Body Composition Variations for Cerebral Infarction Patients Classified as Male and Female in Long-term Care Hospitals

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ABSTRACT

Indicators to quantitatively assess the physical conditions can help optimize the effectiveness of rehabilitation therapy for stroke patients. The body composition variations in the paretic and non-paretic regions of stroke patients with cerebral infarction (7 males, 31 females) were analyzed using multi-frequency bioelectrical impedance. Specifically, resistance (R), lean mass (LM), fat mass (FM), extracellular water (ECW), intracellular water (ICW), R/LM relation, basal metabolic rate (BMR)/LM relation were utilized to evaluate the paretic and non-paretic regions of subjects with cerebral infarction. These values showed significant differences in gender and paretic/non-paretic regions. R and FM were high but LM and ICW were lower in female and paralysis. ECW was lower in females than males, but there was no considerable difference between paralysis and non-paralysis in both males and females. In addition, there was an inverse distribution between R and LM in paretic and non-paretic regions, with males on the upper left and females on the lower right. Furthermore, the relationship between BMR and LM showed excellent linearity (slope 22.17 kcal/day/kg) irrespective of gender, paralysis, and non-paralysis. An easy, non-invasive and quantitative assessment using bioelectrical impedance would provide an useful tool for evaluating patients with cerebral infarction receiving rehabilitation therapy.

Key words: Bioelectrical Impedance, Body Composition Variations, Stroke Patient, Cerebral Infarction, Rehabilitation Therapy, Non-Invasive and Quantitative Assessment

1. INTRODUCTION

Stroke is a clinical syndrome characterized by a rapid onset of focal neurological signs with underlying vascular causes. It results from many different disease processes: 80% is ischemic and 20% is due to cerebral hemorrhage [1]. Due to advancements in medical technology, the number of deaths from stroke has fallen. However, many stroke patients are left with severe disabilities, including hemiplegia, language impairment, communication disorders, cognitive impairment, and emotional disorders [2]. In particular, hemiparesis is characterized by weakness on one side of the body, whereas hemiplegia is the paralysis of one side of the body [3]. Individuals with hemiparesis might not be able to move one of their arms, or may feel tingling or other unusual sensations on one side.

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of the body. Those with paralysis may retain some sensation, and the paralysis degree can change over time. One of the most common problems after a stroke is limb dysfunction, which severely reduces the quality of life because it affects the normal bodily function and activities of daily living [4]. In addition, the following clinical results are considered as closely related to strokes. Muscle tissue wasting and functional changes are frequently observed in stroke patients, but this has not been thoroughly studied [5]. Nutritional disorders (e.g., obesity, or malnutrition) were observed in about one-third of the individuals the year following a stroke [6]. In particular, hemiparetic strokes may lead to secondary muscle atrophy and specific changes in metabolic and contractile capacity [7]. Given the above mentioned post-stroke disabilities, stroke patients often receive long-term rehabilitation, such as rehabilitation medicine treatments and physical therapy [8].

Bioimpedance techniques have advanced substantially in recent years due to availability of simple-to-use analyzers and simplified measurement protocols. The method has been well validated and increasingly adopted in nutritional and clinical practice [9]. The use of more simple and inexpensive bioelectrical impedance analysis (BIA) has become more and more popular [10]. Other advantages of BIA include its ease of use, relatively inexpensiveness, and universality, as it can be performed on subjects in a wide range of age and body shape [11].

In this study, resistance (R), lean mass (LM), fat mass (FM), extracellular water (ECW), intracellular water (ICW), R/LM relation, and basal metabolic rate (BMR)/LM was utilized to evaluate the body composition variations in the parietic and non-parietic regions of 38 stroke patients (7 males, 31 females) with cerebral infarction.

