

Research on Bioelectrical Impedance Analysis Method Based On Eight-Segment Impedance Model

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Abstract:- Bioelectrical impedance is one of the most important parameters in body composition prediction, reflecting physiological condition of human body to a certain extent, but its accurate measurement is of great difficulty. Although eight-segment model has been established to analyses bioelectrical impedances, there is not a comprehensive analysis method currently. In order to solve this problem, we have proposed the impedance analysis method based on eight-segment model, and verified the correctness of this method through theoretical derivation and experimental verification. The results have shown that the impedance analysis method based on eight-segment model can provide more accurate impedances to predict body composition, which is a considerable improvement for the impedance analysis method.

Keywords:- Bioelectrical impedance analysis, Eight-segment model, Trunk subdivision

I. INTRODUCTION

Percentage of body composition is strongly associated with people's physical health and its changes are of great significance for nutritional status and disease prevention, but its accurate measurement is difficult [1-2]. Bioelectrical impedance analysis (BIA) can detect bioelectrical impedance through electrodes placed on the surface of body, and obtain the correlative physiological information to analyses body composition [3-4]. Studies have shown that BIA is a relatively convenient, quick, non-invasive and accurate technique to measure body composition developed nearly 20 years, which has bright application prospects, the references therein [5]. One of the most important factors to measure body composition by BIA is to establish proper impedance model. Currently the most widely used model is five-segment impedance model. For more results on this topic, we refer readers to [6-8]. This model divides body into five parts including limbs and trunk, regarding trunk as a whole. The advantage of this model is that it has taken the impedance differences of different body parts into account, having solved the technical problem that whole-body impedance model measures overall impedance to some extent; however, it is unable to accurately measure the impedance distribution in the trunk, such as the impedance of abdomen and chest. In allusion to defects of five-segment impedance model, the literature [9] have proposed the trunk subdivision BIA, subdividing the trunk to obtain the improved impedance model, but this literature did not provide effective calculation method. Therefore, how to establish an accurate impedance calculation method is the key for further research.

Based on this, we have proposed the impedance analysis method based on eight-segment impedance model, using the eight-electrode measurement method to obtain corresponding voltage value when different weak alternating current is passed into the body to calculate the impedances of corresponding segments. For more results on this topic, we refer readers to [10]. Finally, the impedance analysis method based on eight-segment model is verified through theoretical derivation and experimental verification.

II. EIGHT-SEGMENT IMPEDANCE MODEL

Although the impedance of trunk is about several tens Ω while the limbs' is approximately 200 Ω , the trunk contains almost 40% of body composition, the references therein [11]. In addition, the upper trunk is chest, whose fat distribution is mainly subcutaneous fat, while the lower trunk is abdomen, whose fat distribution is mainly visceral fat, the references therein [12]. Therefore, in order to ensure the accuracy of trunk impedance measurement, it is quiet necessary to distinguish between upper trunk (chest) and lower trunk (abdomen) in body composition measurement.

Eight-segment impedance model is shown in Figure 1. On the basis of the five-segment impedance model, the Eight-segment model subdivides the trunk and finally divides body into right arm R_1 , left arm R_2 ,

right leg R_6 , left leg R_8 , right longitudinal trunk R_4 , left longitudinal trunk R_5 , upper trunk R_2 and lower trunk R_7 .

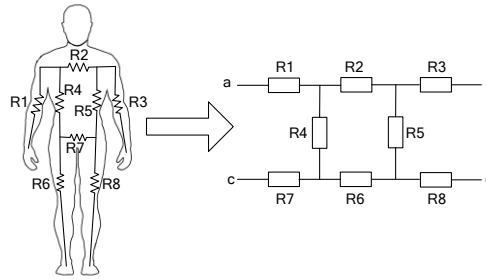


Fig.1: Eight-segment impedance model

III. ANALYSIS METHOD OF EIGHT-SEGMENT MODEL

A. Calculation method of eight-segment model

As shown in Figure 1, the measurement model in this study is a four-port impedance network. Eight-electrode measurement method is used; namely, each of left hand, right hand, left foot, and right foot is placed two electrodes, one is current electrode and the other is voltage electrode. Current incentive is sent into body through two current electrodes, and the incentive-measurement voltage is measured through two voltage electrodes, then the corresponding impedances can be calculated through the measured voltage. The electrodes distribution and the current flowing through the body in different incentive-measurement modes are shown in Figure 2. Where 1-8 are eight electrodes; $I(t)$ is the Current incentive; $V(t)$ is the corresponding measured voltage.

As shown in Figure 2, take Figure 2-a for example, when the current is sent to right hand and right foot, the current flows through right arm, trunk and right leg; if now the voltage is measured between right hand and right foot, we can get corresponding arm, trunk and right leg voltage. There are totally 36 pairs combination of this kind, as shown in Table 1, where I is the incentive current, and V is the measured voltage.

