Relationship between bioelectric impedance, body muscularity and body adiposity in young children

Relazione tra impedenza bioelettrica, grado di adiposità e muscolarità corporea in bambini dai 6 ai 12 anni di età

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Riassunto

Abbiamo studiato la relazione tra l'impedenza bioelettrica (IB) e il grado di adiposità e muscolarità corporea in 1540 bambini in età compresa tra 6 e 12 anni. IB e l'indice di impedenza (altezza²/IB) aumentano all'aumentare del livello di adiposità (determinata sulla base dell'area adiposa del braccio e della somma delle quattro pliche secondo Durnin & Womerseley) e muscolarità (determinata sulla base della circonferenza e dell'area muscolare del braccio), rispettivamente. Sulla base del raffronto con il body mass index, il peso relativo e la plica tricipitale, IB si dimostra un indice di adiposità migliore dell'indice di impedenza. Comunque, l'indice di impedenza appare un migliore indice di muscolarità rispetto a IB. Si conclude che IB e l'indice di impedenza hanno il potenziale per essere utilizzati come indici di adiposità e muscolarità, rispettivamente, in età pediatrica. Sono forniti i valori percentili di IB e dell'indice di impedenza per bambini italiani in età compresa tra 6 e 12 anni.

Introduction

The opposition of a biologic conductor to the flow of an alternating electrical current is known as bioelectric impedance (BI). Based on the high impedance of fat and bone and the low impedance of water, bioelectric impedance analysis (BIA) has been proposed as a simple and expedient tool for assessing body composition. The prediction of total body water (TBW) and fat-free mass (FFM) from BI is based on the principle that the impedance (Z) of an ohmic conductor is related to its length, configuration and cross-sectional area [1]. At a given frequency, Z is related to the volume of the conductor according to the formula:

$$V = a \times \text{length}^2/Z + b$$

On the basis of this model, a number of equations have been developed for predicting TBW or FFM from BI by substituting the length of the conductor with body height, thus leading to the definition of the impedance index (height²/Z or ZI). Though the electrical behaviour of the human body is far from that of an ideal ohmic conductor [2], it has nonetheless been clearly demonstrated that ZI allows a precise and accurate assessment of TBW and FFM [3].

To date, the interest of researchers on BIA has focused primarily on the development of formulae for predicting body composition in different physiological and clinical conditions [4]. However, owing to the different impedance of fat and fat-free tissues, BI may potentially be used as an adiposity and/or muscularity index, independent of any prediction formula. Such a property of BI would be of particular interest in paediatrics, where it may represent a simple and expeditious way of monitoring the growing child.

It was therefore the aim of the present study to assess the relationship between Z, ZI and the more commonly employed muscularity and adiposity indexes in a population of italian children aged 6 to 12 years.

Population and methods

Population

The 1540 children recruited for this study came from the cities of Modena (n = 387), Foggia (n = 632) and Cosenza (n = 521). All the subjects were healthy according to their medical history. Measurements were performed in the primary schools attended by the children after having obtained permission from their parents.

Anthropometry

Body weight and height were measured to the nearest 0.1 Kg and 0.5 cm respectively with the subject wearing

