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Assessment of Body Fluid Alteration Using Bioelectrical Impedance in Stroke Patients with Hemiplegia Caused by Cerebral Hemorrhage and Cerebral Infarction

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Abstract

Many stroke patients undergoing rehabilitation therapy require a quantitative indicator for the evaluation of body composition in paretic and non-paretic regions. In this study, the body fluid alteration in the paretic and non-paretic regions of stroke patients with hemiplegia caused by cerebral hemorrhage and cerebral infarction was analyzed using bioelectrical impedance analysis (BIA). Alterations in body fluids were investigated to assess the physical status of the paretic and non-paretic regions of 20 stroke patients with hemiplegia caused by cerebral hemorrhage (7 patients) and cerebral infarction (13 patients). Extracellular water (ECW), intracellular water (ICW), ICW/ECW, total body water (TBW), ECW/TBW, and TBW/fat-free mass were utilized to evaluate the functional status of the paretic and non-paretic regions. Compared with the non-paretic region, the paretic region had high ECW and low ICW. Due to the loss of motor function and nutritional imbalance caused by the stroke, the amount of fat increased while the muscle quantity and quality significantly decreased in the paretic region. Thus, BIA can be a useful tool for quantitatively assessing paretic and non-paretic regions in stroke patients with hemiplegia.

Keywords: Stroke patient with hemiplegia, Cerebral hemorrhage, Cerebral infarction, Bioelectrical impedance, Body composition, Body fluid alteration

1. INTRODUCTION

Stroke is a neurologic disturbance caused by damage to the cerebral blood vessels and one of the most common diseases of adulthood [1]. Many stroke patients have a number of serious disorders such as hemiplegia, motor disturbance, sensory disability, language impairment, communication disorders, emotional disorders, and cognitive impairment [2]. Hemiplegia is paralysis on one side of the body, whereas hemiparesis weakens one side of the body [3]. Hemiparesis is less severe than hemiplegia. Both are common side effects of stroke or cerebrovascular accidents. Unilateral paralysis or weakness occurs when a stroke affects the corticospinal tract on the contralateral side of the brain. The right side of the brain controls the motor function on the left side of the body, while the left side of the brain controls the motor (movement) function on the right side of the body. Thus, when one side of the brain is damaged, only one side of the body is affected. After stroke, one of the most commonly occurring problems is the limb dysfunction. Limb dysfunction seriously degrades quality of life since it challenges bodily functions and everyday life [4]. Due to these post-stroke disabilities, patients require long-term rehabilitation such as physical therapy and occupational therapy [5].

Bioelectric impedance analysis (BIA) has become increasingly popular for estimating body composition since it is easy to use, noninvasive, and inexpensive and can be performed across a wide range of individuals [6-9]. A BIA study measures impedance (consisting of resistance and reactance) by passing low alternating currents through the body's tissue [10]. In particular, it has been utilized to diagnose diseases and assess the body's hydration and nutritional status [11].

In this study, body fluid alterations were evaluated in 20 stroke

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patients with hemiplegia (it will be referred to stroke patient) caused by cerebral hemorrhage and cerebral infarction using BIA. The assessment of body fluids is reportedly useful for diagnostic and therapeutic purposes [12]. The accurate assessment of fluid status and body composition in various states of health and disease is a major clinical challenge. This study evaluated and validated body fluid volume, including extracellular water (ECW), intracellular water (ICW) and total body water (TBW). ECW including interstitial fluid (ISF) and connective tissue fluids decreased by 4.59% in the paretic region of stroke patients caused by cerebral infarction. On the other hand, ECW decreased by 11.07% in the paretic region of stroke patients caused by cerebral hemorrhage, indicating that the ability of cells to store nutrients and remove waste products from inside the cell significantly deteriorated. In addition, compared to non-paretic regions, ICW consisting of muscle and organ cells reduced by 12.86% in the paretic regions of stroke patients due to cerebral infarction, while ICW reduced by 12.61% in the paretic regions of stroke patients due to cerebral hemorrhage. This study aimed to quantitatively analyze the paralysis of stroke patients caused cerebral hemorrhage and infarction. BIA was used to assess alterations in body fluids in the paretic and non-paretic regions. Because this method is noninvasive and easy to use, it can be used to quantitatively assess the paralysis and non-paralysis regions in stroke patients undergoing rehabilitation.

