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Body Composition Variations in the Paretic and Nonparetic Regions of Patients with Strokes Caused by Cerebral Hemorrhage or Cerebral Infarction

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Abstract

Indicators to quantitatively evaluate the body function may help to optimize the effectiveness of rehabilitation therapy for stroke patients. In this study, we analyzed the body composition in the paretic and nonparetic regions of stroke patients with hemiplegia caused by cerebral hemorrhage (7 cases) and cerebral infarction (13 cases) using multifrequency bioelectrical impedance. Specifically, we considered fat mass (FM), fat-free mass (FFM), FFMI index (FFMI), FM/FFM relation, body cell mass (BCM), basal metabolic rate (BMR), and BMR/FFM relation to evaluate the bodily function in the paretic and nonparetic regions. These values showed considerable differences according to grades determined by the stroke causes and the paralysis status. In the paretic regions, the FFM, FFMI, BCM, and BMR were low and the FM was high. In contrast, the nonparetic regions showed a high FFM and low FM. Furthermore, the paretic and nonparetic regions of all patients suitably fit a linear relation (slope: 22.17 kcal/day/kg) between BMR and FFM. Therefore, bioelectrical impedance measurements can be very useful to quantitatively assess paretic and nonparetic regions in hemiplegic stroke patients.

Keywords: Hemiplegic stroke, cerebral hemorrhage, cerebral infarction, bioelectrical impedance, body composition, rehabilitation therapy

1. INTRODUCTION

Stroke is a clinical condition characterized by a rapid onset of focal neurological signs with underlying vascular causes [1]. It results from different disease processes, with 80% being caused by ischemia and 20% by cerebral hemorrhage. In addition, stroke is one of the most common affections in adults given neurological disorders caused by damage to the cerebral blood vessels [2]. Many stroke patients have severe disabilities, such as hemiplegia, motor disturbance, and sensory, speech, communication, emotional, and cognitive disorders [3]. In particular, hemiparesis is characterized by weakness on one side of the body, whereas hemiplegia is the paralysis of one side of the body [4]. Individuals with hemiparesis might not be able to move one of their arms, or may feel tingling or other unusual sensations on one side of the body. Those with paralysis may retain some sensation, and the paralysis degree can change over time. Both conditions often involve side effects of strokes or cerebrovascular accidents. When a stroke affects the cerebral cortex area on one side of the brain, hemiplegia or hemiparesis occurs. The right side of the brain controls the motor function of the left side of the body, and vice versa. Thus, when one side of the brain is damaged, it affects only the contralateral side of the body. 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 [5]. 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 [6]. Nutritional disorders (e.g., obesity, sarcopenia, or malnutrition) were observed in about one-third of the individuals the year following a stroke [7]. In particular,

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hemiparetic strokes may lead to secondary muscle atrophy and specific changes in metabolic and contractile capacity [8]. Alterations in body composition, such as loss of muscle mass and increased fat mass (FM), are also part of aging [9]. Given the abovementioned post-stroke disabilities, stroke patients often receive long-term rehabilitation, such as rehabilitation medicine treatments and physical therapy [10].

Bioelectrical impedance analysis (BIA) is a widely used, noninvasive, and practical method to assess the body composition [11], and it is used in different clinical situations and research [12]. 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 [13]. BIA is based on measuring the impedance (i.e., the complex quantity composed by resistance R and reactance X_C) of the tissue through the injection of a low-intensity (≤1 mA) current [14]. This analysis has been used not only to evaluate the body's hydration and nutritional status, but also to diagnose diseases [15]. In this study, we used FM, fat-free mass (FFM), FFM index (FFMI), FM/FFM relation, body cell mass (BCM), basal metabolic rate (BMR), and BMR/FFM relation to evaluate the bodily function in the paretic and nonparetic regions of 20 stroke patients with hemiplegia caused by either cerebral hemorrhage or cerebral infarction.

2. MATERIALS AND METHODS

2.1 Bioelectrical Impedance

The concept of impedance Z is related to the flow obstruction of an alternating current, and it 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 Equations (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 X_C, which is caused by the cell membrane capacitance [16]:

$$Z = R + jX_C. \tag{1}$$

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.

$$R = |Z|cos\theta \tag{2}$$

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

$$X_C = |Z|sin\theta \tag{3}$$

The physical implication of complex impedance is the phase shift between the steady-state current and the applied voltage [17].

Resistance and reactance together determine the magnitude and phase angle of the impedance, with the former given by

$$|Z| = \sqrt{ZZ^*} = \sqrt{R^2 + X_C^2} \tag{4}$$

In the phasor diagram shown in Fig. 1, the angle between resistance and reactance determines the shift between source voltage V and current I, which corresponds to the angle by which the source voltage signal is displaced from the current signal.

