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Original article

Influence of the type of electrodes in the assessment of body composition by bioelectrical impedance analysis in the supine position

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SUMMARY

Background & aims: The main source of error in body composition assessment of bedridden patients by bioelectrical impedance analysis (BIA) is the electrode inadequacy and placement. As electrocardiogram (ECG) electrodes are often used for BIA measurements, this study aimed to compare three of them with a reference BIA electrode.

Methods: BIA was performed sequentially on 24 healthy subjects in the supine position, using 3 different ECG electrodes (3M® Red Dot® 2330; Ambu® BlueSensor 2300; Ambu® BlueSensor SU-00-C) and the reference electrode (Bianostic AT®) for the BIA device (Nutriguard-M®, Data Input, Germany). Resistance (R), reactance (Xc), phase angle (PhA), appendicular skeletal muscle index (ASMI), fat-free mass index (FFMI) and fat mass percentage (FM%) obtained with the different electrodes were compared using Bland–Altman plots, repeated measures one-way ANOVA and paired *t*-test. Patient characteristics potentially involved in BIA measurement differences were assessed using linear regression analysis.

Results: The study population consisted of 9 men and 15 women, 33% and 47% of whom were overweight, respectively. The measured R was within the physiological range for all men (428–561 Ω) and women (472–678 Ω), regardless of the type of electrodes used. Compared to the reference electrode, the 3M® Red Dot® 2330 and Ambu® BlueSensor SU-00-C electrodes gave significantly different Xc and PhA values, but only the Ambu® BlueSensor SU-00-C gave significantly different ASMI, FFMI and FM% at 50 kHz, with biases of −0.2 kg/m^2, −0.3 kg/m^2 and +1.4%, respectively. The higher the current frequency, the lower was the Xc and PhA measured by the Ambu® BlueSensor SU-00-C compared to the reference electrode. These measurement differences seemed mainly due to the too small gel area of the Ambu® BlueSensor SU-00-C (154 mm^2) compared to the reference electrode (1311 mm^2).

Conclusions: The use of electrodes with small gel area affects BIA measurement in the supine position, especially when PhA is used as an indicator of the nutritional status. Therefore, it is essential to specify the type of electrodes and carry out comparative tests before changing consumables for body composition assessment, to ensure BIA measurement reliability in clinical and research settings.

1. Introduction

Bioelectrical impedance analysis (BIA) is a simple, fast, inexpensive, and non-invasive method for estimating body composition of the patients [1]. The principle of BIA is to measure the total resistance, called impedance (Z), and the phase angle (PhA) generated by a low intensity (≤1 mA) and alternating (1–1000 kHz)

Abbreviations: ASMI, appendicular skeletal muscle index; BIA, bioelectrical impedance analysis; BMI, body mass index; ECG, electrocardiogram; FFMI, fat-free mass index; FM%, fat mass percentage; LoA, limits of agreement; PhA, phase angle; R, resistance; TBW, total body water; Xc, reactance; Z, impedance.

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current that circulates through the human body [2]. Z consists of two vectors: resistance (R) and reactance (Xc). R is inversely proportional to the total body water (TBW) and electrolytes (conductors), while Xc is representative of the body cell mass (condensers). Using R and Xc in addition to demographics (i.e. age, sex, weight, and height), predictive formulae allow calculation of TBW, appendicular skeletal muscle index (ASMI), fat-free mass index (FFMI), and fat mass percentage (FM%) [3]. Although less sensitive and specific than magnetic resonance imaging, computed tomography or dual energy X-ray absorptiometry, BIA has the advantage of being radiation-free and easy-to-use in clinical practice [4]. Moreover, BIA is a guideline-accepted method for muscle mass loss detection. Indeed, the Global Leadership Initiative on Malnutrition (GLIM), a working group bringing together clinical nutrition experts, has validated ASMI and FFMI measurements with BIA as one of the phenotypic criteria for the diagnosis of malnutrition [5]. The most suitable BIA method for bedridden patients is a tetrapolar and ipsilateral measurement, which requires the placement of two pairs of signal and detection electrodes, one on the hand and one on the foot of the dominant body side [6]. For the measurement to be accurate and reproducible, the signal and detection electrodes must be attached to specific locations with a distance ≥5 cm from each other [7]. An error of 1 cm in electrode placement may cause an error of 2% in the BIA measurement corresponding to a deviation of up to 20 Ω and 1 L of TBW [8]. The type of electrodes used can also prevent accurate BIA measurement. To reduce costs by increasing purchase volumes, caregivers often use electrocardiogram (ECG) electrodes, which supposedly provide good reproducibility in the assessment of human body composition by BIA [9]. However, there are many different ECG electrodes on the market. The objective of this study was to compare three of them, which are commonly used in hospitals, with a reference electrode for body composition assessment by BIA.

2. Materials and methods

2.1. Study design and objectives

This prospective observational study was carried out at the Geneva University Hospitals after obtaining the approval of the Cantonal Research Ethics Committee. The objective was to compare the BIA measurements performed with 3 different ECG electrodes with those performed with the electrodes recommended by the manufacturer of the BIA device used in clinical practice at the Geneva University Hospitals (Nutriguard-M, Data Input GmbH, Pöcking, Germany) [10].