2. EXPERIMENTAL

2.1 Method

2.1.1 Whole-Body BIA Measurement

Body composition consists of lean body mass (LBM) (fat-free mass [FFM]), body water, protein, minerals, and body fat. LBM is the sum of the minerals that form the muscles and skeleton and is composed of water (73%) and protein (27%). Body mass is the sum of LBM and FFM. Whole-body bioelectrical impedance is the most commonly used method for estimating entire body compartments. Body composition is considered to be one of the most important factors in evaluating the general health status of a person.

Whole-body bioelectrical impedance was measured at Medifarm Hospital in Korea between October and November 2015 using bioelectrical impedance spectroscopy (MultiScan 5000, Bodystat Ltd., Isle of Man, UK) according to the recommendations of the National Institutes of Health (NIH) Technology Assessment Statement. Before the measurement, the subjects were instructed to fast for at least 4 hours and not consume alcohol for 24 hours. The subjects were also instructed to drink at least eight glasses of water and empty their bladders before the measurement was taken. Eight cutaneous electrodes (Bodystat-0525, Bodystat Ltd, Isle of Man, UK) 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 (Fig. 1). The distance between the electrode used to apply current and the electrode used to collect voltage was maintained at least 5 cm to prevent an interactional effect between them. To provide more accurate measurements, the anthropometric measurement was combined with body composition determined using BIA, which provides accurate measurements of body composition. Prior to participation in this study, each patient received an explanation of the study purpose and methods and provided written informed consent. The study was approved by the Ethics Committee of Inje University Institutional Review Board for Clinical Studies (document number: 2014250).

Fig. 1. Eight cutaneous electrodes were attached to the wrists (left, right) and the ankles (left, right) of the stroke patient who was in a supine position on a nonconductive surface. The outer electrodes (connected by red wires) are used to inject current into the human body, while the inner electrodes (connected by black wires) are used to measure voltage across the body.

2.1.2 Subjects

Twenty stroke patients caused by cerebral hemorrhage (2 males, 5 females) and cerebral infarction (2 males, 11 females) were included. Table 1 shows anthropometric data (age, height, mass, and body mass index) of the 20 stroke patients. The mean age (75.8 years) of stroke patients caused by cerebral infarction was 10.3 years higher than that (65.5 years) of stroke patients caused by cerebral hemorrhage. Illness duration represents the period

Table 1. Subjects' anthropometric data and illness duration

Variables \ Status	Cerebral hemorrhage	Cerebral infarction
Age [years]	65.4 ± 9.1	75.8 ± 9.6
Stature [cm]	165.0 ± 5.7	160.2 ± 2.0
Mass [kg]	65.4 ± 9.1	58.1 ± 7.1
BMI [kg/m^2]	22.9 ± 2.2	22.6 ± 2.1
Duration [years]	2.1 ± 0.3	1.8 ± 0.6

BMI, body mass index. BMI was calculated by dividing body mass (kg) by height squared (m2).

from the diagnosis of the disease to the time of the measurement.

3. RESULTS AND DISCUSSION

3.1 Body Composition

3.1.1 Extracellular Water (ECW)

ECW consists of 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. For normal healthy adults, the total ECW is 13.2–15.3 L, with an optimal value of 14.8 L [13].

Fig. 2 shows the ECW content of the paretic and non-paretic regions of 20 stroke patients caused by cerebral hemorrhage and cerebral infarction. P_CH represents a paretic region in stroke patients caused by cerebral hemorrhage, NP_CH represents a non-paretic region in stroke patients caused by cerebral hemorrhage, P_CI represents a paretic region in stroke patients caused cerebral infarction, and NP_CI represents a non-paretic region in stroke patients caused cerebral infarction. For stroke patients caused by cerebral hemorrhage and cerebral infarction, ECW was 13.49 ± 2.57 L and 12.48 ± 1.95 L in the paretic region, which was lower than 15.17 ± 3.74 L and 13.08 ± 2.02 L in the non-paretic region. ECW reduced by 4.59% in the paretic region of stroke patients caused by cerebral infarction while ECW reduced by 11.07% in the paretic region of stroke patients caused by cerebral hemorrhage, indicating that the ability of cells to store nutrients and remove waste products from inside the cells was significantly deteriorated. In Fig. 2 (including Fig. 3 and Fig. 5), the standard deviation is larger than the difference between the mean values of each grade. This is because the sample size is small and the measurement values of some people greatly affect the standard deviation.