From the diagram in Fig. 1, we have

$$tan\theta = \frac{X_C}{R} \tag{5}$$

$$\theta = arctan\left(\frac{X_C}{R}\right) \tag{6}$$

The resistance of an object depends on its shape and composition. Hence, for a given shape, the resistance only depends on the materials composing the object, as different materials exhibit different resistance to the current flow. Specifically, resistivity ρ of a material is directly proportional to resistance R of an object, with ρ being an intrinsic object property, independent from the object shape or size. Resistance R of a wire-shaped object of length L, cross-sectional area A, and uniformly composed by a material with resistivity ρ is given by [18]

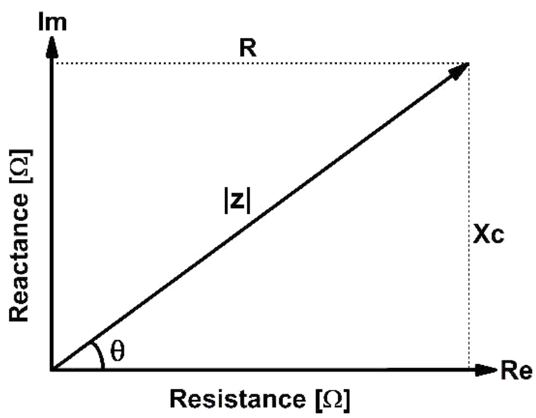

Fig. 1. Diagram showing the concept of a complex impedance. Z is impedance, $|Z|$ is the magnitude of impedance, R is the resistance, Xc is the reactance, and θ is the phase angle.

$$R = \rho \frac{L}{A} \tag{7}$$

Likewise, 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 a purely capacitive impedance in AC, the RMS current value, I, in a circuit with capacitance C is determined by the Ohm law as

$$I = \frac{V}{X_C} \tag{8}$$

where V is the RMS voltage value and impedance X_C is defined as

$$X_C = \frac{1}{2\pi f C} \tag{9}$$

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 (i.e., a high capacitance implies a large charge storage and consequently a large current flow) and frequency f (i.e., a high frequency implies a short time to charge the capacitor and consequently a reduced resistance to the current flow) [18].

2.2 Experimental Setup

2.2.1 Participants

The subjects were 20 stroke patients with hemiplegia who suffered either a cerebral hemorrhage (2 males and 5 females) or cerebral infarction (2 males and 11 females). Table 1 lists general information and the BMI of the 20 subjects. The mean age (75.8 years) of subjects who suffered cerebral infarction was considerably higher than that (65.4 years) of those who suffered cerebral hemorrhage. The BMI was 22.9±2.2 kg/m^2 for the former, and 22.6±2.1 kg/m^2 for the latter subjects, which is comparable to the Korean reference range from 22 to 23 kg/m^2 [19]. The BMI, a risk factor for both ischemic and hemorrhagic strokes, showed different relations among subjects. The time since stroke represents the elapsed time between the stroke diagnosis and the impedance measurements performed for this study.

Table 1. Anthropometric characteristics (age, height, mass), BMI and duration of illness of the subjects

Characteristic	Cerebral hemorrhage	Cerebral infarction
Age [years]	65.4±9.1	75.8±9.6
Height [cm]	165.0±5.7	160.2±2.0
Weight [kg]	65.4±9.1	58.1±7.1
BMI [kg/m^2]	22.9±2.2	22.6±2.1
Time since stroke [years]	2.1±0.3	1.8±0.6

BMI was calculated as the weight [kg] divided by the squared height (m^2)

2.2.2 Measurement of whole-body bioelectrical impedance

Whole-body bioelectrical impedance is the most commonly used parameter to estimate its compartments. In addition, the assessment of body composition is considered a key factor to determine a person's general health status. The human body consists of two main compartments: FM and FFM. The latter consists of somatic mass, including bone mineral, and skeletal muscle. For this study, we measured the systemic composition using a bioelectrical impedance spectroscopy device (MultiScan 5000, Bodystat Ltd., Isle of Man, UK) according to the recommendations of the Technical Assessment provided by the National Institutes of Health. In addition, we conducted the bioelectrical impedance measurements at the Medifarm Hospital in Korea, between October and November 2015. Prior to their participation in this study, we explained its purpose and method to the subjects, and obtained their written consents. The study was approved by the ethics committee of the Inje University Institutional Review Board for Clinical Studies (Document number: 2014250).