2.2. Subjects

As R and Xc measurement accuracies certified by the Nutriguard-M manufacturer are ±0.5% and ±2%, respectively, at least 22 subjects were required to be 90% sure that the limits of a two-sided 90% confidence interval excluded R and Xc measurement differences ≥2% between the electrodes, using a sample size calculator for equivalence trial (https://www.sealedenvelope.com/power/continuous-equivalence/). Therefore, 24 healthy Caucasian subjects were recruited among the employees of the Geneva University Hospitals. As BIA measurement is fast, non-invasive, painless, and safe, even with implanted cardiac defibrillator [11], anyone who gave informed consent could participate in the study. In order to avoid skewing BIA measurement, the subjects should not have been dehydrated, taken medication affecting fluid and electrolyte balance (e.g. diuretics or calcium channel blockers), performed physical exercise or drunk alcohol in the last 8 h according to the ESPEN guidelines [6].

2.3. Electrodes

2.3.1. Bianostic AT®

The Bianostic AT® electrodes were specially developed and tested for BIA measurements by the Nutriguard-M manufacturer. They have the largest skin contact area among the 4 electrodes tested. Their double surface size of 1311 mm^2 reduces the contact resistance with the skin. They were compared to 3 single-use ECG electrodes made of silicone-free radiolucent silver/silver chloride (Ag/AgCl) polymers, which guarantees reliable conduction values. These ECG electrodes differ essentially in their size and contact area with the skin. According to manufacturer recommendations, the shelf life (24–36 months) of the 3 ECG electrodes is longer than that of Bianostic AT® (18 months), but once the pouch is opened the 3 ECG electrodes have to be used in a month while the Bianostic AT® electrodes can be used for up to 2 months (Table 1).

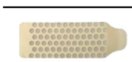
2.3.2. 3M® Red Dot® 2330

The 3M® Red Dot® 2330 electrodes have the smallest skin contact area with a measuring gel area of 400 mm^2. Their pressure-sensitive and skin-friendly gel makes them easy to apply and remove without residue on all skin types.

2.3.3. Ambu® BlueSensor 2300

The Ambu® BlueSensor 2300 electrodes feature a skin-friendly solid gel that provides optimal signal quality with a slightly larger measuring area of 575 mm^2.

Table 1
Characteristics of the tested electrodes.

Electrodes		Use	Type of gel	Contact area (mm)	Gel area (mm^2)	Shelf life[a] (months)	Indicative price (Euro)
	Bianostic AT®	BIA	Hydrogel	68 × 23	1311	18	0.18
	3M® Red Dot® 2330	ECG	Soft hydrogel	30 × 20	400	36	0.10
	Ambu® BlueSensor 2300	ECG	Solid gel	34 × 23	575	24	0.14
	Ambu® BlueSensor SU-00-C	ECG	Wet gel	49 × 33	154	24	0.11

[a] Shelf life in unopened pouches.

2.3.4. Ambu® BlueSensor SU-00-C

The Ambu® BlueSensor SU-00-C electrodes are the world's first tab electrodes featuring a wet gel. The conductive wet gel with Ag/AgCl sensor optimizes contact between skin and electrode, lowers skin impedance efficiently and immediately, and provides stable signal quality. Offset connector allows to connect and disconnect the lead wire without applying pressure to the sensor area, which reduces the risk of gel spreading and adhesive detachment from skin. Although their adhesive area is of 772 mm^2, the measuring gel area of 154 mm^2 is the smallest among the tested electrodes.

2.4. Standard procedure

Demographics (age, sex, weight, and height) were recorded in a case report form. Body weight and height were measured with minimal clothing and barefoot, using a calibrated weight scale and stadiometer, respectively. BIA measurement was then carried out after the subjects lay on their back for approximately 10 min with their legs apart at an angle of approximately 45° and their arms at an angle of approximately 30°, as described in the ESPEN guidelines [6]. Subjects could wear jewelry and watch, but their body was not in contact with metal parts of the bed frame. The measurement was performed on the right side of the body, using a single-site electrode placement with anatomical landmarks. On the hand (Fig. 1A), the signal electrode was attached between the base joints of the index and middle fingers, and the detection electrode between the radius and ulna heads. On the foot (Fig. 1B), the signal electrode was attached between the base joints of the 2nd and 3rd toes, and the detection electrode between the highest point of the outer and inner ankle bones.

The skin was cleaned with hydroalcoholic solution and dried between each electrode change. To avoid bias due to fluid shift in the body from standing to lying down [12], the order of the BIA measurements with the four electrodes was carried out according to the following sequences in 8 subjects per sequence: ABCD, DABC, CDAB, and BCAD. Raw data (R, Xc, Z, and PhA [14]) were recorded sequentially at 5, 50, and 100 kHz using the Nutriguard-M. This device also provides hand (R_H) and foot (R_F) skin-electrode contact resistances, which make it possible to identify problems of electrode-skin adhesion in case of R_H or $R_F > 300\ \Omega$.