2. THEORY

The concept of impedance Z is related to the flow obstruction of an alternating current. Z is dependent on the frequency of the applied current. Impedance Z can be represented by its magnitude |Z| and phase angle θ, as shown in Eq. (1) - (3) and illustrated in Fig. 1. Likewise, bioelectrical impedance is a complex quantity composed of resistance R, which is caused by the total body water, and reactance Xc, which is caused by the cell membrane capacitance [12]:

\[ Z = R + jXc. \]  

(1)

Resistance (R) is the real part of impedance; hence, an object with purely resistive impedance exhibits no phase shift between voltage and current. In BIA, resistance reflects the hydration status in the body:

\[ R = |Z| \cos \theta \]  

(2)

Reactance (Xc) is the imaginary part of impedance; hence, an object with finite reactance induces a phase shift (90°) between its voltage and current components. In BIA, reactance reflects the muscle mass in the body.

\[ Xc = |Z| \sin \theta \]  

(3)

The physical implication of complex impedance is the phase shift between the steady-state current and the applied voltage [13]. Resistance and reactance together determine the magnitude and phase angle of the impedance, with
the former given by

\[ |Z| = \sqrt{Z^2} = \sqrt{R^2 + X_c^2} \quad (4) \]

In phaser diagram as shown in Fig. 1, the angle between the resistance and the reactance is the phase angle of the source voltage \( V \) with respect to the current \( I \): that is the angle by which the source voltage leads the current.

From the diagram in Fig. 1, we have

\[ \tan \theta = \frac{X_c}{R} \quad (5) \]

\[ \theta = \tan^{-1} \left( \frac{X_c}{R} \right) \quad (6) \]

Capacitance affects the current flow, and it can stop the flow when a capacitive object is completely charged. When an AC voltage is applied, the root mean square (RMS) value of the current is limited by the capacitance. For purely capacitive impedance in AC, the RMS current value, \( I \), in a circuit with capacitance \( C \) is determined by the Ohm's law as

\[ I = \frac{V}{X_c} \quad (7) \]

where \( V \) is the RMS voltage value and impedance \( X_c \) is defined as

\[ X_c = \frac{1}{2\pi fC} \quad (8) \]

with \( X_c \) being the capacitive reactance (i.e., the capacitor acts to resist the current flow) in ohms, which is inversely proportional to both capacitance \( C \) and frequency \( f \) [14].

Biopendence analysis has been shown to be more precise for determining LM or FM in humans [15]. Compared to body mass index (BMI), anthropometry and skin fold methods, BIA provides reliable results in the estimation of fatness (FM) across human tissues when assessing body tissue obesity [16].

Kyle et al. [17] developed equation (9) for predicting LM, using 343 normal subjects aged from 22 to 94 years old, with BMI between 17.0 and 33.8 kg/m² in reference to dual-energy X-ray absorptiometry (DXA) method:

\[
LM = -4.104 + 0.518 H^2 / R_{[30]} + 0.231 W + 0.130 X_{[50]}
+ 4.229 Sex
\]

where \( H \) is body height, \( R_{[30]} \) and \( X_{[50]} \) is resistance and reactance at 50 kHz, \( W \) is body weight, and \( Sex \) is 1 for male and 0 for female.

Heitmann [18] compared three body composition methods (BMI, skinfolds and BIA) among 139 healthy subjects aged from 35 to 65 years old:

\[
FM = 14.94 - 0.079 H^2 / R_{[30]} + 0.818 W - 0.231 H \\
&+ 0.064 Sex W - 0.077 Age
\]

where \( Sex \) is 1 for male and 0 for female.

Body fluid is the total volume of fluids inside a human body that represents the majority of the LM volume percentage. Total body water (TBW) includes the fluids inside the cellular mass known as intracellular water (ICW); and the fluid located outside the cell body which is composed of plasma and interstitial fluid which is known as extracellular water (ECW). ECW and ICW fluids that are incorporated under TBW, contain several ion types with different concentrations, however the main ions in ECW are Na⁺ and Cl⁻, and for ICW are K⁺ and PO₄⁻ [19].

Multifrequency BIA has been proposed to improve the accuracy of TBW, ECW and ICW estimation. Deurenberg et al. [20] used MF-BIA to predict TBW using \( Z_{[50KH]} \):

\[
TBW_{[50KH]} = 6.53 + 0.36740 H^2 / Z_{[50]} + 0.17531 W \\
&- 0.110 Age + 2.83 Sex
\]

where \( Z_{[50]} \) is impedance at 100 kHz and \( Sex \) is 1 for male and 0 for female.