First, the subjects were in a comfortable supine position for at least 5 minutes before starting the experiment. Four gel electrodes (Bodystat 0525, Bodystat Ltd., Isle of Man, UK) were placed in the right side of the body along the third metacarpal base and along the third metatarsal base, between the medial and lateral navel of the ankle, as shown in Fig. 2. Before attaching the electrodes, we cleaned their locations with an alcohol swab. The electrodes were connected to the device via a sensor cable, after they were secured in the correct positions. The bioelectrical impedance spectroscopy device measures the voltage in the body (inner pair of electrodes) while allowing an alternating current of 800 μA to flow through the body (outer pair of electrodes). The whole-body impedance was measured in the paretic and nonparetic regions of the 20 subjects. P_CH indicates the paretic region of the subjects who suffered cerebral hemorrhage, NP_CH indicates the nonparetic region of those who suffered cerebral hemorrhage, P_CI indicates the paretic region of those who suffered cerebral infarction, and NP_CI indicates the nonparetic

Fig. 2. Eight cutaneous electrodes were attached to the wrists (left, right) and the ankles (left, right) of the stroke patient while they were in a supine position on a nonconductive surface. Outer electrodes (connected by red wires) are for injecting current through the human body while inner electrodes (connected by black wires) are for measuring the voltage across the body.

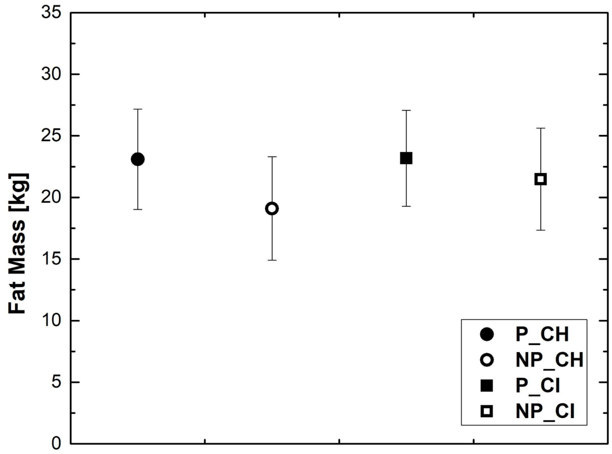

Fig. 3. FM in the paretic and nonparetic regions of stroke patients caused by cerebral hemorrhage and cerebral infarction. FM in the paretic regions of stroke patients caused by cerebral hemorrhage increased by 20.94% over the nonparetic regions whereas FM in the paretic regions of stroke patients caused by cerebral infarction increased by 7.91% over the nonparetic regions.

region of those who suffered cerebral infarction. This study was conducted to determine the body composition variations in paretic and nonparetic regions of stroke patients who suffered either cerebral hemorrhage or cerebral infarction.

3. RESULTS AND DISCUSSIONS

3.1 FM

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 also 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 [20].

Fig. 3 shows the FM in the paretic and nonparetic regions of the subjects who suffered either cerebral hemorrhage or cerebral infarction. The FM (23.10±4.07 kg and 23.18±3.88 kg) in their paretic regions was higher than that (19.10±4.56 kg and 21.48±4.14 kg) in their nonparetic regions. 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 nonparalyzed limbs [21,22]. Given that among the subjects, those who suffered cerebral hemorrhage participated in the study after approximately 2.1 years from their stroke, and those who suffered cerebral infarction participated after approximately 1.8 years from their stroke, we expected a substantial increase in body fat. In addition, the subjects showed a higher fat content in the paretic region than in the nonparetic region, possibly because they lost motor function in the former. Compared to the subjects who suffered cerebral infarction, those who suffered cerebral hemorrhage showed a considerable difference in FM (approximately 4 kg) between the paretic and nonparetic regions. In fact, an FM increase can be also observed in other diseases where the body movements are compromised. For instance, Azevedo et al. [23] 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). Those in the tetraplegic and inactive group showed higher FM values, even reaching obesity levels. Specifically, the FM was 16.66±9.71 kg for paraplegic and active patients, and 18.59±7.58 kg for paraplegic and inactive patients, whereas it was 11.22±5.16 kg for tetraplegic and active patients, and the highest value of 25.59±2.91 kg for tetraplegic and inactive patients.

3.2 FFM

Opposite to FM, FFM 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. In fact, FFM contains almost all the body's water, metabolically active tissues, and bone. Therefore, FFM is the source of all caloric expenditure. Moreover, the relation between FFM reduction and mortality has been extensively verified using BIA. FFM can be divided into BCM and extracellular mass. Overall, the loss of muscle mass after a stroke is expected to accompany weight loss, and a reduction of FFM is associated with increased mortality, poor clinical outcomes, and impaired quality of life [24]. Furthermore, an accelerated tissue wasting due to the combined effects of insufficient nutritional supply, catabolic activation, and anabolic failure may occur in stroke patients [22]. A variety of changes in skeletal muscle occurs with aging. For instance, sarcopenia is the age-related loss of muscle mass and is one of the main contributors to musculoskeletal impairments in the elderly [25].