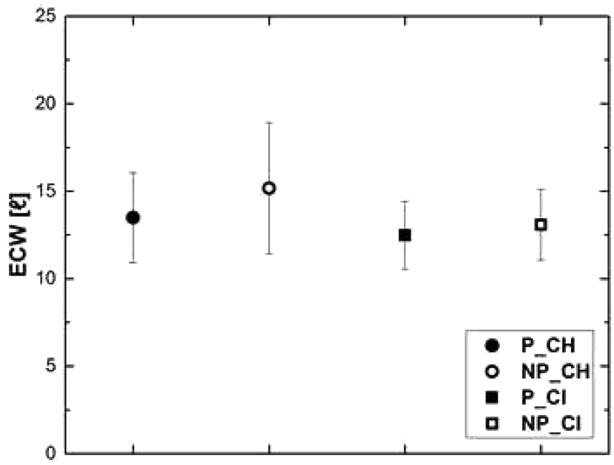

Fig. 2. Extracellular water (ECW) in the paretic and non-paretic regions of stroke patients caused by cerebral hemorrhage and cerebral infarction. P_CH represents a paretic region in stroke patients caused by cerebral hemorrhage, NP_CH represents a non-paretic region in stroke patients caused by cerebral hemorrhage, P_CI represents a paretic region in stroke patients caused cerebral infarction, and NP_CI represents a non-paretic region in stroke patients caused cerebral infarction. ECW reduced by 11.07% in the paretic region of stroke patients caused by cerebral hemorrhage, indicating that the ability of cells to store nutrients in the cells and to remove waste products from the cells was severely impaired.

3.1.2 Intracellular Water (ICW)

ICW is a measure of the amount of water inside the cell. Healthy cells maintain their integrity and hold their fluid inside the cell membrane. Water is essential in cells 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. 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. 3 shows ICW in the paretic and non-paretic regions of 20 stroke patients caused by cerebral hemorrhage and cerebral infarction. Stroke patients caused by cerebral hemorrhage and cerebral infarction had a lower ICW in the paretic region (12.41 ± 2.89 L and 11.10 ± 2.37 L) than in the non-paretic region (14.20 ± 4.37 L and 12.74 ± 2.52 L). ICW in the paretic region was significantly lower than the known values (22.9–25.0 L) [13], indicating severe dehydration and nutritional and hormonal imbalance in the paretic regions of stroke patients. ICW reduced by 12.86% in the paretic region of stroke patients caused by cerebral infarction but reduced by 12.61% in the paretic region of stroke patients caused by cerebral hemorrhage.

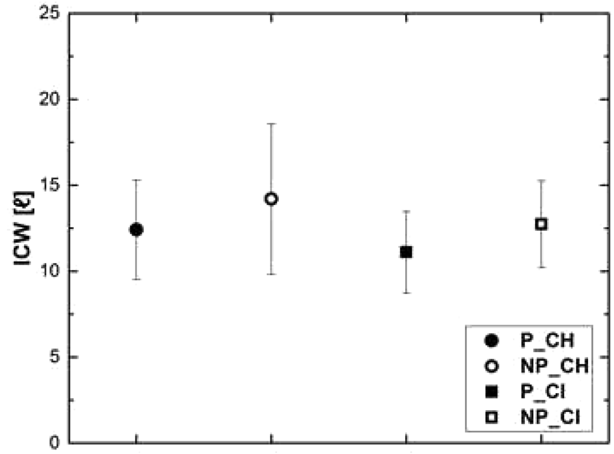

Fig. 3. Intracellular water (ICW) in the paretic and non-paretic regions of stroke patients caused by cerebral hemorrhage and cerebral infarction. ICW reduced by 12.86% in the paretic region of stroke patients caused by cerebral infarction but reduced by 12.61% in the paretic region of stroke patients caused by cerebral hemorrhage, indicating severe dehydration and nutritional and hormonal imbalances in the paretic regions of stroke patients.