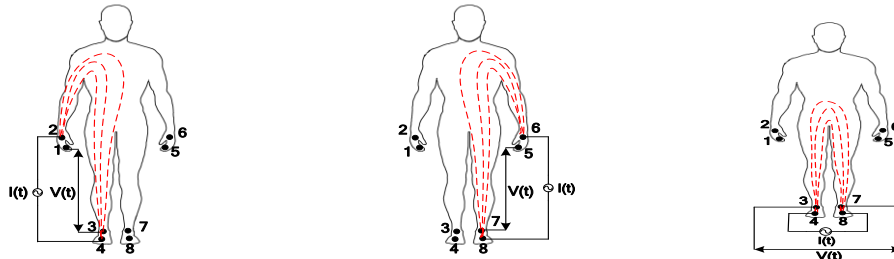


Fig.2: Electrodes distribution and the current flowing through body

Table I: Incentive-measurement port of eight-segment model

Measurement Incentive	ab	ac	ad	bc	bd	cd
I_{ab}	V_{ab1}	V_{ac1}	V_{ad1}	V_{bc1}	V_{bd1}	V_{cd1}
I_{ac}	V_{ab2}	V_{ac2}	V_{ad2}	V_{bc2}	V_{bd2}	V_{cd2}
I_{ad}	V_{ab3}	V_{ac3}	V_{ad3}	V_{bc3}	V_{bd3}	V_{cd3}
I_{bc}	V_{ab4}	V_{ac4}	V_{ad4}	V_{bc4}	V_{bd4}	V_{cd4}
I_{bd}	V_{ab5}	V_{ac5}	V_{ad5}	V_{bc5}	V_{bd5}	V_{cd5}
I_{cd}	V_{ab6}	V_{ac6}	V_{ad6}	V_{bc6}	V_{bd6}	V_{cd6}

Table II: The effective measurement mode

Valid values	The effective measurement mode					
Current value	I_{ab-ac}	I_{ab-bd}	I_{ab-cd}	I_{ac-ad}	I_{ac-cd}	I_{ad-bd}
Voltage value	V_{ac1}	V_{bd1}	V_{cd1}	V_{ad2}	V_{cd2}	V_{bd3}

Known from the circuit principles, there are only six effective measurement modes for a four-port network, as shown in Table 2. According to the six effective measurement modes, the corresponding impedance formulas are as follows:

$$(R_1 + \frac{R_2 * R_4}{R_2 + R_4 + R_5 + R_6}) * I = V_{ac1} \quad (1)$$

$$(R_3 + \frac{R_2 * R_5}{R_2 + R_4 + R_5 + R_6}) * I = V_{bd1} \quad (2)$$

$$\frac{R_2 * R_6}{R_2 + R_4 + R_5 + R_6} * I = V_{cd1} \quad (3)$$

$$\frac{R_4 * R_5}{R_2 + R_4 + R_5 + R_6} * I = V_{ad2} \quad (4)$$

$$(R_7 + \frac{R_4 * R_6}{R_2 + R_4 + R_5 + R_6}) * I = V_{cd2} \quad (5)$$

$$(R_8 + \frac{R_4 * R_5}{R_2 + R_4 + R_5 + R_6} + \frac{R_5 * R_6}{R_2 + R_4 + R_5 + R_6}) * I = V_{bd3} \quad (6)$$

Where: V_{ac1} is the voltage measured between right hand and right foot when current is send between left hand and right hand; V_{bd1} is the voltage measured between left hand and left foot when current is send between left hand and right hand; V_{cd1} is the voltage measured between left foot and right foot when current is send between left hand and right hand; V_{ad2} is the voltage measured between right hand and left hand when current is send between right foot and right hand; V_{cd2} is the voltage measured between left foot and right foot when current is send between right foot and right hand; V_{bd3} is the voltage measured between left hand and left foot when current is send between left foot and right hand.

According to the eight-segment model, there are eight impedances to be measured. Not all impedance values can be obtained through equations (1)-(6), and another two linearly independent equations are needed to obtain all eight-segment impedances. Clinical studies have shown that the bilateral sides of body are not absolutely symmetrical, but different parts of body have shown different degrees of symmetry. The symmetry of trunk is poorer due to the uneven distribution of internal organs, while limbs show a higher degree of symmetry. Lots of scholars have done research on body's physical symmetry and meridian symmetry. In terms of physical symmetry, the structure of body is almost symmetrical, such as eyes, hands and feet. But the seemingly symmetrical structure is not exactly identical. For example, the bilateral half faces are not exactly the same, so are the eyes size, feet length and even feet area. In terms of meridian symmetry, although the organizational structure of meridians has not been identified in modality in traditional Chinese medicine, it is obvious that it conveys varieties of life information in some way to maintain physiological balance. In addition, meridian lines have low resistance and the impedance of bilateral meridians is symmetrical.