Fig. 4 shows the FFM (39.19±9.86 kg in the paretic regions, 43.19±12.60 kg in the nonparetic regions) of the subjects who suffered cerebral hemorrhage and that (34.21±7.21 kg in the paretic regions, 35.9±7.45 kg in the nonparetic regions) of those who suffered cerebral infarction. The FFM was lower in the paretic regions than in the nonparetic regions of all the study subjects. A possible reason for the subjects who suffered cerebral infarction to have the lowest FFM levels is as follows. The mean age of these subjects was 10.38 years higher than that of the subjects who suffered cerebral hemorrhage, and their cerebral infarction appeared to have lasted for a long time. For the subjects who suffered cerebral hemorrhage, the FFM in the paretic regions was 9.26% lower than that in the nonparetic regions. Likewise, for the subjects who suffered cerebral infarction, the FFM in the paretic regions was 4.71% lower than that in the nonparetic region. The subjects have been suffering from FFM reduction in the paretic and nonparetic regions over the years possibly due to the loss of motor function, and nutritional and hormonal imbalances [26]. It has also been reported that the decrease of muscle mass and strength is proportional to age, and that the effects on muscular strength and muscle mass related to aging are caused by the decline of anabolic hormones, which results in a catabolic effect on muscles and bones [27]. In addition, a decrease in FFM was observed in sarcopenia. Furthermore, loss of FFM at hospital admission, which reflects an inadequate nutritional status, is known to be associated with an increased length of hospital stay [28]. Finally, the reduction of FFM is dramatically high in sedentary people and is driven by a chronic imbalance between muscle protein synthesis and breakdown, and facilitated by a decreased activation of the nutrient signaling pathway [29].

3.3 FFMI

The FFMI of a person is defined as the FFM divided by the squared height. This index is significantly lower in hospitalized patients, as found in controls matched by age, height, and gender [30]. The assessment of FFM by BIA is a more sensitive method to detect undernutrition than anthropometry [24]. In fact, the FFMI is used to assess the nutritional status of hospitalized

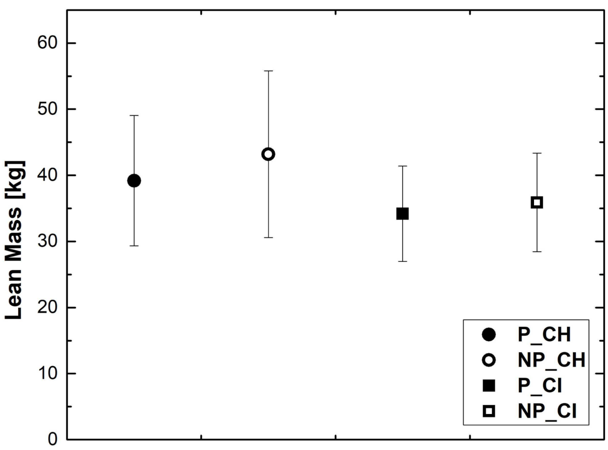

Fig. 4. FFM in the paretic and nonparetic regions of stroke patients caused by cerebral hemorrhage and cerebral infarction. Loss (-4.00kg) of FFM in the paretic regions of stroke patients caused by cerebral hemorrhage was more prominent than that (-1.69kg) in the paretic regions of stroke patients caused by cerebral infarction.

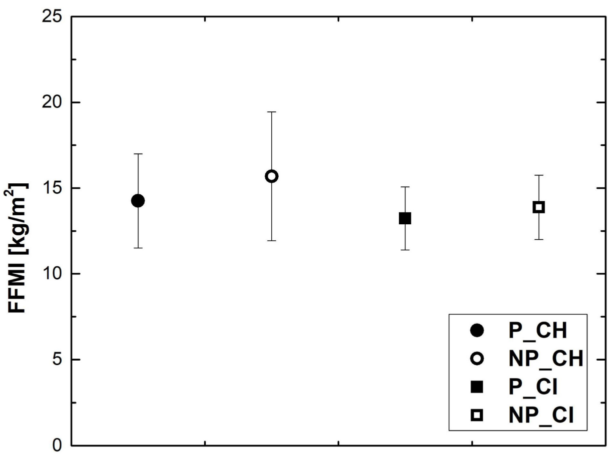

Fig. 5. FFMI in the paretic and nonparetic regions of stroke patients caused by cerebral hemorrhage and cerebral infarction. FFMI in the paretic region of stroke patients caused by cerebral hemorrhage reduced by 9.26% compared to that in the non-paretic region whereas FFMI in the paretic region of stroke patients caused by cerebral infarction reduced by 4.71% compared to that in nonparetic region.

patients, and nutritional disorders such as obesity, sarcopenia, and malnutrition have been observed in about one-third of individuals in the year following a stroke [7]. In addition, the FFMI is a more sensitive determinant of the length of hospital stay than either a weight loss above 10% or the BMI.

