J. Phys. Ther. Sci. 28: 2708-2712, 2016

The Journal of Physical Therapy Science

Original Article

# Bioelectrical impedance analysis for severe stroke patients with upper extremity hemiplegia

Chanuk Yoo[1)], Jaehyung Kim[2)], Yeongae Yang[3)], Jinsu Lee[4)], Gyerok Jeon[5)*]

[1)] *Department of Occupational Therapy, Hanlyo University, Republic of Korea*
[2)] *Department of Computer Simulation, Inje University, Republic of Korea*
[3)] *Department of Occupational Therapy, Inje University, Republic of Korea*
[4)] *Department of Physical Therapy, Medifarm Hospital, Republic of Korea*
[5)] *Department of Biomeical Engineering, Pusan National University: Beomeo-ri, Mulgeum-eup, Yangsan-si, Gyeongsangnam-do, Republic of Korea*

**Abstract.** [Purpose] This study is to analyze bioimpedance parameters and occupational assessment for severe stroke patients with upper extremity hemiplegia. [Subjects and Methods] Experimental subjects were 20 hemiplegic stroke patients receiving rehabilitation therapy between November to October, 2015. Prediction marker (PM), and phase angle (θ), a nd characteristic frequency (*fc*) were measured using bioelectrical impedance spectroscopy (MultiScan 5000). Bioelectrical impedance vector analysis (BIVA) was also obtained from the bioimpedance data. Then, these values were compared with occupational assessment tools. [Results] A significant differences in PM, θ, *fc*, and BIVA were observed between paretic region and non-paretic region of 5 severe stroke patients. These results were in good agreement with occupational assessment (pinch and hand grip strength, and ADL by MBI). [Conclusion] There were significant differences in impedance parameters between paretic region and non-paretic region of 5 severe stroke patients with upper extremity hemiplegia. Thus, the BIA could be useful tool for evaluating hemiplegic stroke patients receiving the rehabilitation therapy in the clinical application.

**Key words:** Stroke patient with upper extremity hemiplegia, Bioimpedance parameters (Z: R, *Xc*, PM, *θ*, *fc*, and BIVA), Occupational assessment tool (pinch and hand grip strength, ADL by MBI)

*(This article was submitted Mar. 24, 2016, and was accepted Jun. 9, 2016)*

## INTRODUCTION

Stroke is a neurologic disturbance caused by damage to the cerebral blood vessels and one of the most common diseases in the adults[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)]. After stroke, one of the most commonly occurring problems is the limb dysfunction. About 30 to 60% of the stroke patients have serious problems in their lives due to paralysis of the arm[3)]. The dysfunction of the limb seriously degrades the quality of life since it causes the challenges of bodily function and everyday life[4)]. Due to these post-stroke disabilities, patients are subjected to long-term rehabilitation, such as physical therapy and occupational therapy[5)].

Bioelectrical impedance analysis (BIA) is a safe, practical, and non-invasive method for measuring components of biological tissues[6–9)]. BIA relies on the conduction of radio-frequency electrical current by the fluid (water, interstitial fluid, and plasma), electrolytes, and permeability or conductivity of cell membrane in the body[10)]. In particular, it has been utilized to diagnose the diseases as well as assess the hydration status and nutritional condition of the body[11)]. Gupta et al. demonstrated that phase angle was an independent prognostic indicator in patients with breast cancer and concluded that nutritional interventions targeted at improving phase angle could potentially lead to an improved survival in patients with breast cancer[12)].

*Corresponding author. Gyerok Jeon (E-mail: grjeon@pusan.ac.kr)

Norman et al. observed that the impedance parameters, R/H and *Xc*/H, were related to hand grip strength and might therefore be used as a cooperation-independent method to reproducibly assess muscle function[13]. Buffa et al. concluded that BIVA represented a promising indicator of nutritional status, suitable in screening programs and clinical practice[14].

In this study, impedance parameters (Z, R, *Xc*, θ) were measured at 50 frequencies for 20 stroke patients with upper extremity hemiplegia, using bioelectrical impedance spectroscopy (MultiScan 5000, BodyStat Ltd., UK). The body compositions were simultaneously obtained during impedance measurement. In addition, the characteristic frequency (*fc*) and bioelectrical impedance vector analysis (BIVA) was obtained to clarify more precisely the paretic and non-paretic status. Furthermore, occupational assessment (pinch and hand grip strength, and ADL by MBI) were conducted on severe stroke patients with upper extremity hemiplegia. We report the bioelectrical impedance analysis and the occupational assessment for 5 severe stroke patient of 20 stroke patients with upper extremity hemiplegia.