2.5. Prediction equations used for calculating body composition

The measured R and Xc values at 50 kHz were used to calculate FFMI and FM% from our previously validated prediction equation [13]:

$$\mathrm{FFMI}\left(\frac{\mathrm{kg}}{\mathrm{m}^2}\right)=\frac{-4.104+\left(\frac{0.518\times \mathrm{height}^2}{R}\right)+(0.231\times \mathrm{weight})+(0.130\times Xc)+(4.229\times \mathrm{sex})}{\mathrm{height}^2}$$

where sex = 0 for women, 1 for men

$$\mathrm{FM\%}=\frac{\left(\mathrm{weight}-\mathrm{FFMI}\times \mathrm{height}^2\right)\times 100}{\mathrm{weight}}$$

$$\mathrm{PhA}\ (^\circ)=\mathrm{arctangent}\left(\frac{Xc}{R}\right)\times\left(\frac{180^\circ}{\pi}\right)$$

For the calculation of ASMI, we used the Sergi equation [15], which was developed from the model of Kyle et al. [16], and recommended by the European expert group on sarcopenia [17], after being compared favorably with other prediction equations [18]:

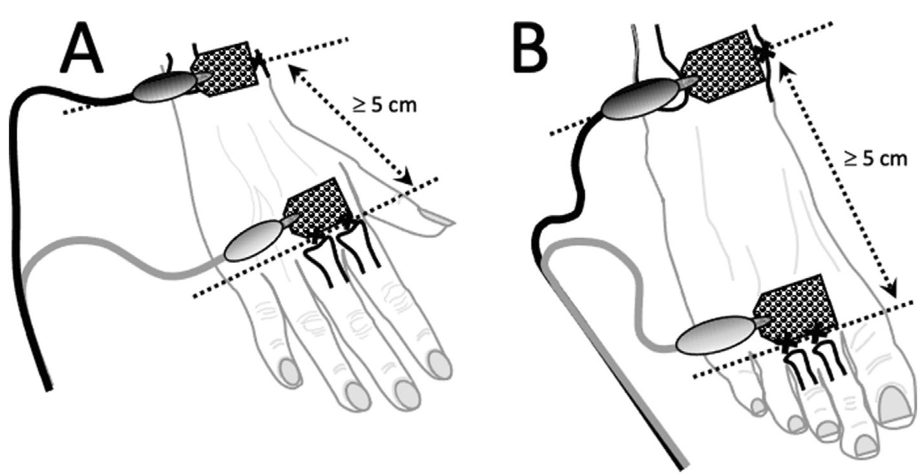


Fig. 1. Schematic drawing of the adhesive electrode positions for tetrapolar and ipsilateral bioelectrical impedance analysis in the supine position. (**A**) On the hand, the signal electrode is attached between the base joints of the index and middle fingers, and the detection electrode between the radius and ulna heads. (**B**) On the foot, the signal electrode is attached between the base joints of the 2nd and 3rd toes, and the detection electrode between the highest point of the outer and inner ankle bones.

Table 2
Physical and bioelectrical characteristics of the subjects according to the sex and the BMI.

	All	Men	Women	BMI <25 kg/m^2	BMI ≥25 kg/m^2
Men/Women	9/15	9/0	0/15	6/8	3/7
Age (years)	39.9 ± 12.8	45.5 ± 12.4	36.6 ± 12.1	36.0 ± 13.1	45.4 ± 10.4
Height (cm)	169.3 ± 9.5	178.5 ± 6.9[a]	163.7 ± 5.7[a]	169.3 ± 9.3	169.3 ± 10.2
Weight (kg)	69.5 ± 11.6	73.7 ± 13.2	66.9 ± 10.1	63.0 ± 7.7[b]	78.5 ± 10.1[b]
BMI (kg/m^2)	24.2 ± 3.3	23.0 ± 3.2	24.9 ± 3.2	22.0 ± 1.9[b]	27.4 ± 2.0[b]
R (Ω)	527 ± 59	481 ± 40[a]	555 ± 52[a]	546 ± 57	500 ± 54
Xc (Ω)	59 ± 7	57 ± 6	61 ± 8	62 ± 7	56 ± 7
PhA (°)	6.5 ± 0.6	6.8 ± 0.5	6.3 ± 0.7	6.5 ± 0.6	6.5 ± 0.7
ASMI (kg/m^2)	6.8 ± 0.7	7.3 ± 0.6[a]	6.5 ± 0.6[a]	6.5 ± 0.6[b]	7.2 ± 0.6[b]
FFMI (kg/m^2)	17.3 ± 1.6	18.5 ± 1.3[a]	16.6 ± 1.4[a]	16.6 ± 1.4[b]	18.3 ± 1.5[b]
FM%	27.7 ± 8.6	18.9 ± 6.0[a]	33.0 ± 4.4[a]	24.0 ± 8.3[b]	32.9 ± 6.0[b]

Abbreviations: ASMI, appendicular skeletal muscle index; BMI, body mass index; FFMI, fat-free mass index; FM%, fat mass percentage; PhA, phase angle; R, resistance; Xc, reactance.
BIA values according to the measurement with Bianostic AT® electrodes.
[a] Significantly different between sex categories (t-test, $P \le 0.01$).
[b] Significantly different between BMI categories (t-test, $P < 0.01$).

Table 3
Differences in BIA measurements at 50 kHz between the tested ECG electrodes and the reference Bianostic AT® electrodes.