Fig. 5 shows the FFMI in the paretic and nonparetic regions of the study subjects. For all the subjects, the FFMI (14.25±2.75 kg/m^2 and 13.23±1.84 kg/m^2) in the paretic regions was lower than that (15.69±3.76 kg/m^2 and 13.88±1.87 kg/m^2) in the nonparetic regions. The low FFMI in the paretic regions reflects deficient nutritional status in the paralyzed area after the stroke, suggesting the necessity for a long-term rehabilitation. Overall, the FFMI in the paretic regions of the subjects who suffered cerebral hemorrhage was 9.26% lower than that in their nonparetic regions, whereas the FFMI in the paretic regions of those whose suffered cerebral infarction was 4.71% lower than that in their nonparetic regions.

3.4 FM/FFM Relation

Fig. 6 shows the relation between FM and FFM obtained from the study subjects. The relation in the nonparetic regions is mostly distributed in the lower-right part of the graph (i.e., high FFM and low FM), whereas that in the paretic regions is mostly distributed in the upper-left part of the graph (i.e., high FM and low FFM). In the sequel, we describe some of the characteristics of particular stroke patients (i.e., patients #4, #5, #9, #12, and #16). Patient #4 is a 72-year-old female (height: 156 cm; weight: 45 kg) who suffered a hemiplegic stroke caused by a cerebral hemorrhage that occurred 2 years and 4 months before participating in our study. Her FM (23.6 kg and 23.4 kg) was high and her FFM (21.4 kg and 21.6 kg) was considerably low in the paretic and nonparetic regions. Patient #5 (height: 173 cm; weight: 75 kg) showed notably different measurements between the paretic and nonparetic regions. Considering that the patient is relatively young (52 years) and has a strong physical condition compared with the other subjects, we can conclude that his paretic region was severely damaged from the hemiplegic stroke caused by a cerebral hemorrhage. Patient #9 is a 77-year-old female (height: 155 cm; weight: 55 kg) who suffered a stroke caused by a cerebral infarction that occurred 2 years and 1 month before participating in our study. Her FM was high and her FFM was low in both regions. Patient #12 is a 90-year-old female (height: 160 cm, weight: 63 kg) who suffered a stroke also caused by a cerebral infarction that occurred 2 years and 1 month before her participation. Likewise, her FM was notably high in both regions.

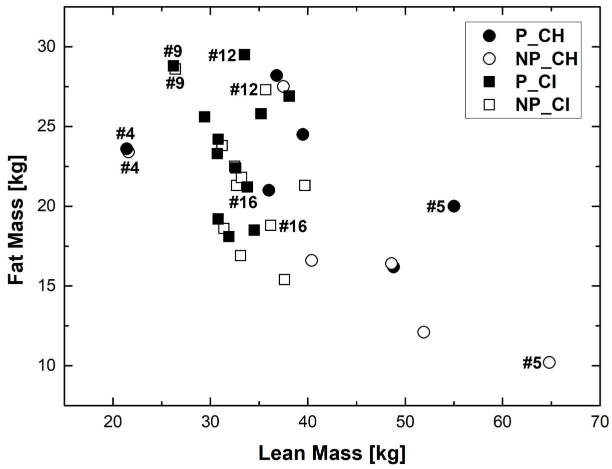

Fig. 6. The relationship between FM and FFM in the paretic and nonparetic regions of stroke patients caused by cerebral hemorrhage and cerebral infarction. The paretic positions of stroke patients are distributed in the upper left while the nonparetic positions of stroke patients are distributed in the lower right.

Finally, patient #16 is another 90-year-old female (height: 162 cm, weight: 55 kg) who suffered a stroke caused by a cerebral infarction that occurred 2 years and 3 months before her participation.