For ECW and ICW estimation using single frequency–BIA, a few studies performed were based on measurement of bi impedance in 50 kHz frequency.

\[
ECW_{[50KH]} = -7.24 + 0.34 H^2 / R_{[30]} + 0.06 W + 2.63 Health \\
+ 2.57 Sex
\]
where \( R \) is resistance at 1 kHz, \( Health \) is 1 for healthy and 0 for diseased, and \( Sex \) is 1 for male and 0 for female.

ICW is obtained by subtracting ECW from TBW as follows:

\[
ICW = TBW - ECW
\]

3.1 Subject

The subjects were 38 patients with cerebral infarction patients (7 males and 31 females) hospitalized in three long-term care hospitals. Table 1 lists general information (age, height, mass, and time since cerebral infarction) and BMI of 38 subjects. BMI was 22.6±2.5 kg/m² for 7 males, and 22.1±2.8 kg/m² for 31 females, which was comparable to the reference category (22 to 23 kg/m²) [22]. The time since cerebral infarction represents the elapsed time between the stroke diagnosis and the impedance measurements performed in this study.

### 3.2 Measurement of bioelectrical impedance and body composition

Whole-body bioelectrical impedance is most commonly used to estimate the body compartments. In addition, the assessment of body composition is considered a key factor to determine a person’s general health status. For this study, the body composition variations were measured using a bioelectrical impedance spectroscopy device (Multi Scan 5000, Bodystat Ltd., Isle of Man, UK) according to the recommendations of the Technical Assessment provided by the National Institutes of Health. In addition, bioelectrical impedance measurements were performed at three long-term hospitals in Korea, from November 26th, 2015 to November 10th, 2017. Prior to their participation in this study, the purpose and method of this study was explained to the subjects, and their written consents were obtained. The study was approved on April 20, 2017 by IRB of the Yangsan Pusan National University Hospital (Number: 03-2017-005, Title: correlation between body composition, bioelectrical impedance, motor function and activities of daily living (ADL) in stroke patients with hemiplegia using bioelectrical impedance spectroscopy).

The bioelectrical impedance and the body composition were measured using BIS. The subjects were in a comfortable supine position for at least 5 minutes before starting the experiment. Before attaching the electrodes, their locations were cleaned with an alcohol swab. Four outer electrodes (Bodystat 0525, Bodystat Ltd., Isle of Man, UK) were attached to the subject’s hands and feet, while the four inner electrodes were attached to the
ankles and wrists as shown in Fig. 2. In order to prevent the interfacial effect between the electrodes, the distance between the external electrodes and the internal electrodes should be at least 7 cm. Second, the electrodes were connected to the device via a sensor cable, after they were secured in the correct positions. While allowing an alternating current of 800 µA to flow through the body (outer pair of electrodes), the voltage in the body (inner pair of electrodes) was measured using the bioelectrical impedance spectroscopy.

3.3 Flow chart of research process

Fig. 3 is a flow chart illustrating the process of measuring bioimpedance and body composition in this study. After attaching the electrode to the arm and leg of the patient described in 3.2 and connecting it to the electrode part of the BIS using a cable, in the process of initializing the BIS, the subject’s name, birth date, height, weight, gender, waist, hip, and physical activity are entered as shown in the screen on the left. The measurement region of bioimpedance and body composition for each subject is set as shown in the screen on the top right. The measurement site has whole body, left/right arms, and left/right legs. The bioimpedance and the body composition are measured. At this time, the subject should be in a comfortable position with his/her arms slightly apart from his/her body and legs open. Bioimpedance measurements appear as shown on the right center screen. Impedance, resistance, reactance, and phase angle for each wavelength are obtained. Body composition measurements appear as shown on the lower right screen. Total body water (TBW), extracellular water (ECW), intracellular water (ICW), lean mass (LM), fat mass (FM), basal metabolic rate (BMR) are obtained. The measured BIS data (bioimpedance and body composition) are transferred to the PC using Wi-Fi. The transmitted BIS measurement data are analyzed using Excel 2016 (Microsoft Corporation, Redmond, Washington, USA) and OriginPro 9.0.0 (OriginLab Corporation, Northampton, Massachusetts, USA) program.