	Bianostic AT® AT®	3M® Red Dot® 2330		Ambu® BlueSensor 2300		Ambu® BlueSensor SU-00-C	
	Mean ± SD	Mean ± SD	Bias [LoA]	Mean ± SD	Bias [LoA]	Mean ± SD	Bias [LoA]
R_H (Ω)	142 ± 26*	282 ± 26	140 [88; 192][c]	284 ± 83	142 [-58; 341][c]	594 ± 54	452 [344; 559]*
R_F (Ω)	153 ± 16*	282 ± 34	129 [72; 186][c]	286 ± 77	133 [-9; 276][c]	585 ± 45	432 [356; 508]*
R (Ω)	526.8 ± 59.5	526.8 ± 59.7	0.0 [-19.3; 19.2]	527.3 ± 58.2	0.5 [-11.9; 12.8]	528.2 ± 57.7	1.3 [-15.7; 18.4]
Xc (Ω)	59.4 ± 7.5	58.6 ± 7.8	−0.8 [−3.7; 2.2][a]	58.9 ± 7.9	−0.5 [−3.4; 2.5]	52.6 ± 7.3	−6.8 [−10.7; −2.9]*
PhA (°)	6.5 ± 0.6	6.4 ± 0.7	−0.1 [−0.4; 0.2][b]	6.4 ± 0.6	−0.1 [−0.4; 0.3]	5.7 ± 0.9	−0.8 [−1.6; 0.0]*
ASMI (kg/m^2)	6.8 ± 0.7	6.8 ± 0.7	0.0 [−0.2; 0.1]	6.8 ± 0.7	0.0 [−0.1; 0.1]	6.6 ± 0.7	−0.2 [−0.3; 0.0]*
FFMI (kg/m^2)	17.3 ± 1.6	17.3 ± 1.6	0.1 [−0.4; 0.3]	17.3 ± 1.6	0.0 [−0.3; 0.2]	17.0 ± 1.6	−0.3 [−0.6; −0.1]*
FM%	27.7 ± 8.6	27.9 ± 8.5	0.2 [−1.2; 1.5]	27.8 ± 8.4	0.1 [−1.0; 1.3]	29.1 ± 8.5	1.4 [0.3; 2.6]*

Abbreviations: ASMI, appendicular skeletal muscle index; FFMI, fat-free mass index; FM%, fat mass percentage; LoA, limits of agreement; PhA, phase angle; R, resistance; R_F, foot resistance; R_H, hand resistance; Xc, reactance.
Significant difference from Bianostic AT® electrodes: [a], $P < 0.05$; [b], $P < 0.01$; [c], $P < 0.001$ (paired t-test).
Significant difference from all other electrodes: *, $P < 0.001$ (Repeated measures ANOVA followed by Bonferroni's correction for *post hoc* multiple comparison tests).

$$\text{ASMI}\left(\frac{\text{kg}}{\text{m}^2}\right)=\frac{-3.964+\left(\frac{0.227\times R}{\text{height}^2}\right)+(0.095\times\text{weight})+(0.064\times Xc)+(1.384\times\text{sex})}{\text{height}^2}$$

where sex = 0 for women, 1 for men.

2.6. Data analysis

All variables were expressed as proportions or means ± standard deviation (SD). Repeated measures ANOVA followed by Bonferroni's correction for *post hoc* multiple comparison tests were performed to highlight statistical differences between the four electrodes. Agreement between the electrode measurements was assessed by Bland–Altman plots with limits of agreement (LoA, bias ± 1.96 × SD), and paired t-test. Patient characteristics that could have played a role in the measurement difference between the four electrodes were assessed using univariate linear regression. Statistical analysis was performed with the Stata/IC 13.1 software for Windows (StataCorp LP, College Station, TX, USA). Statistical significance level was set at $P < 0.05$.

3. Results

3.1. Population description

The study population consisted of 62.5% women with an average ASMI and FFMI smaller by 0.8 and 1.9 kg/m^2, respectively, and a FM % greater by 14.1% than men. The overweight subjects (3 men and 7 women) differed from the normal weighed subjects by an increased ASMI, FFMI, and FM% of 0.7 kg/m^2, 1.7 kg/m^2, and 8.9%, respectively (Table 2). The measured R value was within the physiological range for all men (428–561 Ω) and women (472–678 Ω), regardless of the type of electrodes [19].

3.2. Raw data comparison between the electrodes

R_H and R_F measurements were significantly smaller with Bianostic AT® featuring the largest gel area among the 4 electrodes, and higher with Ambu® BlueSensor SU-00-C featuring the smallest gel area ($P < 0.001$), while 3M® Red Dot® 2330 and Ambu®