As an estimate method of body composition, limbs can be considered symmetrical in the absence of distinct limb disorder and visible limb asymmetry, namely, the impedance values can be considered to be the same. It is also possible that the left and right limb is asymmetry due to aplasia or disease; obvious body asymmetry can be corrected by other means.

From the above analysis, we may assume:

$$R_1 = R_3 \quad (7)$$

$$R_6 = R_8 \quad (8)$$

Corresponding to the equations (1)-(6), the measured impedance values are:

$$X_1 = V_{ac1} / I, X_2 = V_{bd1} / I, X_3 = V_{cd1} / I, X_4 = V_{ad2} / I, X_5 = V_{cd2} / I, X_6 = V_{bd3} / I$$

Solve simultaneous equations (1)-(8) and assume:

$$m = \frac{X_1 - X_2}{X_4 + X_5 - X_6}, n = \frac{X_1 - X_2}{X_3}, k = \frac{\sqrt{n^2 X_3^2 + 4mX_3X_4 - nX_3}}{2X_3}$$

Eight-segment impedance values are as follows:

$$R_1 = R_3 = X_2 - kX_3 \quad (9)$$

$$R_2 = (m + n + 2k + 1)X_3 \quad (10)$$

$$R_4 = \frac{(k + n)(m + n + 2k + 1)X_3}{m} \quad (11)$$

$$R_5 = \frac{k(m + n + 2k + 1)X_3}{m} \quad (12)$$

$$R_6 = \frac{(m+n+2k+1)X_3}{m} \quad (13)$$

$$R_7 = R_8 = X_5 - \frac{(k+n)X_3}{m} \quad (14)$$

B. Theoretical Derivation of the Eight-segment Impedance Values

The correctness of the obtained formulas (9)-(11) can be verified by theoretical derivation because the impedances of different parts are also different theoretically. In the above analysis, we have assumed that limbs are symmetrical; therefore, what is required to be verified is that whether the relative impedance value of the trunk and limbs is in line with the existing theory analysis.

Studies have shown that the impedance value of the trunk is about several tens Ω , while the limbs impedance is approximately 200Ω . Based on this, the impedance range is:

$$0 \leq R_2, R_4, R_5, R_6 \leq 100$$

$$200 \leq R_1, R_3, R_7, R_8 \leq 300$$

Formula (1)-(2) show: if $R_4 > R_5$, then $X_1 > X_2$; if $R_4 < R_5$, then $X_1 < X_2$. Namely:

$$(X_1 - X_2) * (R_4 - R_5) > 0$$

Now, substitute R_4, R_5 with formula (11)-(12) and simplify:

$$(X_1 - X_2) * (X_4 + X_5 - X_6) * q > 0$$

From $m = \frac{X_1 - X_2}{X_4 + X_5 - X_6}$ and the above inequation, we can get:

$$mq > 0$$

From formula (5)-(6), we can get:

$$X_6 > X_5$$

Then, substitute m, n into p and simplify:

$$p = m(X_6 - X_5) > 0$$

Compared to limbs, the impedance of trunk is much lower. In the eight-segment model, four trunk resistors R_2, R_4, R_5, R_6 are in series, so the impedance of trunk is approximately the sum of four impedances. Therefore, we can verify the obtained formulas by comparing whether trunk impedance is less than limbs impedance, namely:

$$R_2 + R_4 + R_5 + R_6 - R_1 < 0$$

$$R_2 + R_4 + R_5 + R_6 - R_7 < 0$$

Substitute formula (9)-(14) into the above inequations, we can obtain:

$$qX_3 / p + mqX_4 / p + q + qX_3 / mp - (X_2 - mX_3) < 0$$

$$qX_3 / p + mqX_4 / p + q + qX_3 / mp - (X_5 - mX_4X_3 / p) < 0$$

Substitute $m, n, p = m(X_6 - X_5), q = m(X_3 + 2X_4) + X_3 + X_2 - X_1$ into the above inequalities, and regard the all other inequalities as the limitation, then two inequalities can be simplified as:

$$m^2[X_4(X_5 - 2X_4 - X_3 - 2X_6)] + m[X_3^2 + X_3(3X_4 + X_6 - X_5)] + X_3(2X_3 + 2X_4 - X_1 + X_2) < 0$$

$$m^2[(2X_4 + X_3)(X_5 - X_4 - X_6)] + m[X_3^2 + (X_3 + 1)(X_6 - X_5)] + X_3(2X_3 + 2X_4 - X_1 + X_2) < 0$$

The two inequalities are both in the form of $am^2 + bm + c < 0$, and the coefficients meet $a < 0$ and $\Delta = b^2 - 4ac > 0$. Known from the mathematical principles, the two inequalities are reasonable.