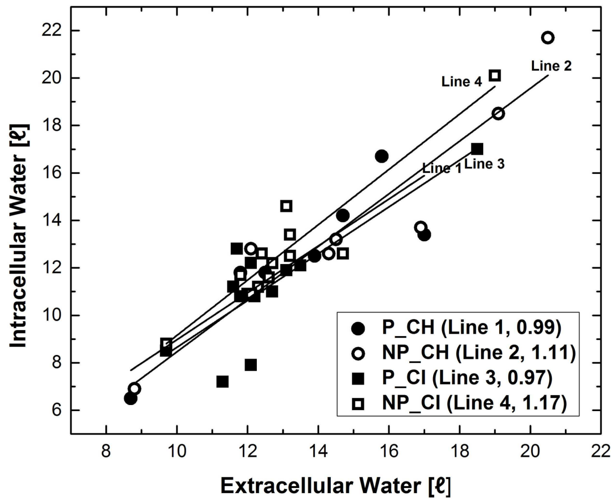

Fig. 4. Relationship between intracellular and extracellular water in the paretic (0.99 and 0.97) and non-paretic (1.11 and 1.17) regions of stroke patients due to cerebral hemorrhage and cerebral infarction. The slope of each line is shown in parentheses. These values were lower than that (1.15 and 1.24) of other reported stroke patients as well as that (1.33) of healthy patients.

3.1.3 Intracellular/Extracellular Water

The ratio of ICW to ECW in normal healthy adults is approximately 1.33, which represents the water distribution of the human body [13]. A low ICW reflects the low amount of muscle tissues due to factors such as dehydration, nutritional imbalance, hormonal imbalance, or toxicity, whereas a high ECW reflects highly connective and adipose tissue levels [14].

Fig. 4 shows the relationship between ICW and ECW in the paretic and non-paretic regions of 20 stroke patients caused by cerebral hemorrhage and cerebral infarction. Stroke patients caused by cerebral hemorrhage and cerebral infarction had lower ICW/ECW in the paretic region (0.99 and 0.97) than in the non-paretic region (1.11 and 1.17). The paretic regions have less muscle tissue but more connective and adipose tissue than the non-paretic regions. Stroke patients caused by cerebral hemiplegia have a significantly lower ICW than ECW. This is similar to what happens in patients with Duchenne muscle dystrophy (DMD), in whom the muscles slowly turn into connective tissue and fat [15]. ICW/ECW in the paretic and non-paretic regions of 20 stroke patients caused by cerebral hemorrhage and cerebral infarction were significantly lower from that obtained by individual nutritional supplementation for the elderly severe stroke patients admitted to the hospital (1.21 and 1.24 for males and 1.14 and 1.15 for females in the control and intervention groups, respectively) [16].

3.1.4 Total Body Water (TBW)

TBW, the total amount of fluid in the body that consists of ICW and ECW, is used to basic hydration status. The body needs water for various purposes, such as transporting nutrients around the body and removing waste from the body in the form of urine. It also acts on the body's organs, regulates the body's temperature, helps digestion, and contracts and relaxes the muscles [17]. TBW is an important component of LBM since clinical manifestations such as dehydration and edema have been observed in stroke patients. For healthy adults, TBW is usually between 69% and 74% of the LBM.

Fig. 5 shows TBW in the paretic and non-paretic regions of 20 stroke patients caused by cerebral hemorrhage and cerebral infarction. Stroke patients caused by cerebral hemorrhage and cerebral infarction had a lower TBW in the paretic region (25.90 ± 5.32 L and 23.58 ± 4.10 L) than in the non-paretic region (29.40 ± 8.03 L and 25.82 ± 4.47 L). These values in the paretic and non-paretic regions were significantly lower than the known values (36.6–38.9 L) [16], indicating dehydration and nutritional and hormonal imbalances. In addition, stroke patients caused by cerebral infarction had a significantly lower mean TBW (23.58 L) in the paretic region. These patients were on average 10.38 years older than stroke patients caused by cerebral hemorrhage. Their status on cerebral infarction have progressed significantly before they were confirmed to have