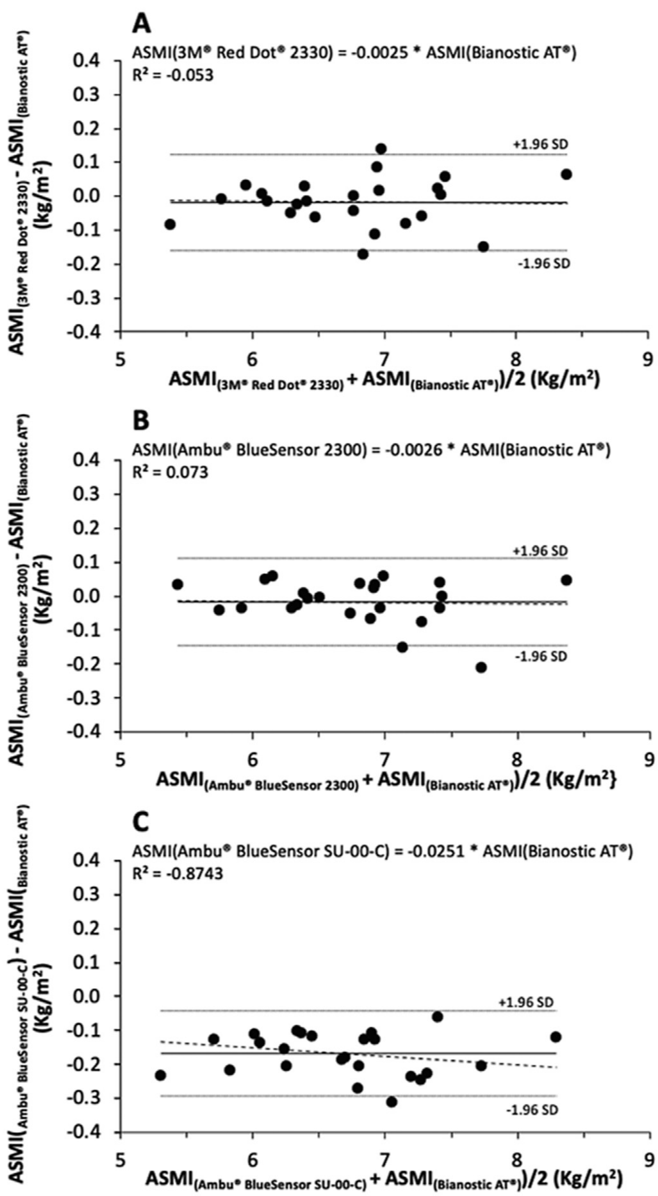


Fig. 2. Adjusted Bland–Altman plots showing the difference of appendicular skeletal muscle index (ASMI) measurement between 3M® Red Dot® 2330/Bianostic AT® (**A**), Ambu® BlueSensor 2300/Bianostic AT® (**B**), and Ambu® BlueSensor SU-00-C/Bianostic AT® (**C**) electrodes. The solid line represents the mean bias. The dashed regression line represents the trend of mean differences between the two electrodes.

BlueSensor 2300 gave similar values. However, there was no significant difference in R measurement between the four tested electrodes. Compared to Bianostic AT® reference electrodes, Xc and PhA measurements were significantly different with 3M® Red Dot® 2330 and Ambu® BlueSensor SU-00-C electrodes, but not with Ambu® BlueSensor 2300 (Table 3).

3.3. *Influence of electrodes on body composition assessment*

The difference in Xc and PhA measurements with 3M® Red Dot® 2330 compared to Bianostic AT® electrodes ultimately had no significant impact on ASMI (Fig. 2A), FFMI (Fig. 3A), and FM% (Fig. 4A). There was also no bias in ASMI (Fig. 2B), FFMI (Fig. 3B), and FM% (Fig. 4B) measurement between Ambu® BlueSensor 2300 and Bianostic AT® electrodes. Only the Ambu® BlueSensor SU-00-C electrodes gave ASMI (Fig. 2C), FFMI (Fig. 3C), and FM% (Fig. 4C) values significantly different from Bianostic AT® electrodes with biases of -0.2 kg/m^2, -0.3 kg/m^2, and $+1.4$%, respectively (Table 3).

3.4. *Influence of electrodes at different current frequencies*

BIA measurements at 5, 50, and 100 kHz failed to show significant differences in R between the four electrodes (Fig. 5A). The differences in Xc (Fig. 5B) and PhA (Fig. 5C) measurements with the Ambu® BlueSensor SU-00-C compared to the Bianostic AT® electrodes were more marked at 5 and 100 kHz than at 50 kHz. Xc and PhA were overestimated by 10.8 $\pm$ 16.8% and 10.7 $\pm$ 16.1% at 5 kHz and underestimated by 27.9 $\pm$ 7.7% and 27.5 $\pm$ 9.2% at 100 kHz, respectively.

3.5. *Potential factors affecting electrode measurement*

Univariate linear regression analysis did not identify any potential factor, among sex, age, height, weight, or BMI, that might have emphasized the difference of PhA measurement between Ambu® BlueSensor SU-00-C and Bianostic AT® electrodes (Table 4).