3.5 BCM

The BCM comprises all the metabolically active tissues of the body, including muscle cells, organ cells, blood cells, and immune cells. Likewise, it includes the "living" portion of fat cells, excluding the stored fat lipids, and considers the water contents within cells, which is called intracellular fluid. The reduction of BCM is a hallmark of aging, and a reduction above 40% of FFM is considered incompatible with life. The terms "wasting," "cachexia," and "sarcopenia" are commonly used to describe and distinguish the type of weight loss. Wasting is the unintentional weight loss comprising both fat and fat-free compartments, and is largely driven by inadequate dietary intake. Cachexia, which is the weakening and wasting of the body cells due to severe chronic diseases, shows reduction of FFM and especially BCM, but does not exhibit a clear weight loss, and it is associated with increased protein degradation. As mentioned above, sarcopenia is the loss of muscle mass and strength that is considered as an intrinsic age-related condition and as a major cause of disability in the elderly population. Moreover, sarcopenia is independent of nutritional aspects, and its prevalence is determined depending on the employed muscle mass measure. For instance, in [31], sarcopenia

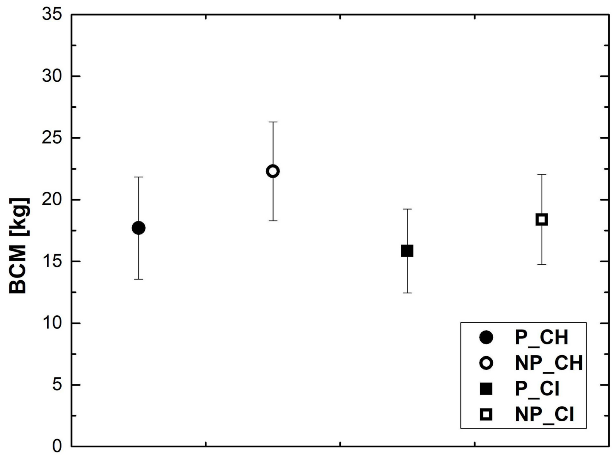

Fig. 7. BCM in the paretic and nonparetic regions of stroke patients caused by cerebral hemorrhage and cerebral infarction. For stroke patients with cerebral hemorrhage and cerebral infarction, BCM (17.70±4.14 kg and 15.85±3.39 kg) in the paretic regions was lower than that (22.30±4.02 kg and 18.40±3.65 kg) in the nonparetic regions.

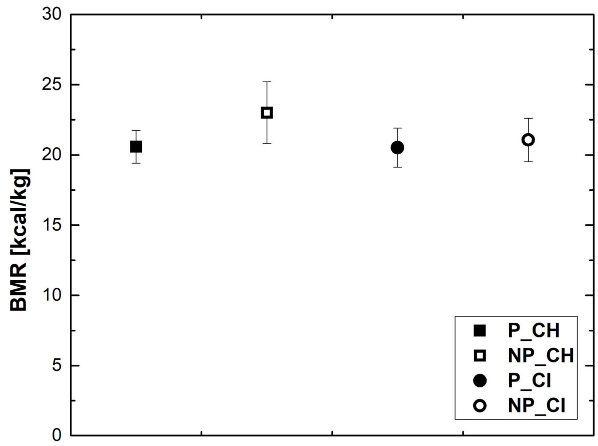

Fig. 8. BMR in the paretic and nonparetic regions of stroke patients caused due to cerebral hemorrhage and cerebral infarction. BMR in the paretic regions of hemiplegic stroke patients with cerebral infarction was reduced by 2.61% in the paretic regions compared to that in the nonparetic regions whereas BMR in the paretic regions of stroke patients with cerebral hemorrhage was significantly reduced by 10.50% in the paretic regions compared to the nonparetic regions.

was present in 22% of male and 20% of female subjects when using BCM as measure, whereas it was present in 4% of male and 11% of female subjects when using FFM. In addition, studies have shown that body composition measures such as BCM is directly correlated to a continuum of health, ranging from mortality and morbidity to immunity, longevity, proper bodily function, and athletic performance [32]. In fact, a low BCM is usually seen in individuals with a sedentary lifestyle, malnutrition, excessive FM, and other conditions associated with loss of muscle mass. The underlying causes of a low BCM and an elevated FM include insulin resistance, unbalanced hormone levels, and elevated cortisol levels due to chronic stress, growth hormone deficiency, and chronic illnesses.

Fig. 7 shows the BCM in the paretic and nonparetic regions of the study subjects. For all of them, the BCM (17.70±4.14 kg and 15.85±3.39 kg) in the paretic regions was lower than that (22.30±5.02 kg and 18.40±3.65 kg) in the nonparetic regions. The BCM was notably lower in the paretic regions of the subjects who suffered cerebral infarction. Such low BCM may be explained by the high average age of these subjects, which leads to loss of muscle mass due to aging (i.e., sarcopenia).