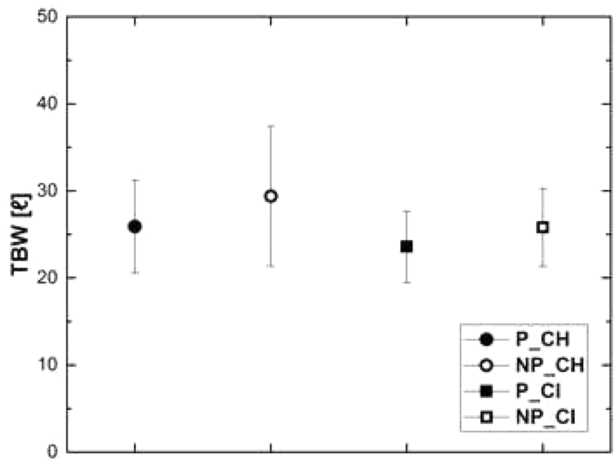

Fig. 5. Total body water (TBW) in the paretic and non-paretic regions of stroke patients caused by cerebral hemorrhage and cerebral infarction. Stroke patients caused by cerebral hemorrhage had a lower mean TBW in the paretic region (25.90 ± 5.28 L) than in the non-paretic region (29.37 ± 8.01 L), indicating dehydration as well as nutritional and hormonal imbalances.

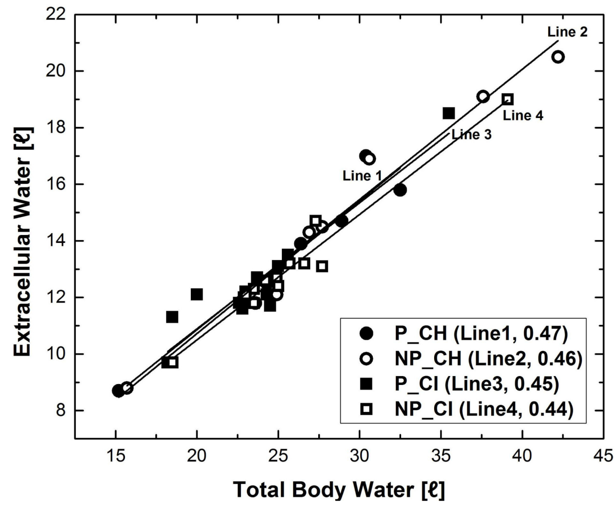

Fig. 6. Relationship between extracellular and total body weight in the paretic and non-paretic regions of stroke patients caused by cerebral hemorrhage (0.47 and 0.46) and cerebral infarction (0.45 and 0.44). Slope of each line is shown in parentheses.

stroke due to infarction, suggesting that their bodies had been deprived of water for long periods of time.

3.1.5 Extracellular Water/Total Body Water

ECW/TBW is an interesting biomarker of aging. This ratio correlate with age, body mass index, dry weight, and pre-dialysis systolic and diastolic blood pressure. ECW/TBW is a measure of the "quality" of lean body mass (LBM). The higher the ratio, the less healthy the LBM. This can help diagnose the condition of sarcopenic obesity, which features a high fat and low muscle content. Between 20 and 85 years of age, the ratio gradually increases from 0.36 to 0.39. In some disease states, the ratio may exceed 0.40. For example, the ECW/TBW ratio was 0.45 ± 0.03 (0.40–0.49) in cases of patients who underwent hemodialysis for end-stage renal disease [18].

Fig. 6 shows the relationship between ECW and TBW in the paretic and non-paretic regions of 20 stroke patients caused by cerebral hemorrhage and cerebral infarction. Stroke patients caused by hemorrhage had ECW/TBW (0.47 and 0.46) in the paretic and non-paretic regions, whereas stroke patients caused by cerebral infarction had a high ECW/TBW (0.45 and 0.44) in the paretic and non-paretic regions. These values are much higher than ECW/TBW (0.40) of patients in the disease status as well as the ECW/TBW (0.36–0.39) of the general population. Hence, it seems that stroke patients with hemiplegia who participated in this study had lost a large amount of muscle and that the remaining muscle had deteriorated significantly.

3.1.6 Intracellular Water/Total Body Water

ICW is calculated by subtracting ECW from TBW. Because of the well-known age-related decline in FFM, TBW and ICW reduced in elderly persons [19]. In addition, ICW has been observed to reduce in clinical situations in which TBW is increased, such as uremia, post-trauma, or cirrhosis [20]. Furthermore, DMD is characterized by a progressive loss of muscle tissue and replacement with adipose and connective tissue. Thus, children with DMD have a higher ECW/TBW and lower ICW/TBW than healthy controls. In all of the studies listed above, changes in ICW could arise from the loss of body cell mass and/or cellular dehydration. Cellular dehydration was reported in critical ill patients [21].

