeve Gastrectomy: a Comparative Prospective Study. Obes Surg 2019;29(2):406–13.
[16] Viratanapanu I, Romyen C, Chaivanijchaya K, Sornphiphatphong S, Kattipatanapong W, Techagumpuch A, et al. Cost-Effectiveness Evaluation of Bariatric Surgery for Morbidly Obese with Diabetes Patients in Thailand. J Obes 2019;2019:5383478.
[17] Welbourn R, Hollyman M, Kinsman R, Dixon J, Liem R, Ottosson J, et al. Bariatric Surgery Worldwide: Baseline Demographic Description and One-Year Outcomes from the Fourth IFSO Global Registry Report 2018. Obes Surg 2019;29(3):782–95.
[18] Nicoletti CF, Camelo JS, dos Santos JE, Marchini JS, Salgado W, Nonino CB. Bioelectrical impedance vector analysis in obese women before and after bariatric surgery: changes in body composition. Nutrition 2014;30(5):569–74.
[19] Di Vincenzo O, Marra M, Sacco AM, Pasanisi F, Scalfi L. Bioelectrical impedance (BIA)-derived phase angle in adults with obesity: A systematic review. Clin Nutr 2021;40(9):5238–48.
[20] Jensen MD, Ryan DH, Apovian CM, Ard JD, Comuzzie AG, Donato KA, et al. 2013 AHA/ACC/TOS guideline for the management of overweight and obesity in adults: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines and The Obesity Society. Circulation 2014;129(25 Suppl 2):S102–38.
[21] Wharton S, Lau DCW, Vallis M, Sharma AM, Biertho L, Campbell-Scherer D, et al. Obesity in adults: a clinical practice guideline. CMAJ 2020;192(31):E875–91.
[22] Semlitsch T, Krenn C, Jeitler K, Berghold A, Horvath K, Siebenhofer A. Long-term effects of weight-reducing diets in people with hypertension. Cochrane Database Syst Rev 2021;2:CD008274.
[23] Ma C, Avenell A, Bolland M, Hudson J, Stewart F, Robertson C, et al. Effects of weight loss interventions for adults who are obese on mortality, cardiovascular disease, and cancer: systematic review and meta-analysis. BMJ 2017;359:j4849.
[24] Park SK, Lee T, Yang HJ, Park JH, Sohn CI, Ryu S, et al. Weight loss and waist reduction is associated with improvement in gastroesophageal disease reflux symptoms: A longitudinal study of 15 295 subjects undergoing health checkups. Neurogastroenterol Motil 2017;29(5):e13009.
[25] Nielsen SM, Bartels EM, Henriksen M, Wæhrens EE, Gudbergsen H, Bliddal H, et al. Weight loss for overweight and obese individuals with gout: a systematic review of longitudinal studies. Ann Rheum Dis 2017;76(11):1870–82.
[26] Nuñez C, Beyer J, Strain G, Zumoff B, Kovera A, Gallagher D, et al. Composition of weight loss while dieting: Comparison of research and clinically-based method. NAASO Poster Presentations. Obes Res 1997;5:72S.
[27] Thomson R, Brinkworth GD, Buckley JD, Noakes M, Clifton PM. Good agreement between bioelectrical impedance and dual-energy X-ray absorptiometry for estimating changes in body composition during weight loss in overweight young women. Clin Nutr 2007;26(6):771–7.

[28] Brunani A, Perna S, Soranna D, Rondanelli M, Zambon A, Bertoli S, et al. Body composition assessment using bioelectrical impedance analysis (BIA) in a wide cohort of patients affected with mild to severe obesity. Clin Nutr 2021;40(6):3973–81.
[29] Kyle UG, Bosaeus I, De Lorenzo AD, Deurenberg P, Elia M, Gómez JM, et al. Bioelectrical impedance analysis–part I: review of principles and methods. Clin Nutr 2004;23(5):1226–43.
[30] Friedrich AE, Damms-Machado A, Meile T, Scheuing N, Stingel K, Basrai M, et al. Laparoscopic sleeve gastrectomy compared to a multidisciplinary weight loss program for obesity–effects on body composition and protein status. Obes Surg 2013;23(12):1957–65.
[31] Koliaki C, Liatis S, Kokkinos A. Obesity and cardiovascular disease: revisiting an old relationship. Metabolism 2019;92: 98–107.
[32] Al-Sharif FM, Abd El-Kader SM, Neamatallah ZA, AlKhateeb AM. Weight reduction improves immune system and inflammatory cytokines in obese asthmatic patients. Afr Health Sci 2020;20(2):897–902.
[33] Pedersen LR, Olsen RH, Anholm C, Astrup A, Eugen-Olsen J, Fenger M, et al. Effects of 1 year of exercise training versus combined exercise training and weight loss on body composition, low-grade inflammation and lipids in overweight patients with coronary artery disease: a randomized trial. Cardiovasc Diabetol 2019;18(1):127.
[34] Abd El-Kader SM, Saiem Al-Dahr MH. Weight loss improves biomarkers endothelial function and systemic inflammation in obese postmenopausal Saudi women. Afr Health Sci 2016;16(2):533–41.
[35] Kilic MK, Kizilarslanoglu MC, Arik G, Bolayir B, Kara O, Varan HD, et al. Association of Bioelectrical Impedance Analysis–Derived Phase Angle and Sarcopenia in Older Adults. Nutr Clin Pract 2017;32(1):103–9.
[36] Marini E, Buffa R, Saragat B, Coin A, Toffanello ED, Berton L, et al. The potential of classic and specific bioelectrical impedance vector analysis for the assessment of sarcopenia and sarcopenic obesity. Clin Interv Aging 2012;7:585–91.
[37] Koehler KB, de Moraes RAG, Rodrigues JB, de Portela BSM, Miguel GPS, Pedrosa RG, et al. Bioimpedance phase angle is associated with serum transthyretin but not with prognostic inflammatory and nutritional index during follow-up of women submitted to bariatric surgery. Clin Nutr ESPEN 2019;33:183–7.
[38] Venâncio FA, Almeida LA, Zovico PV, Barauna VG, Miguel GPS, Pedrosa RG, et al. Roux-en-Y Gastric Bypass and Sleeve Gastrectomy Differently Affect Oxidative Damage Markers and their Correlations with Body Parameters. Obes Surg 2021; 31(4):1680–7.
[39] Teixeira J, Marroni CA, Zubiaurre PR, Henz A, Faina L, Pinheiro LK, et al. Phase angle and non-alcoholic fatty liver disease before and after bariatric surgery. World J Hepatol 2020;12(11):1004–19.
[40] Ballesteros-Pomar MD, González-Arnáiz E, Pintor-de-la Maza B, Barajas-Galindo D, Ariadel-Cobo D, González-Roza L, et al. Bioelectrical impedance analysis as an alternative to dual-energy x-ray absorptiometry in the assessment of fat mass and appendicular lean mass in patients with obesity. Nutrition 2022;93:111442.
[41] Verdich C, Barbe P, Petersen M, Grau K, Ward L, Macdonald I, et al. Changes in body composition during weight loss in obese subjects in the NUGENOB study: comparison of bioelectrical impedance vs. dual-energy X-ray absorptiometry. Diabetes Metab 2011;37(3):222–9.