4. Discussion

This study confirms that tetrapolar and ipsilateral BIA measurement is a robust and reproducible method, since ASMI, FFMI, and FM% measurements were generally not affected by the type of electrodes. Of the 3 types of ECG electrodes tested, only the Ambu® BlueSensor SU-00-C gave significantly different ASMI, FFMI, and FM % values from the reference Bianostic AT®, with R_H and R_F at 50 kHz out of the acceptable limit of 300 Ω defined by the manufacturer of the Nutriguard-M device. Although the measurement difference was small at 50 kHz, it was amplified both at 5 and 100 kHz, suggesting that multi-frequency BIA methods are probably more impacted by the type of electrodes than single-frequency BIA methods. The type of gel probably plays a role, synthetic polymer hydrogel being the most reliable [20]. However, the gel area in contact with the skin seems to be the main issue. Indeed, the Ambu® BlueSensor SU-00-C electrodes features the largest skin contact surface, but the smallest gel area compared to the other electrodes tested. The ESPEN guidelines recommend an electrode surface size $\geq$400 mm^2, without however referring to any study [6]. Our results confirm those of a previous study showing that 3M® Red Dot® 2330 electrodes with a gel surface of 400 mm^2 were suitable to replace the electrodes recommended by the manufacturer of the BIA device to assess FFM and FM% [21]. However, electrodes of this size may not be sufficient for the interpretation of PhA as a predictor of malnutrition, since Xc and PhA values measured with 3M® Red Dot® 2330 electrodes differed slightly but significantly from those measured with Bianostic AT® electrodes (paired *t*-test). PhA measurement is increasingly used to evaluate patients' nutritional status and estimate their survival rate [22]. Attempts have been made to establish reference values for PhA by age and sex [23], and to define cut-off values for sarcopenia and cachexia [24]. However, this approach is limited by the high variability of PhA measurement between patients [22], BIA devices [25], and electrode placement [26,27], so that PhA interpretation can only be used for monitoring the nutritional status of a patient, rather than by comparison with population data [2,22]. The results of the present study highlight the importance of using the same type of suitable electrodes throughout the nutritional follow-up of a given patient. It is particularly important to check that the gel area

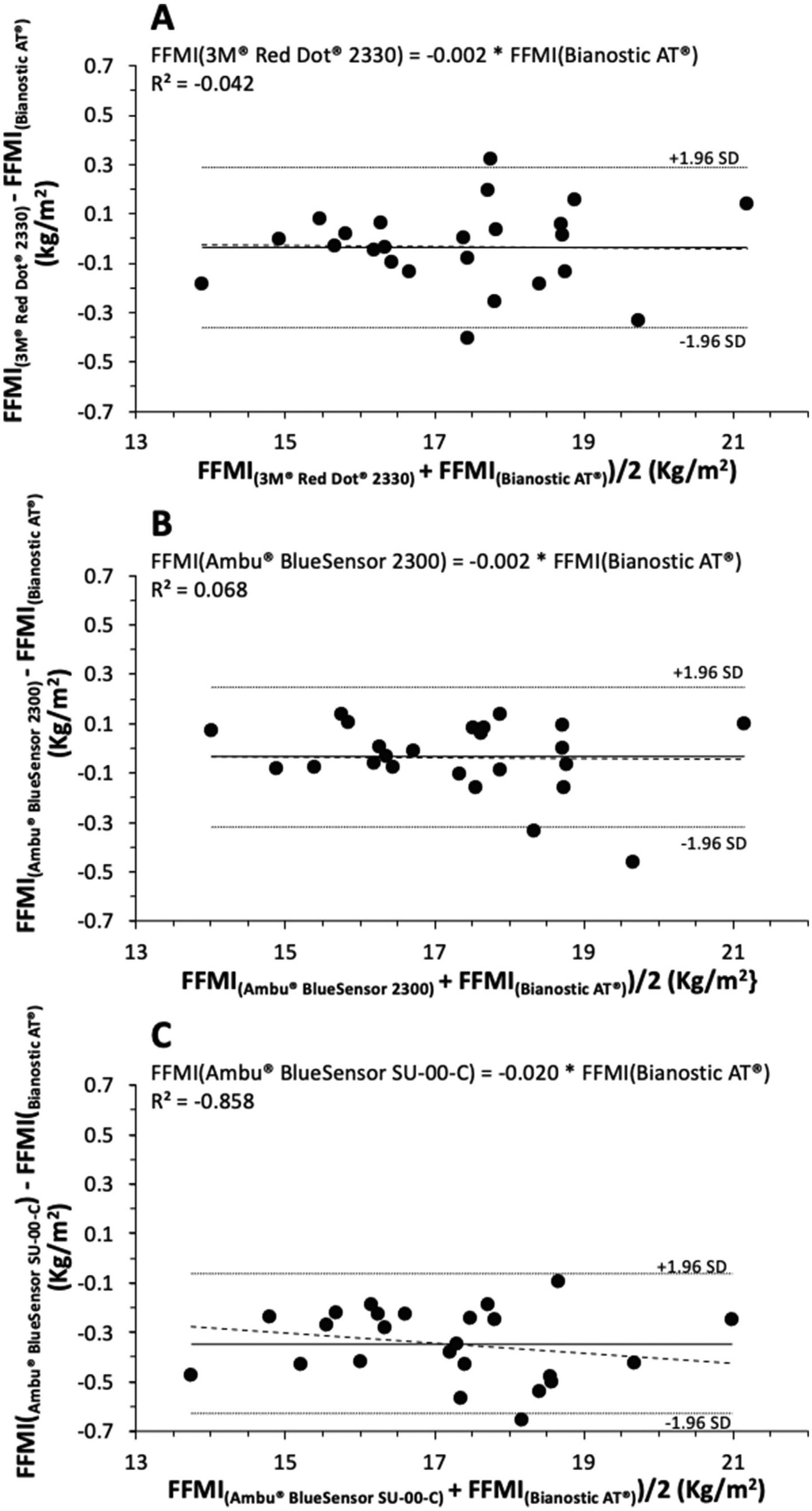


Fig. 3. Adjusted Bland–Altman plots showing the difference of fat-free mass index (FMMI) measurement between 3M® Red Dot® 2330/Bianostic AT® (**A**), Ambu® BlueSensor 2300/Bianostic AT® (**B**), and Ambu® BlueSensor SU-00-C/Bianostic AT® (**C**) electrodes. The solid line represents the mean bias. The dashed regression line represents the trend of mean differences between the two electrodes.