Fig. 7 shows the relationship between ICW and TBW in the paretic and non-paretic regions of 20 stroke patients caused by cerebral hemorrhage and cerebral infarction. Stroke patients caused by cerebral hemorrhage had similar ICW/TBW (0.54 and 0.55) in the paretic and non-paretic regions, whereas stroke patients caused by cerebral infarction had lower ICW/TBW in the paretic region (0.53) than in the non-paretic region (0.56). These values were higher than ICW/TBW (0.42) obtained for aged patients (80.5 years) but much lower than ICW/TBW (0.56 and 0.55) for healthy adults (38.1 years) and healthy elderly subjects (66.1 years) [22].

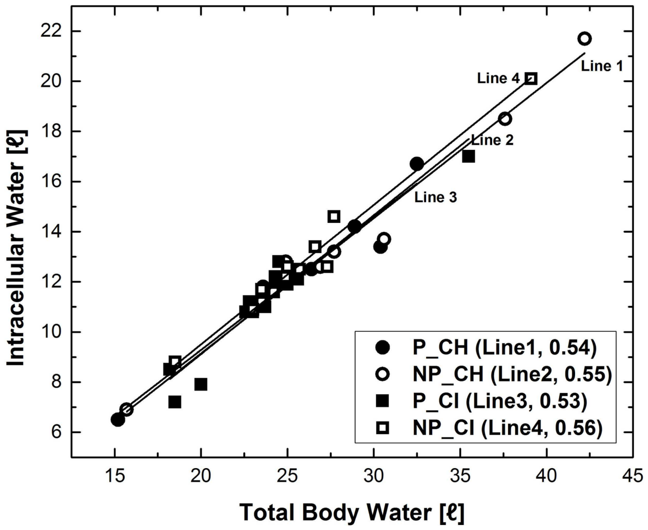

Fig. 7. Relationship between intracellular water (ICW) and total body water (TBW) in the paretic and non-paretic regions of stroke patients due to cerebral hemorrhage (0.54 and 0.55) and cerebral infarction (0.53 and 0.56). Patients with stroke due to cerebral infarction had a lower ICW/TBW in the paretic region (0.53, Line 3) than in the non-paretic region (0.56, Line 4). Slope of each line is shown in parentheses.

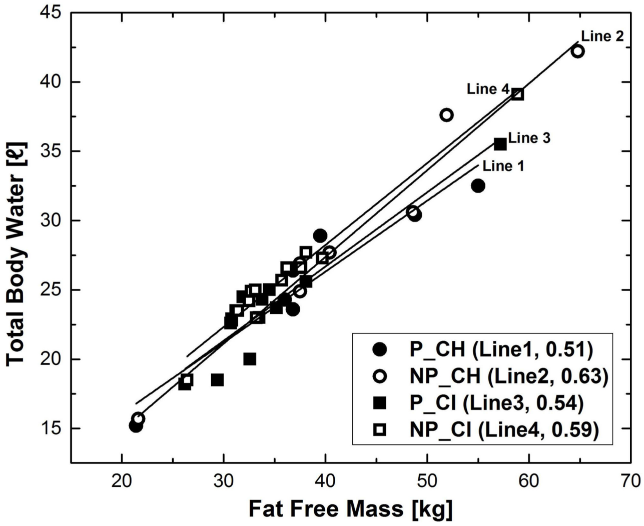

Fig. 8. Relationship between total body water (TBW) and fat-free mass (FFM) in the paretic and non-paretic regions of stroke patients caused by cerebral hemorrhage and cerebral infarction. For stroke patients caused by cerebral hemorrhage and cerebral infarction, TBW/FFM in the paretic regions was 0.51 and 0.54, respectively, lower than that (0.63 and 0.59) in the non-paretic regions. The slope of each line is shown in parentheses.

3.1.7 Total Body Water/Fat-Free Mass

The human body is composed of two main compartments, FM and FFM (or LBM). FFM is composed of bone minerals and body cell mass (BCM), which includes skeletal muscle mass. BCM contains proteins and TBW that represents 73% of the LBM in normal hydrated subjects. TBW/FFM is defined as the total body water for the body mass, representing the body's water status. This ratio is considered over-hydration when >0.74, normal hydration at around 0.73, and dehydration when <0.72 [16].