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only light cotton cloths. Skinfold thickness was measured at the triceps (TSF), biceps (BSF), subscapular (SSF) and suprailiac (SISF) sites with an Holtain caliper (Holtain, Crymich, UK) following the directions of the Anthropometric Standardization Reference Manual [5]. Arm circumference was measured following the same source. Skinfold measurements were taken in triplicate to the nearest 0.1 mm and the mean value of the measurements was used for statistical analysis. Skinfold and circumference measurements were always performed by the same operators in the different cities. These expert anthropometrists had previously undergone training sessions in Modena to standardize measurements as described by Johnston & Martorell [6]. Intra-measurer errors were of 0.5 mm for TSF, 0.7 mm for BSF, 0.8 mm for SSF, and 0.6 for SISF. Inter-measurer errors were of 0.9 mm for TSF, 1.0 mm for BSF, 0.9 for SSF and 1.0 for SISF. These values are in agreement with those published in the literature [7]. Body mass index (BMI) was calculated as weight (Kg) / height^2 (m) and relative weight (RW) as the ratio between the measured weight and the ideal weight for age according to NCHS growth-charts [8]. Arm muscle area (AMA), arm fat area (AFA) and arm muscle circumference (AMC) were calculated as described by Frisancho [8]. The Durnin-Womerseley sum (DW-sum) of four skinfolds (TSF, BSF, SSF and SISF) was also calculated to provide an index of whole-body fat depots [8 9]. The growth-standards provided by NCHS were taken as a reference for establishing the adiposity level of the children [8 10]. These standards were adopted following our observation that they may be safely used for establishing growth status of italian children aged 6 to 12 years [10]. Comparison with reference values was done by means of Z-scores [8]. The adiposity level of the children was assessed on the basis of the values of BMI, RW and TSF. For BMI and TSF, values under the 5th and over the 95th percentile of age were employed for the diagnosis of under- and overweight. This cutoff was chosen following the recommendations of Rolland-Cacherà [10 11]. For RW, the classification reported by Paige [11] was utilised, which distinguishes between underweight (≤ 90%), normal-weight (91-109%), overweight (110-119%) and obese (≥ 120%) children.

BIA

BIA was performed on the right side of the body after 15 minutes in the supine position. The current-injecting electrodes were placed on the dorsal surfaces of the hand and foot proximal to metacarpal-phalangeal and metatarsal-phalangeal joints respectively. The voltage-sensing electrodes were placed between the wrist and ankle [12]. Body impedance was determined at a frequency of 50 kHz with a tetrapolar impedance plethysmograph (Human-Im Scan, Dietosystem, Milan, Italy) and ZI was calculated as Height^2(cm^2)/Z (Ω). Three of these plethysmographs were employed in the study. Each instrument had a measurement precision comprised between 1 and 3 Ω, as determined by repeated measurements on the same subject. Inter-instrument variability was comprised between 2 and 4 Ω, as determined from repeated measurements on the same subject without moving the electrodes. Intra- and inter-measurer variability was of 1-3 Ω and of 1-4 Ω, respectively. These values are in agreement with those published in the literature [12].

Statistical analysis

Statistical analysis (mean ± sd, one-way ANOVA, linear regressions and percentiles) was performed on a Macintosh computer using the Statview 4.01 software package [13].

Results

The characteristics of the study population are given in Table I.

The male and female children were matched for age, weight, height, BMI and RW. TSF was higher in females than males, reflecting a higher fat mass in females as compared to males [10 14 15]. Moreover, Z was lower and ZI higher in males than in females.

The relationship between Z and ZI and the more commonly employed anthropometrical indexes of muscularity (AMA, AMC) and adiposity (AFA, DW-sum) is given in Table II.

As expected, body impedance and ZI were highly correlated with AMA and AMC whereas this correlation was lower with AFA and the DW-sum.

In Tables III, IV and V, children of both sexes were classified on the basis of their adiposity level (class) as determined by BMI, RW and TSF respectively.

The *p*-values for the inter-class variability of Z and ZI are given in the same Tables. Z shows a better agreement with BMI than ZI (Tab. III). The number of male subjects > 95th percentile of BMI for age was however too low (n = 2) to test the behaviour of Z and ZI as compared to BMI and thus led to a non significant result. On the basis of its *p*-values, Z shows a better agreement with RW than ZI (Tab. IV). However, neither Z nor ZI were able to discriminate between overweight and obese females. Z shows a better agreement with TSF than ZI (Tab. V). The number of male and female subjects > 95th percentile of TSF was however too low (n = 1) to test the behaviour of Z and ZI as compared to TSF and thus led to a non significant result.

Taken together, these data clearly show that the variability in body impedance closely follows the class of adiposity established by BMI, RW and TSF whereas these relationships breakdown for ZI.

Furthermore, Z decreases with increasing levels of body fatness as determined by the DW-sum (Fig. 1).