4. RESULTS AND DISCUSSION

4.1 The resistance (R) in the paretic and non-paretic regions

Table 2 shows the median and standard deviation of the resistance at seven frequencies in the paretic and non-paretic regions of 7 male subjects and 31 female subjects. P_M indicates the paretic region of male subjects, NP_M indicates the non-paretic region of male subjects, P_F indicates the paretic region of female subjects, and NP_F indicates the non-paretic region of female subjects. Resistance in female subjects was higher than that in male subjects. This is because females have less lean mass (LM) than males. In addition, the resistance in the paretic regions was higher than that in the non-paretic regions. This indicates that the muscle mass and total body water (TBW) are further reduced in the paretic regions than in the non-paretic regions. At 50 kHz, for male subjects, the resistance in the paretic region increased by 5.6% over the resistance in the non-paretic region. For female subjects, the resistance in the paretic region increased by 4.6% over the non-paretic region.
4.2 Body composition in the paretic and non-paretic regions

Lean mass (LM) is the total amount of non-fat tissues and organs in the body, and it consists of approximately 73% water, 20% protein, 6% mineral, and 1% ash. LM contains almost all the body’s water, metabolically active tissues, and bone. Therefore, LM is the source of all caloric expenditure. The loss of muscle mass after a stroke is expected to accompany weight loss, and a reduction of LM is associated with increased mortality, poor clinical outcomes, and impaired quality of life [23]. Furthermore, an accelerated tissue wasting due to the combined effects of insufficient nutritional supply,

Table 2. Mean and standard deviations of resistance (R) measured in paretic and non-paretic regions for 7 male and 31 females

<table>
<thead>
<tr>
<th>Frequency (kHz)</th>
<th>P_M (Ω)</th>
<th>NP_M (Ω)</th>
<th>P_F (Ω)</th>
<th>NP_F (Ω)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5kHz</td>
<td>685.5±97.1</td>
<td>609.3±94.5</td>
<td>693.8±105.0</td>
<td>669.2±103.5</td>
</tr>
<tr>
<td>10kHz</td>
<td>631.2±97.1</td>
<td>604.7±95.0</td>
<td>687.7±103.9</td>
<td>662.3±103.2</td>
</tr>
<tr>
<td>50kHz</td>
<td>597.0±98.4</td>
<td>565.2±100.0</td>
<td>642.3±97.2</td>
<td>614.3±97.6</td>
</tr>
<tr>
<td>100kHz</td>
<td>577.1±98.1</td>
<td>546.1±101.1</td>
<td>622.4±94.8</td>
<td>591.7±96.0</td>
</tr>
<tr>
<td>200kHz</td>
<td>592.2±97.4</td>
<td>526.2±100.1</td>
<td>602.3±92.6</td>
<td>567.8±91.2</td>
</tr>
<tr>
<td>300kHz</td>
<td>560.2±96.1</td>
<td>521.0±101.4</td>
<td>591.6±89.9</td>
<td>558.7±86.2</td>
</tr>
<tr>
<td>500kHz</td>
<td>587.0±91.9</td>
<td>501.4±96.2</td>
<td>578.1±87.8</td>
<td>542.7±86.9</td>
</tr>
</tbody>
</table>
catabolic activation, and anabolic failure may occur in stroke patients [24].

Fig. 4 shows LM (475.48.0 kg in the paretic regions, 50.27.0 kg in the non-paretic regions) of males and that (34.5±6.0 kg in the paretic regions, 35.9±6.2 kg in the non-paretic regions) of 38 females. LM was lower in the paretic regions than in the non-paretic regions of all study subjects. For male subjects with cerebral infarction, LM in the paretic regions was 5.9% lower than in the non-paretic regions. Likewise, for female subjects with cerebral infarction, LM in the paretic regions was 3.9% lower than in the non-paretic region.