## SUBJECTS AND METHODS

The experimental subjects were 5 severe stroke patients with upper extremity hemiplegia (1 male and 4 females) with a mean age of 78.6 years (± 5.31 years), average height of 161.6 cm (± 5.43 cm), average mass of 56.2 kg (± 6.76 kg), and average BMI of 21.5 kg/m$^2$ (± 1.72 kg/ kg/m$^2$). Bioelectrical impedance (Z) measurement and occupational assessment were conducted at Medifarm Hospital in Korea between October and November, 2015. Prior to participation in this study, the purpose and method of the study was explained to the patients, and their written consents were obtained. The study was approved by the ethics committee of Inje University Institutional Review Board for Clinical Studies (Document number: 2014250).

Bioimpedance parameters (Z, R, *Xc*, θ) were measured at 50 frequencies ranging from 5 to 1,000 kHz, using bioelectrical impedance spectroscopy (MultiScan 5000, Bodystat Ltd., UK) according to the recommendations in the National Institutes of Health (NIH) Technology Assessment Statement. Eight cutaneous electrodes (Bodystat－0525) 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. The distance between current applying electrode and voltage detecting electrode was maintained at least 5 cm to prevent interaction between electrodes. Body composition of severe hemiplegic stroke patients was simultaneously obtained during the impedance measurement.

The prediction marker (PM) is the ratio of the impedance (Z) at 5 kHz to that at 200 kHz. At 5 kHz, the current cannot penetrate the cell membrane and then flows in ECF (*Re*) in equivalent circuit proposed in our previously published paper[15]. However, at 200 kHz, the current is strong enough to penetrate the cell membrane and then flow in ICF (*Zi*) as well as ECF (*Re*). The greater two variances between two impedance at 5 kHz and 200 kHz are, the healthier the body cells are. A ratio closer to 1.00 indicates poor cellular health or extreme fluid overload[16].

Phase angle (θ), associated with changes in cellular membrane integrity and alterations in fluid balance, has been established as a global marker for the diagnosis of malnutrition and clinical prognosis[17]. A higher phase angle means an increase in BCM (muscle mass) or a decrease in fluid, either recovery from infection or injury or a decrease in fluid from dehydration. A loss of fat could also increase phase angle. On the other hand, a lower phase angle could mean a loss of BCM, or an increase of fluid (rehydrating, or sign of inflammation or infection[18].

Characteristic frequency (*fc*) is frequency where the current passing through the capacitive path reaches a peak reactance (*Xc*), and is a useful parameter for evaluating physiological function of cell membrane. When the function of cell membranes is healthy, *fc* is lowered. This is due to the fact that even though the energy applied to the cell membranes is lower than 0.21 eV (50 kHz in the frequency), the permeability and conductivity of ions inside and outside the cell membranes can be increased. On the other hand, when the function of cell membranes are unhealthy, *fc* is increased. The permeability and conductivity of ions inside and outside the cell membranes cannot be increased although the energy applied to the cell membranes is higher than 0.21 eV (50 kHz in the frequency). Thus, the characteristic frequency could be a useful indicator for determining the status of the muscles or the cell membrane.

The BIVA illustrates the plot of the resistance (R) and reactance (*Xc*) normalized per height as a bivariant vector in the R/H (X axis) and *Xc* /H (Y axis)[19]. The impedance vector (length, direction) provides valuable information about hydration status, muscle mass and cell integrity. A migration sideways of the impedance vector due to low or high reactance indicated decrease or increase of muscle mass of soft[13]. The length of the impedance vector indicates hydration status from fluid overload (decreased resistance, short vector) to exsiccosis which is insufficient intake of fluids (increased resistance, longer vector)[20]. Significant vector displacement is seen with increasing disease severity[21, 22]. The BIVA parameter has gained attention as a tool to assess and monitor patients' hydration and nutrition status.