Despite the higher mean value of Z in females, the relationship appears to be the same in both sexes. Note

Tab. I.
Main characteristics of the study population. Values are expressed as mean ± sd (range). BMI = body mass index, RW = relative weight, TSF = triceps skinfold, Z = bioelectric impedance, ZI = impedance index (Height²/Z).
Principali caratteristiche della popolazione studiata. Valori espressi come media ± ds (range). BMI = indice di massa corporea, RW = peso relativo, TSF = plica tricipitale, Z = impedenza bioelettrica, ZI = indice di impedenza (altezza²/ Z).

	females	males
Number of subjects	756	784
Age (ys)	9.3 ± 1.9 (6.0-12.0)	9.4 ± 1.9 (6.0-12.0)
Weight (Kg)	34.6 ± 10.3 (14.1-73.4)	35.1 ± 10.5 (17.4-74.0)
Height (cm)	137.2 ± 12.3 (106.0-167.5)	137.6 ± 12.0 (109.2-170.0)
BMI (Kg/m²)	18.1 ± 3.1 (12.3-32.0)	18.3 ± 3.2 (12.3-30.8)
RW (%)	110.7 ± 21.7 (63.6-194.6)	110.3 ± 24.2 (63.6-207.0)
TSF (mm)	13.7 ± 5.5 (3.2-35.2)	11.9 ± 5.7* (3.4-33.2)
Z (Ω)	680 ± 85 (370-946)	634 ± 73* (389-851)
ZI (cm²/Ω)	28.6 ± 7.8 (11.9-65.2)	30.7 ± 8.1 * (16.2-69.1)

* $p < 0.0001$ vs females at ANOVA.

Tab. II.
Coefficients for the regression of Z and ZI vs muscularity indexes (AMA, arm muscle area and AMC, arm muscle circumference) and adiposity indexes (AFA, arm fat area and DW-sum, four-skinfolds sum according to Durnin & Womerseley) in male (m) and female (f) children from 6 to 12 years of age.
Coefficienti per la regressione di Z e ZI contro gli indici di muscolarità (AMA, area muscolare del braccio e AMC, circonferenza muscolare del braccio) e di adiposità (AFA, area adiposa del braccio, somma delle quattro pliche secondo Durnin & Womerseley) in maschi (m) e femmine (f) in età compresa tra 6 e 12 anni.

	Z		ZI	
	m	f	m	f
AMA	.576	.623	.728	.715
AMC	.642	.586	.733	.727
AFA	.404	.368	.483	.420
DW-SUM	.356	.287	.402	.318

Significance for all the regression coefficients: $p < 0.0001$.

mainly on the development of formulae for predicting TBW or FFM [4].
In the present study, we have addressed the question of

Tab. III.
p-values (by one-way ANOVA) for the inter-class variability of Z and ZI according to the adiposity level (class) established by body mass index (BMI) in male (m) and female (f) children. The number of subjects is given in parentheses. Subjects < 5th and > 95th percentile of BMI for age were considered underweight and overweight respectively.
Valori di p (one-way ANOVA) per la variabilità interclasse di Z e ZI in relazione alla classe (livello) di adiposità determinata dall'indice di massa corporea (BMI) in bambini di sesso maschile (m) e femminile (f). Il numero di soggetti è riportato tra parentesi. I soggetti con BMI < 5° e > 95° percentile per età sono stati considerati sottopeso e sovrappeso.

		5-95		> 95	
		m (689)	f (697)	m (2)	f (4)
< 5 (m: 93) (f: 55)	Z ZI	< .0001 < .0001	.0002 ns	.0042 ns	.0015 ns
5-95	Z ZI	/ /	/ /	ns ns	.0196 ns

that the DW-sum was preferred to AFA because, in spite of a lower correlation with Z (Tab. II), it is a more reliable index of whole-body fat depots [9]. On the contrary, ZI increases with increasing values of the DW-sum (not shown). This finding may explained by the sensitivity of the numerator (Height²) of the impedance index to the quantity of fat-free tissues [1].
The relationship between ZI and AMA is depicted in Figure 2.
It is evident from this Figure that ZI increases with increasing levels of body muscularity as determined by AMA. Again, despite the higher mean value of ZI in males, the relationship is similar in both sexes. On the contrary, Z decreases with increasing values of AMA (not shown). The latter finding can be explained on the basis of the lower impedance of muscle in comparison to fat. Finally, the relationships between Z and adiposity indexes and ZI and muscularity indexes were constant for all of the explored ranges of age and sexes (not shown). Provisionary percentile values for Z and ZI in Italian male and female children aged from 6 to 12 years are given in Tables VI and VII respectively.