Fig. 8 shows the relationship between TBW and FFM in the paretic and non-paretic regions of 20 stroke patients caused by cerebral hemorrhage and cerebral infarction. Stroke patient caused by cerebral hemorrhage had a lower TBW/FFM in the paretic region (0.51) than in the non-paretic region (0.59). In addition, stroke patients caused by cerebral infarction had a lower TBW/FFM in the non-paretic region (0.54) than in the paretic region (0.63). For stroke patients caused by cerebral hemorrhage and cerebral infarction, TBW/FFM in the paretic regions was 0.51 and 0.54, respectively, lower than those in the non-paretic regions (0.63 and 0.59), and these four values were significantly lower than the dehydration threshold of 0.72.

3.2 Discussion

Long-term muscle changes such as losses of muscle mass, reductions of fiber cross-sectional area, and increased intramuscular fat depositions reportedly occur between 3 weeks and 6 months after stroke in both paretic and non-paretic limbs [23, 24]. Therefore, timely rehabilitation (within 3–6 months) is necessary for patients who have had a stroke. A noninvasive measurement method is also essential for assessing paralysis and non-paralysis in stroke patients according to rehabilitation therapy. Measurements of recovery after stroke have been becoming increasingly important with the advent of new treatment options under investigation in stroke rehabilitation researches [5, 25, 26]. The effect of inpatient rehabilitation on the functional recovery of chronic stroke patients with cognitive impairment was investigated [5]. In addition, the Fugl-Meyer scale was developed as the first quantitative evaluative instrument for measuring sensorimotor stroke recovery based on Twitchell and Brunnstrom's concept of sequential stages of motor return in the stroke patient [25]. Furthermore, among patients who had a stroke within the previous 3–9 months, constraint-induced movement therapy produced statistically significant and clinically relevant improvements in arm motor function that persisted for at least 1 year [26]. However, these methods are quite subjective in the assessment of body function in the paralysis caused by stroke and are time- and labor-intensive for examiner proficiency and evaluation results. On the other hand, evaluating the paretic and non-paretic regions of stroke patients with hemiplegia using BIA provides a simple, noninvasive, and easy way to obtain information about the physiological/pathological functions of the muscle [27] as well as cellular body water and composition. BIA has proven to be vital since physiological/pathological information as well as body composition for paretic and non-paretic regions of stroke patients can be obtained simultaneously. Since BIA is noninvasive and quick, it may be a vital tool for the rehabilitation evaluation of stroke patients with hemiplegia

4. CONCLUSIONS

The alterations in body fluid of 20 stroke patients with hemiplegia caused by to cerebral hemorrhage and cerebral infarction were assessed using BIA. This study aims to assess and validate body water measurements such as ECW, ICW, and TBW. BIA was used to compare the alterations in the body fluids of the paretic and non-paretic regions. ECW including ISF and connective tissue reduced by 4.59% in the paretic region of stroke patients caused by cerebral infarction and reduced by 11.07% in the paretic region of stroke patients caused by cerebral hemorrhage, suggesting that the ability of cells to store nutrients in the cells and to remove waste products from cells was significantly impaired. In addition, compared to non-paretic regions, ICW consisting of the fluid in muscle and organ cells reduced by 12.86% in the paretic region of stroke patients caused by cerebral infarction and reduced by 12.61% in the paretic region of stroke patient caused by cerebral hemorrhage. Thus, BIA could access quantitatively the paretic and non-paretic regions of stroke patients undergoing rehabilitation therapy since it was noninvasive and ease to use.

The limitation of this study was that the number of stroke patients was limited to 20. Stroke patients were classified as those caused by cerebral hemorrhage (7 patients) and stroke patients caused by cerebral infarction (13 patients). Patient age, physical status, and disease duration were so different that the standard deviations were greater than the differences between the patients. When a sufficient number of stroke patients are categorized by sex, age, and disease and impedance measurement are performed for long time intervals in the rehabilitation therapy, the standard errors will be significantly reduced and the intergroup differences will be more clearly distinguished. Thus, the paretic and non-paretic statuses of stroke patients with hemiplegia can assessed more confidently in the future.

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