According to the occupational therapy assessment guide[23], there are 3 methods to measure the pinching strength of fingers. That is, tip-pinch is to measure the strength between thumb finger and index finger. Lateral (or Key) pinch is to measure the strength between thumb pad and lateral aspect of index finger. Palmar (or 3-Jaw Chuck) pinch is to measure the strength among thumb, index, and middle finger. Pinches (Tip, Lateral and, Palmar) were measured using a Jamar hydraulic pinch gauge (7498-05, Jamar Ltd., USA). Maximum pinch strength of a Jamar hydraulic pinch gauge is up to 45 lbs (20 kg).

Hand grip strength test is to measure the maximum isometric strength of the hand and forearm muscles. Hand grip strength was measured using Jamar hydraulic hand dynamometer (503330J1, Jamar Ltd., USA). Hand grip strength of a Jamar hydraulic pinch gauge has the measurement range from 0 to 200 lbs (90 kg). The subject holds the dynamometer in the hand to be tested, with the arm at right angles and the elbow by the side of the body. The handle of the dynamometer is adjusted if required—the base should rest on first metacarpal (heel of palm), while the handle should rest on middle of four fingers. When ready the subject squeezes the dynamometer with maximum isometric effort, which is maintained for about 5 seconds. No other body movement is allowed. The subject should be strongly encouraged to give a maximum effort. Hand grip strength was measured three times and a minute break time was given to subjects between measurements.

The modified Barthel Index (MBI) is a measure of activities of daily living (ADL), which shows the degree of independence of a patient from any assistance[24]. It covers 10 domains of functioning (activities): bowel control, bladder control, as well as help with grooming, toilet use, feeding, transfers, walking, dressing, climbing stairs, and bathing. Each activity is given a score ranging from 0 (unable to perform task) to a maximum of 5, 10, or 15 (fully independent- exact score depends on the activity being evaluated). A total score is obtained by summing points for each of the items. Total scores may range from 0 to 100, with higher scores indicating greater independence.

## RESULTS

Table 1 shows body composition for 5 severe stroke patients with upper extremity hemiplegia. Lean mass (also muscle mass), total body water (TBW), body cell mass (BCM), and basal metabolic rate (BMR) in paretic region were lower than those in non-paretic region, whereas fat in paretic region was higher than that in non-paretic region. For patient (#4), fat content was high, whereas lean mass, TBW, BCM, and BMR were lower even in non-paretic region as well as paretic region, suggesting high impedance.

Table 2 shows PM, θ, and *fc* for paretic and non-paretic regions of 5 severe stroke patients with upper extremity hemiplegia. PM in paretic region was higher than that in non-paretic region. In particular, PM (0.936 for #10, 0.935for # 20) in paretic region of patients (#10, #20) was higher than that (0.881 for #10, 0.876 for #20) in non-paretic region, indicating poor cellular health in paretic region. Phase angles (2.0° for #10, 2.1° for #20) in paretic region of patients (#10, #20) were lower than those (3.7° for #10, 3.4° for #20) in non-paretic region. A lower phase angle means a loss of muscle mass (body cell mass), or an increase of fluid (rehydrating, or sign of inflammation or infection).

In particular, the characteristic frequency was higher than 100 kHz in paretic and non-paretic region of patients (#10, #11, #20), suggesting the deteriorated integrity of their cell membrane. This is due to the phenomena that since the cell membranes of severe stroke patient with upper extremity hemiplegia was unhealthy, the current having low frequency (about 50 kHz) could not pass cell membrane but a current having high frequency (about 100–182 kHz) could flow in ICF through cell membrane.