Discussion

BIA is a safe and rapid method for body composition assessment. These characteristics, together with its precision and accuracy make of BIA one of the methods of choice for studying body composition in children [3]. To date, the interest of researchers on BIA has focused

Tab. IV.
p-values (by one-way ANOVA) for the inter-class variability of Z and ZI according to the adiposity level (class) established by relative weight (RW) in male (m) and female children (f). The number of subjects is given in parentheses. UW = underweight, NW = normal weight, OW = overweight, OB = obese.
Valori di *p* (one-way ANOVA) per la variabilità interclasse di Z e ZI in relazione alla classe (livello) di adiposità determinata dal peso relativo (RW) in bambini di sesso maschile (m) e femminile (f). Il numero di soggetti è riportato tra parentesi. UW = sottopeso, NW = normopeso, OW = sovrappeso, OB = obeso.

		NW		OW		OB	
		m (348)	f (293)	m (87)	f (113)	m (191)	f (168)
UW (m:158) (f: 182)	Z	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
	ZI	.0070	.0054	.0001	.0058	<.0001	<.0001
NW	Z	/	/	.0207	.0043	<.0001	<.0001
	ZI	/	/	.0391	ns	<.0001	.0076
OW	Z	/	/	/	/	<.0001	ns
	ZI	/	/	/	/	<.0001	ns

Tab. V.
p-values (one-way ANOVA) for the inter-class variability of Z and ZI according to the adiposity level (class) established by triceps skinfold (TSF) in male (m) and female (f) children. The number of subjects is given in parentheses. Subjects < 5th and > 95th percentile of TSF for age were considered underweight and overweight respectively.
Valori di *p* (one-way ANOVA) per la variabilità interclasse di Z e ZI in relazione alla classe (livello) di adiposità determinata dalla plica tricipitale (TSF) in bambini di sesso maschile (m) e femminile (f). Il numero di soggetti è riportato tra parentesi. I soggetti con TSF < 5° e > 95° percentile per età sono stati ritenuti sottopeso e sovrappeso rispettivamente.

		5-95		> 95	
		m (708)	f (717)	m (1)	f (1)
< 5 m: 75 f: 38	Z	< 0.0001	.0002	ns	ns
	ZI	< 0.0001	.0354	ns	ns
5-95	Z	/	/	ns	ns
	ZI	/	/	ns	ns

whether BIA could provide a simple and expeditious way for monitoring body composition in the growing child, independent of any prediction formula. We reasoned that, if muscle had a lower impedance in comparison to fat, BI could serve as an index for monitoring body adiposity, muscularity or both, during growth.
The results of this study are consistent with this hypothesis. Bioelectric parameters were found to be in agreement with adiposity and muscularity indexes. When considering both sexes, ZI explained 33 to 51% of the variance in AMA and 34 to 53% of the variance in AMC.

Tab. VI.
Percentile values (10th, 50th and 90th) for body impedance (Ω) in a series of 756 female and 784 male Italian children, from 6 to 12 years of age.
Valori percentili (10°, 50° e 90°) per l'impedenza corporea (Ω) in un gruppo di 756 bambine e 784 bambini italiani in età compresa tra 6 e 12 anni.