3.6 BMR

The BMR indicates the number of calories consumed during an average day. For a typical person, the 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. In addition, the BMR represents the total number of calories that our bodies require to perform basic, life-sustaining functions, such as breathing, digestion, heart rate, cell production, nutritional processing, protein synthesis, transportation of fluids and tissue, and blood pressure [33]. A high FFM implies an increased rate of caloric expenditure. Hence, one of the main benefits of exercise is the maintenance of the FFM level. In contrast, dieting alone may cause a reduction in FFM and reduce the body’s ability to burn calories [20].

Fig. 8 shows the BMR in the paretic and nonparetic regions of the study subjects. All of them showed a lower BMR (20.59±1.16 kg and 20.52±1.40 kg) in the paretic regions than that (23.00±3.65 kg and 21.07±1.55 kg) in the nonparetic regions. Furthermore, the BMR in the paretic regions of those who suffered cerebral infarction was 2.61% lower than that in their nonparetic regions, whereas the BMR in the paretic regions of those who suffered cerebral hemorrhage was a considerable 10.50% lower than that in their nonparetic regions, reflecting a substantial inactivation of the paretic regions in the subjects who suffered cerebral hemorrhage.

3.7 BMR/FFM Relation

The BMR is related to the number of cells that produce oxidative energy, and the more cells a body has, the more energy is needed for its survival, which is indicated by an increase in

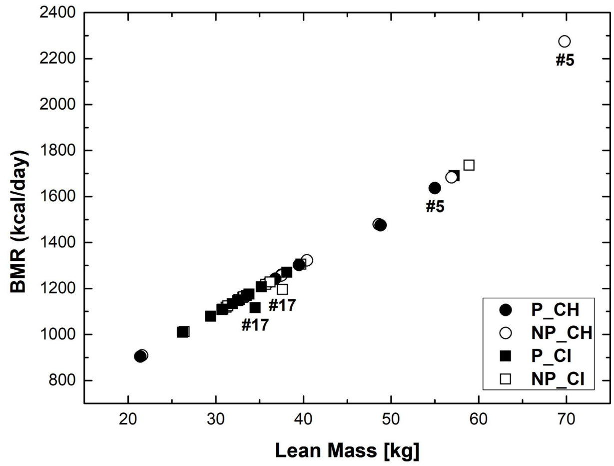

Fig. 9. Relationship between BMR and FFM in the paretic and nonparetic regions of stroke patients caused by cerebral hemorrhage and cerebral infarction. BMR is proportional to FFM (slope: 22.17 [kcal/day/kg]).

BMR. Thyroid and other hormones, medications, and other factors can affect the BMR. A low BMR indicates an improper consumption of the calories needed to support the body, and they are converted into fat. For instance, hypothermia can occur if the rate of burned calories by the body is very low. Metabolism occurs in two distinct and interdependent phases: catabolism, in which the body breaks down food into its constituents and harvests the energy stored in its atomic bonds, and anabolism, in which those constituents and energy are used to build new tissues and perform basic functions [34].

Fig. 9 shows the relation between BMR and FFM obtained from the study subjects. The paretic and nonparetic regions of all patients suitably fit a linear relation (slope: 22.17 kcal/day/kg) between BMR and FFM, regardless of the cause of the stroke and region, except for the nonparetic regions of patient #5 and both regions of patient #17, which are slightly out of the linear trend. Patient #5 is a 52-year-old male (height: 173 cm, weight: 72 kg) with a good physical condition who suffered a cerebral hemorrhage that occurred 2 years and 4 months before participating in this study. His left nonparetic region showed an FFM of 69.5 kg and a BMR of 2275 kcal/day, whereas his right paretic region showed an FFM of 55 kg and a BMR of 1637 kcal/day. These values are supported by the observation that his left-side brain damage associated with a contralateral paralysis seemed severe. Patient #17 is a 75-year-old male (height: 168 cm, weight: 53 kg) with a good physical condition who suffered a cerebral infarction that occurred 1 years and 8 months before participating in this study. His left nonparetic region showed an FFM of 37.6 kg and a BMR of 1196 kcal/day, whereas his right paretic region showed an FFM of 34.5 kg and a BMR of 1117 kcal/day. Hence, both regions showed slightly lower values than those that fit the general linear trend.