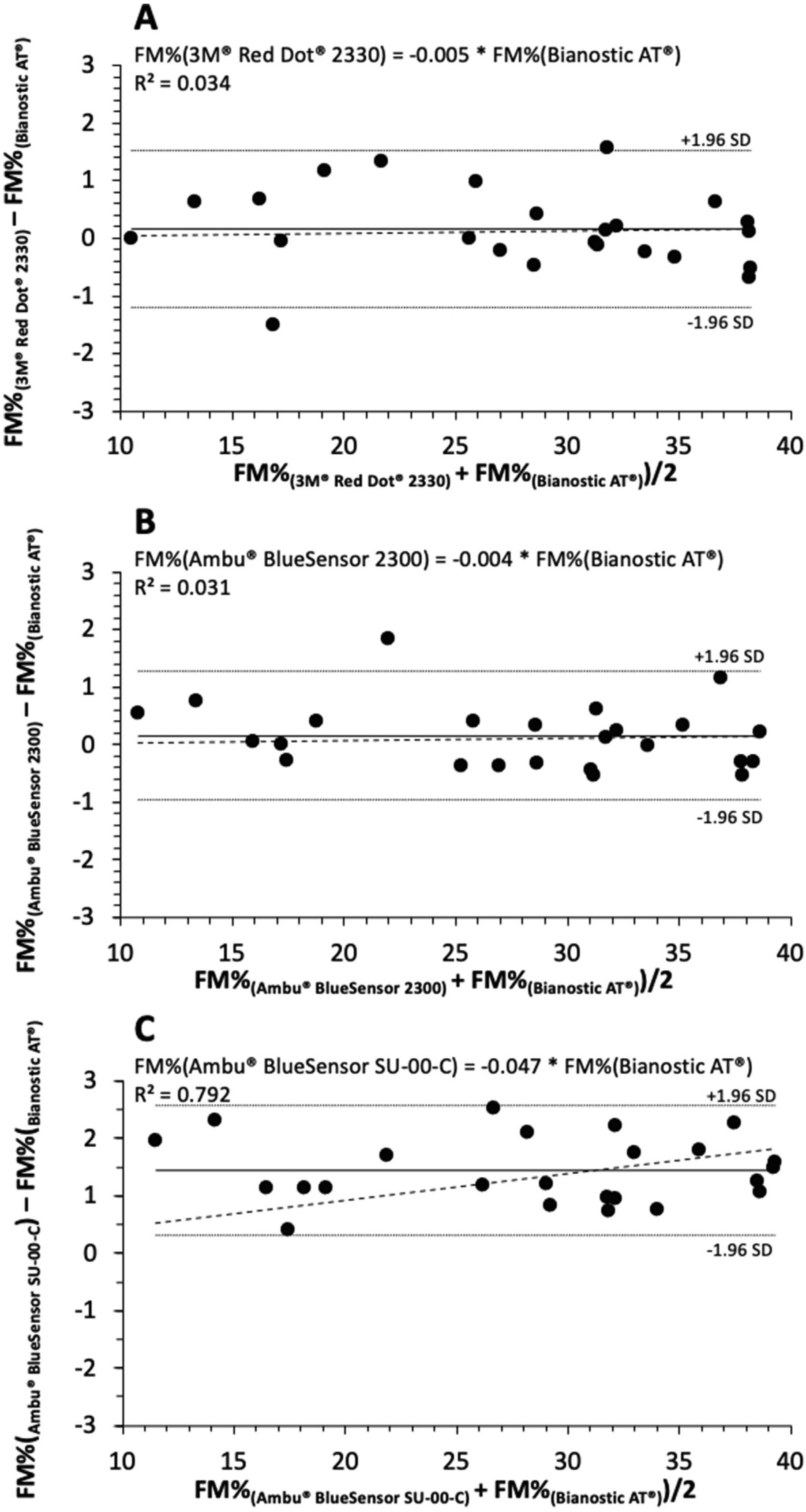


Fig. 4. Adjusted Bland–Altman plots showing the difference of fat mass percentage (FM%) measurement between 3M® Red Dot® 2330/Bianostic AT® (**A**), Ambu® BlueSensor 2300/Bianostic AT® (**B**), and Ambu® BlueSensor SU-00-C/Bianostic AT® (**C**) electrodes. The solid line represents the mean bias. The dashed regression line represents the trend of mean differences between the two electrodes.