Fat mass (FM) corresponds to all liquids extractable from adipose and other tissues in the body and consists of subcutaneous fat and visceral fat. Subcutaneous fat is located just underneath the skin and serves as energy reserve and insulation against outside cold. Visceral fat is located deeper within the body and serves as energy reserve and to guarantee some distance between adjacent organs. Hence, we all need a certain amount of body fat, which depends on age, gender, and physical condition. Variations in FM among the population reference values are attributed to several factors, but are believed to follow from aging and gradual changes in lifestyle [25].

Fig. 5 shows FM in the paretic and non-paretic regions of 38 subjects with cerebral infarction. FM in females was higher than that in males, and FM in paretic regions was also higher than in non-paretic regions. FM in male subjects was 16.5±3.7 kg and 15.1±4.9 kg in the paretic and non-paretic regions, while FM in female subjects was 22.1±4.6 kg and 20.4±4.4 kg in paretic and non-paretic regions. FM in the paretic regions of females was 33.9% higher than that in the paretic regions of males. Long-term muscle changes such as loss of muscle mass, reduction in cross-sectional area of muscle fibers, and increased intramuscular fat have been reported to occur between 3 weeks and 6 months after stroke in both paralyzed and non-paralyzed limbs [24, 26]. The subjects showed a higher fat content in the paretic region than in the non-paretic region, possibly because they lost motor function. In fact, FM increase was also observed in other diseases where the body movements are compromised. For instance, Azevedo et al. classified patients with chronic spinal cord injury into four groups according to both the injury level (i.e., paraplegia or tetraplegia) and physical activity (i.e., active or inactive) [27]. The tetraplegic and inactive group showed higher FM values, even reaching obesity levels.
Extracellular water (ECW) consists of interstitial fluid (ISF), plasma water, and transcellular water. This is a measure of the amount of water outside the cells. ECW stores some nutrients and helps remove waste from inside the cell. Typically, 43% of the body’s water should be outside the cell and 57% should be inside the cell.

Fig. 6 shows ECW content in the paretic and non-paretic regions of male and female subjects. For males, ECW was 17.1±2.2 L in the paretic regions and 16.9±2.0 L in the non-paretic region, which was higher than 12.7±1.6 L in the paretic regions and 12.5±1.8 L in the non-paretic region of females. ECW in male subjects was higher (34.8% in the paretic regions, 35.2% in the non-paretic regions) than that in female subjects, but there was no significant difference between paralysis and non-paralysis.

Intracellular Water (ICW) is a measure of the amount of water inside the cell. Healthy cells maintain their integrity and hold their fluid to maintain water soluble nutrients such as vitamins B and C. The optimum amount of water in the cell depends on sex, age, and body condition [28]. For normal healthy adults, ICW is 22.9–25.0 L with an optimal value of 23.4 L. A low ICW reading may be caused by many factors, including dehydration, nutritional imbalances, hormonal imbalances, or toxicity.

Fig. 7 shows ICW in the paretic and non-paretic regions of male and female subjects. For male subjects, ICW was 15.1±3.4 L in the paretic regions and 18.4±2.6 L in the non-paretic region, which was significantly higher than 11.5±3.2 L in the paretic regions and 13.1±3.1 L in the non-paretic region of females. ICW in male subjects was higher (31.3% in the paretic regions, 40.5% in the non-paretic regions) than that in female subjects. In addition, ICW in the paretic regions decreased (21.9% in males, 13.9% in females) compared with ICW in the non-paretic regions. Low ICW (15.1±3.4 L in males, 11.5±3.2 L in females) in the paretic regions was significantly lower than the known values (22.9–25.0 L) [29], indicating severe dehydration and nutritional and hormonal imbalance in the paretic regions of stroke patients. This reduction in ICW appears to be associated with a decrease in muscle mass due to lack of exercise in the paretic regions.

Fig. 8 shows the relationship between resistance (R) and lean mass (LM) in the paretic and non-paretic regions of male and female subjects. Resistance is inversely related to lean mass. The male subjects are mainly distributed in the right lower side with high mass and low resistance, and the female subjects are distributed in the upper left.
with low mass and high resistance. The paretic regions are generally located below the non-paretic regions. The higher resistance in the paretic regions compared to the non-paretic regions in Table 2 reflects the fact that the paretic regions are in a state of reduced LM.