Age (ys)	10th	50th	90th
Females			
6	641	722	767
7	623	724	772
8	638	722	773
9	604	686	732
10	586	661	722
11	550	636	698
12	527	604	652
Males			
6	587	677	713
7	566	655	696
8	582	646	702
9	574	651	688
10	565	628	662
11	535	609	652
12	483	587	650

On the other side, Z was responsible for 16 to 23% of variance in AFA and for 0.8 to 16% of variance in DW-sum. Although correlation coefficients were generally low (Tab. II), it is of interest that Z and ZI were significantly associated with adiposity and muscularity indexes, respectively (Tabb. III, IV, V).
In this study, BMI, RW and TSF have been employed as reference standards for establishing the adiposity level

Tab. VII.
Percentile values (10th, 50th and 90th) for the impedance index (Height²/Z, cm²/Ω) in a series of 756 female and 784 male Italian children, from 6 to 12 years of age.
Valori percentili (10°, 50° e 90°) per l'indice di impedenza (altezza²/Z, cm²/Ω) in un gruppo di 756 bambine e 784 bambini italiani in età compresa tra 6 e 12 anni.

	10th	50th	90th
Females			
6	17.1	19.5	23.6
7	18.0	21.3	24.2
8	19.2	22.9	28.0
9	21.5	26.4	31.3
10	23.8	29.6	36.7
11	26.0	34.0	41.6
12	32.5	39.1	46.1
Males			
6	17.2	20.8	23.8
7	20.2	23.6	28.8
8	21.7	25.9	29.8
9	24.2	28.0	34.1
10	26.2	31.9	37.8
11	29.5	34.4	42.6
12	30.9	37.9	53.6

of the children. Although this approach has obviously some limitations, some points need to be addressed. First, the direct assessment of fat mass involves the use of invasive and expensive techniques so that it is not suitable for use in large populations such as that employed for the present study. Second, although some discrepancies are evident between the different indexes in predicting the adiposity level of the children [16-18], we have established the degree of agreement of Z and ZI with body fatness by simultaneously employing three adiposity indexes, so that the determined adiposity had a greater probability of approaching the true value [19].
Based on our data, Z appears to be a better index of adiposity and a worse index of muscularity than ZI. Thus, a «pure» value of impedance appears to be more directly associated with fat mass rather than the value of its ratio with respect to body height, which introduces a parameter sensitive to FFM [1]. On the contrary, the introduction of such a parameter, in the form of the impedance index, allows a better prediction of muscle mass.
Based on these findings and to stimulate further research into BIA applications which are independent of predictive formulae, we have provided percentiles for the values on Z and ZI from the age of 6 to 12 years in Italian male and female children (Tabb. VI, VII).
We would like to point out that the children recruited for the present study were not regarded as a representative sample of the italian paediatric population. Although the children were randomly recruited in primary schools in both north and south of Italy, we did not classify them for economic class or other parameters which could influence body composition. However, no clear and systematic differences were seen between boys and girls of each age group with respect to their provenience (data not shown). Thus, despite the fact that the study sample may be not completely representative of the Italian population, it may nonetheless give a good impression of bioelectric parameters of italian children from 6 to 12 years of age.
In conclusion, our study shows that a certain degree of agreement exists between bioelectric parameters and adiposity and muscularity indexes. This finding sug-