Table 3 shows BIVA for 5 severe stroke patients with upper extremity hemiplegia. The impedance vectors of paretic regions for 5 severe stroke patients with upper extremity hemiplegia migrated sideway downward due to reduced muscle mass and cell integrity. In addition, the impedance vectors in paretic region were positioned below than those in non-paretic region of 5 severe hemiplegic stroke patients. The positions of impedance vectors in paretic regions of 5 hemiplegic stroke patients are as follows: Patient (R/H=295.64[Ω/m], *Xc*/H=15.00[Ω/m] for #2, R/H=632.69[Ω/m], *Xc* /H=26.54[Ω/m] for #4, R/H=483.94[Ω/m], *Xc* /H=16.88[Ω/m] for #10, R/H=320.13[Ω/m], *Xc* /H=15.13[Ω/m] for #11, and R/H=437.06[Ω/m], *Xc* /H=16.00[Ω/m] for #20, whereas the positions of impedance vectors in non-paretic regions of 5 hemiplegic stroke patients are as follows: (R/H=297.27[Ω/m], *Xc* /H=16.63[Ω/m] for 2, R/H=617.24[Ω/m], *Xc* /H=26.92[Ω/m] for #4, R/H=394.94[Ω/m], *Xc* /H=25.56[Ω/m] for #10, R/H=406.63[Ω/m], *Xc* /H=24.88[Ω/m] for #11, and R/H=419.69[Ω/m], *Xc* /H=24.94[Ω/m] for #20. In particular, the impedance vectors of patient (#4) were longer than those of others due to dehydration (high fat and low

**Table 1.** Body composition data for 5 severe stroke patients with upper extremity hemiplegia

| Patient number | P/N | Fat (%) | LM (%) | TBW (%) | BCM (kg) | BMR (kcal) |
|---|---|---|---|---|---|---|
| #2 | P | 26.5 | 73.0 | 46.9 | 19.2 | 1,469.0 |
| (M, 75 yrs) | N | 25.2 | 74.8 | 47.1 | 19.5 | 1,475.0 |
| #4 | P | 51.9 | 47.5 | 33.6 | 9.2 | 904.0 |
| (F, 85 yrs) | N | 50.9 | 48.1 | 34.9 | 9.7 | 909.0 |
| #10 | P | 46.6 | 53.4 | 33.5 | 10.2 | 1,079.0 |
| (F, 85 yrs) | N | 41.0 | 59.0 | 44.0 | 16.6 | 1,147.0 |
| #11 | P | 42.3 | 57.5 | 38.9 | 15.7 | 1,207.0 |
| (F, 75 yrs) | N | 34.9 | 65.1 | 44.9 | 18.0 | 1,306.0 |
| #20 | P | 40.8 | 59.2 | 36.4 | 11.3 | 1,150.0 |
| (F, 73 yrs) | N | 39.6 | 60.4 | 41.9 | 15.6 | 1,163.0 |

P: Paretic; N: Non-pretic

**Table 2.** Prediction marker, phase angle, and characteristic frequency for 5 severe stroke patients with upper extremity hemiplegia

| Patient number | P/N | PM | PA (°) | Fc (kHz) |
|---|---|---|---|---|
| #2 | P | 0.903 | 2.9 | 65 |
| (M, 75 yrs) | N | 0.893 | 3.2 | 56 |
| #4 | P | 0.922 | 2.4 | 100 |
| (F, 85 yrs) | N | 0.917 | 2.5 | 56 |
| #10 | P | 0.936 | 2.0 | 167 |
| (F, 85 yrs) | N | 0.881 | 3.7 | 143 |
| #11 | P | 0.885 | 2.7 | 143 |
| (F, 75 yrs) | N | 0.849 | 3.5 | 143 |
| #20 | P | 0.935 | 2.1 | 182 |
| (F, 73 yrs) | N | 0.876 | 3.4 | 143 |

P: Paretic; N: Non-pretic

lean mass and TBW) and thus, migrated sideways due to loss of muscle mass.

Table 4 shows pinch (Tip, Lateral and, Palmar) and hand grip strength, and ADL evaluated by BMI for 5 severe stroke patients with upper extremity hemiplegia. Pinch (Tip, Lateral, and Palmar) and hand grip strength in paretic region were lower than those in non-paretic region for 5 severe stroke patients. In particular, pinch and hand grip strength were nil in the paretic region of 3 severe hemiplegic patients (# 10, #11, and #20), illustrating a significant difference in neurophysiological function between paretic region and non-paretic region. These were in good agreement with experimental result that these patients (#10, #11, and #20) had low phase angles and large characteristic frequency. The cell membranes in paretic region of these hemiplegic stroke patients were much degraded functionally since phase angles were low (2.0° for #10, 2.7°, for #11, and 2.1° for #20) and the characteristic frequencies were high (167 kHz for #10, 143 kHz for #11, and 182 kHz for #20). Patient (#4) had relatively small difference in pinch (Tip, Lateral and, Palmar) and hand grip strength between paretic region and non-paretic region. This is due to the fact that patient #4 does not exhibited significant differences in impedance parameters: PM = 0.922 for paretic region and 0.917 for non-paretic region, PA=2.4° for paretic region and 2.5° for non-paretic region, and 100 kHz for paretic region and 56 kHz for non-paretic region. These small differences between paretic region and non-paretic region also appear well on body compositions: fat (51.9% for paretic and non-paretic regions), lean mass (47.5 kg for paretic region and 48.1 kg for non-paretic region), TBW (33.6 for paretic region and 34.9 kg for non-paretic region), BCM (9.2 for paretic and non-paretic regions), BMR (904.0 kcal for paretic region and 909.0 kcal for non-paretic region).