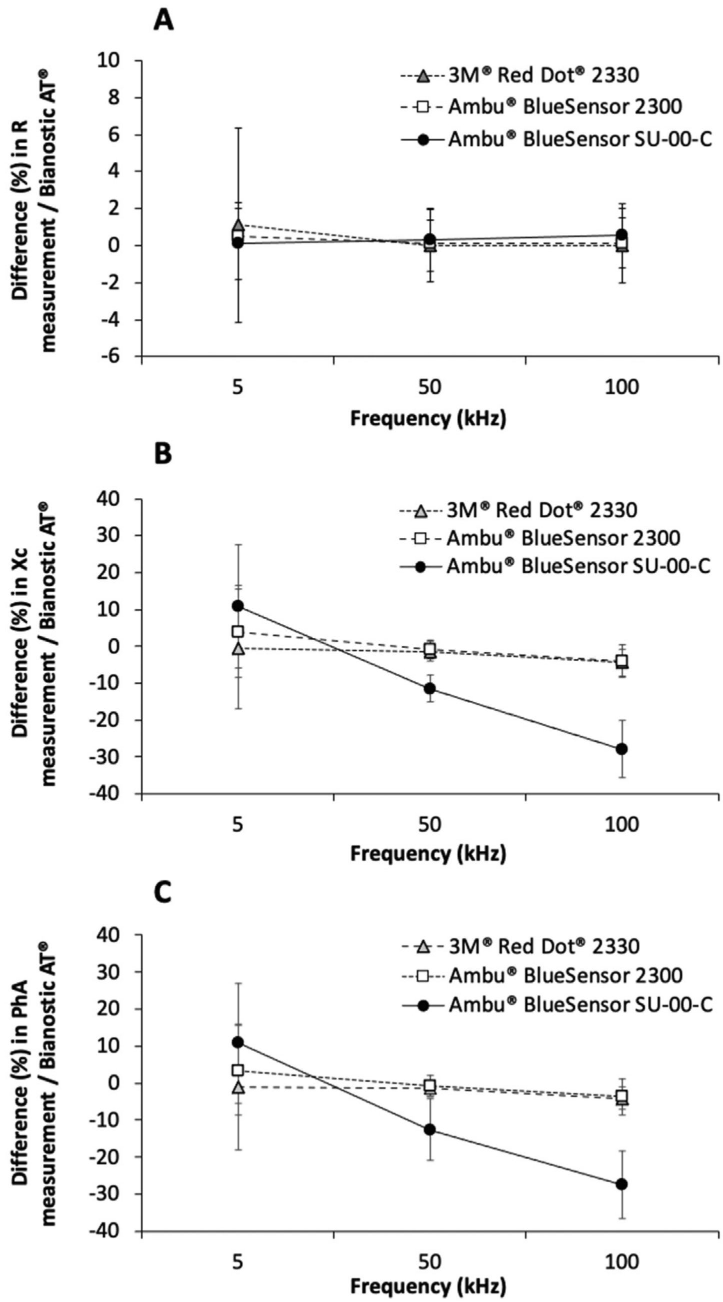


Fig. 5. Difference (%) in R (**A**), Xc (**B**), and PhA (**C**) measurements between 3M® Red Dot® 2330/Bianostic AT® (▲), Ambu® BlueSensor 2300/Bianostic AT® (□), and Ambu® BlueSensor SU-00-C/Bianostic AT® (●) electrodes, according to the current frequency.

Table 4
Univariate linear regression analysis evaluating the association between patient characteristics and the difference (%) in PhA measurement between the Ambu® BlueSensor SU-00-C and reference Bianostic AT® electrodes.

	Coeff.	Std. Err.	t	*P*	[95% CI]	Adj. R^2
Sex (men vs women)	3.46	3.54	0.98	*0.339*	[−3.88; 10.79]	−0.002
Age	−0.25	0.13	−1.97	*0.061*	[−0.52; 0.13]	0.112
Height	0.16	0.18	0.89	*0.385*	[−0.22; 0.55]	−0.009
Weight	−0.06	0.15	−0.38	*0.707*	[−0.38; 0.26]	−0.038
BMI	−0.67	12.73	0.28	*0.780*	[−22.80; 30.00]	0.028

is sufficient, especially since the contact area does not always correspond to the gel area, as is the case for the Ambu® BlueSensor SU-00-C electrodes. The conductive gel can also desiccate quickly depending on the storage conditions. To comply with FDA and EMEA regulations, bulk-packaged electrodes are supplied with an expiration date. However, their shelf life is dramatically reduced once the pouch has been opened. Therefore, it is essential to write the opening date on the pouches for safety and regulatory purposes, and to store the opened pouches no more than 30 days at 6–25 °C [28]. They should never be reused or stored in the fridge to prevent the electrodes from swelling due to high humidity, nor in high temperatures and dry air to prevent them from desiccating. It is possible to check whether the Xc value is within the physiological range of 8–14% compared to R. Although Xc measurements <8% than R can occur in malnourished patients [29], and Xc measurements >14% than R in bodybuilders [30], out-of-range Xc values are mainly due to inadequate or degraded electrodes.

4.1. Limitations

This study was limited to healthy normal and overweight individuals because BIA measurements in underweight or obese individuals are difficult to interpret [31]. This is also true for diseases causing a water imbalance between the intra- and extracellular compartments [32].

5. Conclusion

The use of electrodes with small gel area affects BIA measurement in the supine position, especially when PhA is used as an indicator of the nutritional status. Therefore, it is essential to specify the type of electrodes and carry out comparative tests before changing consumables for body composition assessment, to ensure BIA measurement reliability in clinical and research settings.

Author Contribution

YMD designed the study, performed data analysis, and wrote the paper; AGP and YMD recruited the participants and collected the data; AH, EB, LG, THC, VLK participated in the critical revision of the manuscript. All authors gave final approval of the version to be submitted.

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Conflict of Interest

The authors declare no competing interests.

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