![Graph](image_url)

Fig. 8. The relationship between R and LM in paretic and non-paretic regions for male and female subjects. The male subjects are mainly distributed in the right lower side with high mass and low resistance, and the female subjects are distributed in the upper left with low mass and high resistance.

Basal metabolic rate (BMR) is the daily rate of energy (calories) the body needs to sustain basic life support functions [30]. These basic functions include circulation, respiration, cell production, nutrient breathing, protein synthesis and ion transport. For a typical person, BMR accounts for more than 90% of the total daily expenditure, i.e., more than 90% of the calories are consumed while the person is at rest. High LM implies an increased rate of caloric expenditure. Hence, one of the main benefits of exercise is the maintenance of LM level. In contrast, dieting alone may cause a reduction in LM and reduce the body’s ability to burn calories [22].

Fig. 9 shows the relationship between BMR and LM obtained from the paretic and non-paretic regions of male and female subjects. The paretic and non-paretic regions of all subjects well satisfied with the linear relationship (slope: 22.2 kcal/day/kg) between BMR and LM. This value is significantly lower to basal metabolic rate and body composition of patients with femoral neck fractures and control group by using bioelectrical impedance analysis: LM and BMR of the control group were 47.2±9.8 [kg] and 1490.8±281.9 [kg], while LM and BMR of the patients were 44.0±8.0 [kg] and 1373.2±250.2 [kg] [31]. Male subjects and female subjects are mainly distributed in the lower left and the upper right, respectively. In Fig. 3, LM of male subjects was significantly higher (37.7% in paretic regions, 39.8% in non-paretic regions) than that of female subjects. LM in paretic regions was lower 5.9% for males, 3.9% for females) than that in non-paretic regions. Stefano Lazzer et al. reported that gender in obese studies was a significant determinant of BMR in a children and adolescents but not in adults [32]. However, in studies of patients with cerebral infarction, differences in the muscles of male and female subjects are the major contributor to BMR.

![Graph](image_url)

Fig. 9. Relationship between BMR and LM in the paretic and non-paretic regions of 7 male and 31 female subjects with cerebral infarction, BMR is proportional to LM (slope: 22.2 (kcal/day/kg)).

4.3 DISCUSSION

Long-term muscle changes such as a loss in muscle mass, a reduction of fiber cross-sectional area, and an increase in intramuscular fat deposition have been reported to occur between 3 weeks and 6 months after stroke in both paretic and
non-paretic upper extremity [24, 26]. Therefore, appropriate stroke rehabilitation is needed in a timely manner (within 3–6 months) for stroke patients. Hence, non-invasive measurements are essential for easy assessment of paralysis and non-paralysis in stroke patients according to rehabilitation therapy. Measurement of post-stroke rehabilitation has become increasingly important with the advent of new treatment options in stroke rehabilitation studies. For example, the Fugl-Meyer scale was developed as the first quantitative assessment tool to measure stroke recovery in stroke patients [33]. In addition, among patients who had a stroke within 3–9 months, restraint-induced exercise therapy resulted in statistically significant and clinically relevant improvements in arm motor function lasting at least one year [34]. However, these methods are subjective in assessing body function in the paralysis caused by stroke, and takes a lot of time and labor to test. On the other hand, evaluating paretic and non-paretic regions in stroke patients with cerebral infarction using BIA is a simple, non-invasive approach that provides a easy way to obtain muscle function as well as body composition [35, 36].

5. CONCLUSION

In this study, resistance and body composition were evaluated quantitatively in paretic and non-paretic regions of cerebral infarction patients classified as male and female using impedance. On the other hand, the evaluation of the patients with cerebral infarction performed in the existing physical and occupational therapy is subjective and requires much time and skilled labor for the test. However, evaluating paralysis and paralysis in patients with cerebral infarction using BIA could easily obtain useful information on body function from various impedance parameters and changes in body composition. The limitation of this study is as follows. Impedance characteristics can be quantitatively distinguished in a more reliable manner when impedance measurements are performed over a long period of time in subjects classified as age and disease causes in rehabilitation therapy.

REFERENCE


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