At this point, we can conclude that the above two inequalities are tenable within the prescribed range. That is to say, the proposed analysis method in this paper is correct in theoretical derivation.

IV. EXPERIMENT DESIGN

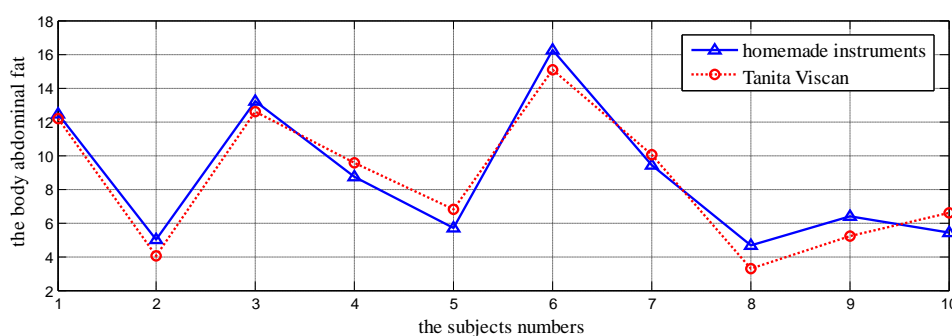
In order to verify the correctness of the impedance analysis method based on eight-segment model, we have designed the contrast verification experiment between the Body Composition Measurement System based on the above method (homemade instruments) and the Tanita Viscan abdominal fat analyzer, the references therein [13-15].

The subjects are 10 healthy volunteers, and the related notes are explained to them before the experiment. Firstly, record the subjects' gender, age, height weight and race. Secondly, use homemade instruments to measure the subjects. Finally, use Tanita Viscan abdominal fat analyzer to measure the subjects. The measurement results are shown in Table 3, where G, A, H, W, respectively means Gender, Age, Height and Weight; G is 1 when gender is male; G is 0 when gender is female; X1-X6 are the measured values in formula (1)-(6); Fat1 is the abdominal fat measured by homemade instruments; Fat2 is the abdominal fat percentage measured by Tanita Viscan.

Table III: Characteristic parameters and impedance measurement values

NO.	Parameters				Impedance values						Fat	
	G	A	H	W	X1	X2	X3	X4	X5	X6	Fat1	Fat2
1	1	23	174	76	296.4	306.2	18.6	18.2	190.1	220.2	11.15	16.4%
2	0	22	174	64.4	311.6	321.3	21.9	21.3	188.9	218.3	4.94	7.8%
3	0	26	184	73.6	345.4	355.8	22.4	22.8	235.2	265.8	12.17	17.9%
4	1	25	175	74.8	308.8	318.2	21.7	21.2	184.0	214.2	9.95	11.7%
5	0	24	168	55	327.8	337.3	25.3	25.3	224.3	254.3	6.76	10.3%
6	0	21	180	70.9	378.4	388.8	23.8	23.8	222.8	252.8	15.5	22.9%
7	1	27	173	68.8	318.1	328.2	22.9	22.2	252.3	282.2	9.92	13.7%
8	0	23	174	58.2	338.8	348.1	25.5	25.1	223.6	253.1	4.15	8.0%
9	1	21	178	63.2	300.1	310.4	22.0	22.4	201.6	231.4	6.18	10.1%
10	1	28	182	78	298.7	308.9	19.8	19.9	181.9	211.9	5.18	6.9%

The result comparison of the two meters is shown in Figure 3. As Figure 3 shown that, when the abdominal fat content of the subjects is too low or too high, the correlation coefficient of the outcomes measured by the two meters is 0.9544; when the subjects of abdominal fat content is comparatively moderate, the correlation coefficient of the outcomes measured by the two meters increases 0.9751. The results have shown that the body abdominal fat contents measured by the two meters have shown great relativity, especially when abdominal fat content is comparatively moderate.


Fig.3: The result comparison of the two measurement methods

V. CONCLUSIONS

The existing trunk subdivision BIA method has improved body impedance model effectively, but there is not an accurate calculation method for this model currently. According to this, we have proposed the analysis method based on eight-segment impedance model, which can provide more accurate impedance values and give a new solution to achieve impedances faster. However, because there is not an unified prediction algorithm between body composition and bioelectrical impedance yet, body composition projection based on bioelectrical impedance will become the focus of further research, and also will be the practical limiting in wide use of eight-segment impedance model analysis method.

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