4. DISCUSSION

Skeletal muscle may be severely affected after a stroke, thus causing disability. A stroke is a condition mainly caused by brain damage; however, less attention is paid to the structural, metabolic, and functional alterations in muscle tissue after its occurrence [21]. FFM can be rapidly lost and may be regained shortly after a stroke, whereas a reduction of BCM is especially apparent in the paretic region [22]. Therefore, a timely rehabilitation is necessary for patients who suffered a stroke, ideally within the 3 to 6 months that follow the stroke occurrence. Noninvasive measurements are essential to recognize paretic and nonparetic regions in stroke patients and guarantee better outcomes from rehabilitation therapy. In fact, the quantitative assessment of recovery after stroke is becoming increasingly important with the advent of new options for rehabilitation treatment that are currently under investigation [35, 36]. For instance, the scores of the modified Barthel index, the Berg balance scale, and walking ability improved significantly, indicating the functional recovery of chronic stroke patients with cognitive impairment after 3 months of enrolment in a rehabilitation program [35]. In addition, the Fugl–Meyer assessment was developed as a quantitative tool to measure sensory–motor stroke recovery based on the Twitchell and Brunnstrom's concept of sequential stages that determine motor recovery in stroke patients [36]. Moreover, patients in the period of 3 to 9 months after a stroke who underwent the constraint-induced movement therapy showed statistically significant and clinically relevant improvements in the arm motor function that persisted for at least 1 year [37]. Nevertheless, such methods rely on subjective assessments of the recovery in the paretic regions after a stroke, and it takes a long time and much effort to obtain examiners' proficiency and the evaluation results. However, significant differences in prediction marker, phase angle θ, characteristic frequency f_C, and bioelectrical impedance vector analysis were observed between the paretic and nonparetic regions of 5 severely affected stroke patients [38]. These results suitably agreed with occupational assessments (e.g., pinch and hand grip strength, and activities of daily living evaluated using the modified Barthel index). Likewise, we verified in this study the usefulness of BIA to simultaneously determine body composition and physiological/pathological information from the paretic and nonparetic regions by evaluating stroke patients with hemiplegia who suffered either cerebral hemorrhage or cerebral infarction. Furthermore, the proposed assessment method is simple and noninvasive, and it can be conducted in a few minutes to evaluate the rehabilitation progress of stroke patients with hemiplegia.

5. CONCLUSIONS

We investigated the alteration of body composition in 20 hemiplegic stroke patients who suffered either cerebral hemorrhage or cerebral infarction by using bioelectrical impedance spectroscopy. Specifically, we quantitatively assessed the body composition considering FM, FFM, FFMI, FM/FFM relation, BCM, BMR, and BMR/FFM relation in their paretic and nonparetic regions. The experimental results are summarized as follows. 1. The FM in the paretic regions of the subjects who suffered cerebral hemorrhage was 20.94% higher than that in their nonparetic regions. Likewise, the FM in the paretic regions of those who suffered cerebral infarction was 7.91% higher than that in their nonparetic regions. 2. For the subjects who suffered cerebral hemorrhage, the FFM in their paretic regions was 9.26% lower than that in their nonparetic regions, and for those who suffered cerebral infarction, the FFM in their paretic regions was 4.71% lower than that in their nonparetic regions. 3. Hence, the nonparetic regions are distributed in the lower-right part of the FM/FFM graph (i.e., high FFM and low FM), whereas the paretic regions are distributed in the upper-left part (i.e., high FM and low FFM). Overall, the FFM was lower and the FM higher in the paretic regions than in the nonparetic regions. 4. For all the study subjects, the BCM in the paretic regions was lower than that in the nonparetic regions. 5. The BMR in the paretic regions of the subjects who suffered cerebral infarction was 2.61% lower than that in their nonparetic regions, and the BMR in the paretic regions of those who suffered cerebral hemorrhage was a notable 10.50% lower than that in their nonparetic regions. 6. The paretic and nonparetic regions of almost all the subjects suitably fit a linear relation between BMR and FFM (slope: 22.17 kcal/day/kg), with exception of the nonparetic regions of patient #5 and both regions of patient #17.

From these outcomes, we determined some limitations of this study and directions for subsequent research, which are summarized as follows. Twenty stroke patients were classified according to the cause of stroke, either cerebral hemorrhage or cerebral infarction, and their paretic and nonparetic regions. However, the study subjects were elderly patients who were receiving rehabilitation treatment at a nursing home. Therefore, the standard deviation may be larger than the difference between the condition grades, given that sex, age, stroke date, and physical conditions are very different. As the number of subjects increases, the standard deviations are expected to decline significantly by further subdividing the patients' condition grades. Moreover, we expect that more reliable results will be obtained, given smaller standard deviations than the differences between the grades, from new experiments with patients within 3 months after the stroke occurrence. The relevant clinical trials have been approved by the Institutional Review Board and are being carried out at rehabilitation hospitals in tertiary medical institutions.

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