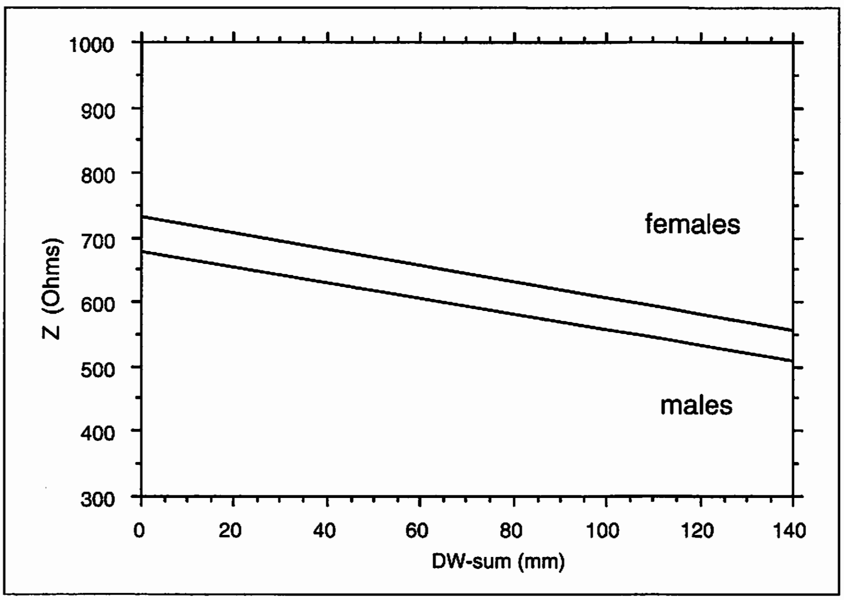

Fig. 1.
Relationship between bioelectric impedance (Z) and the sum of four skinfolds (DW-sum) in 1540 children (M:F = 784: 756).
Relazione tra l'impedenza bioelettrica (Z) e la somma delle quattro pliche secondo Durnin & Womerseley (DW-sum) in 1540 bambini (M : F = 784 : 756).

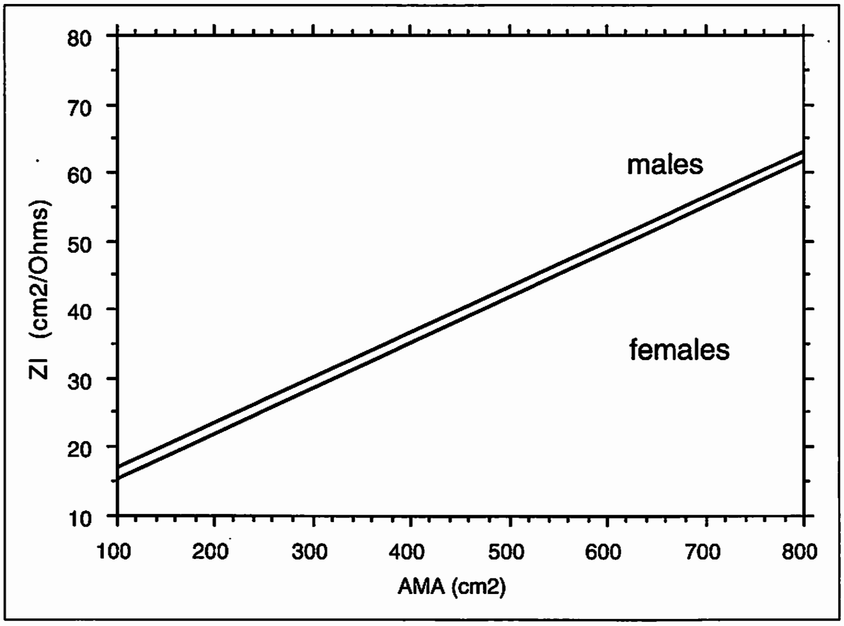

Fig. 2.
Relationship between the impedance index (ZI, Height^2/Z) and arm muscle area (AMA) in 1540 children (M: F = 784: 756).
Relazione tra l'indice di impedenza (ZI, altezza^2/Z) e l'area muscolare del braccio (AMA) in 1540 bambini (M: F = 784: 756).

gests that bioelectric parameters may be employed for monitoring nutritional status in childhood. However, a study employing reference methods for establishing fat mass and muscle mass will ultimately be needed to confirm this hypothesis.

Summary

We examined the relationships between bioelectric impedance (BI), body adiposity and body muscularity in a sample of 1540 Italian children aged from 6 to 12 years. BI and the impedance index (height^2/BI) were found to increase with increasing levels of body adiposity (as determined by arm fat area and by the sum of four skinfolds according to Durnin & Womerseley) and body muscularity (as determined by arm muscle area and circumference), respectively. Based on the comparison with body mass index, relative weight and triceps skinfold, BI was shown to be a better index of body adiposity than height^2/BI. However, the impedance index was a better index of body muscularity than BI. We conclude that BI and height^2/BI have the potential to be employed as indexes of adiposity and muscularity, respectively, in childhood. For this reason, we have provided percentile values for BI and height^2/BI which may be used in italian children from 6 to 12 years of age.

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