In MBI score, Total is in the range of 0–24 points, and patient needs the full assistance in daily life and the help of 27 hours per week. Severe is in the range of 25–49 points, and patient needs the considerable assistance in daily life and the help of 23.5 hours per week. Moderate is in the range of 50–74 points, and patient needs the moderate assistance in daily life and the help of 20 hours per week. ADL score was as follows: 16 (Total) for #2, 42 (Severe) for #4, 54 (Moderate) for #10, 16 (Total) for #11, and 39 (Severe) for #20. Patient (#2) exhibited lower ADL score although body composition, impedance parameters, and pinch and hand grip strength were relatively excellent than other patients. This is due to the fact that patient (#2) have weakly progressed neuropathy due to diabetes. Thus, ADL score was low (Total) because the cognitive ability and the behavioral performance were much degraded by a stroke. Besides, patient (#11) exhibited large difference between pinch (also hand grip) strength and ADL score in paretic and non-paretic regions. This difference was well represented in the large difference of impedance vectors (positions) of BIVA diagram in paretic and non-paretic regions in Table 3.

## DISCUSSION

Study on the analysis of bioimpedance had been performed for a long time by many researchers, and they mainly carried out the body composition and the physiological properties of the tissue using the bioimpedance parameters. However, study, using the body composition and bioimpedance parameters, on the diagnosis and the treatment effect of stroke patients with upper extremity hemiplegia has not been carried out substantially. Accordingly, the aim of this study is a quantitative assessment of paretic and non-paretic regions of severe stroke patients with upper extremity hemiplegia using body composition and bioimpedance parameters. The correlation between them was analyzed by comparing impedance parameters (PM, θ, *fc*, and BIVA) and occupational assessment (pinch and hand grip strength, and ADL by MBI).

The contents of this study are as follows. To investigate the relationship between the BIA and occupational assessment for 5 severe stroke patients with upper extremity hemiplegia, bioimpedance parameters (PM, θ, *fc*, and *fc*) were obtained using bioelectrical impedance spectroscopy. The body compositions were simultaneously obtained during impedance measurement. Lean mass (also muscle mass), TBW, BCM, BMR in paretic region were lower than those in non-paretic region, whereas fat in paretic region was higher than that in non-paretic region. For bioimpedance parameters, PM in paretic region

**Table 3.** BIVA for paretic and non-paretic regions of 5 severe stroke patients with upper extremity hemiplegia

| Patient number | Paretic | | Non-paretic | |
|---|---|---|---|---|
| | R/H (Ω/m) | $X_c/H$ (Ω/m) | R/H (Ω/m) | $X_c/H$ (Ω/m) |
| #2 (M, 75 yrs) | 295.64 | 15.00 | 297.27 | 16.63 |
| #4 (F, 85 yrs) | 632.69 | 26.54 | 617.24 | 26.92 |
| #10 (F, 85 yrs) | 483.94 | 16.88 | 394.94 | 25.56 |
| #11 (F, 75 yrs) | 320.13 | 15.13 | 406.63 | 24.88 |
| #20 (F, 73 yrs) | 437.06 | 16.00 | 419.69 | 24.94 |

**Table 4.** Occupational therapy assessment for pinch, hand grip, and ADL

| Patient number | P/N | Pinch | | | Grip | ADL |
|---|---|---|---|---|---|---|
| | | Tip | Lateral | Palmar | | (MBI) |
| #2 | P | 2.5 | 3 | 2.5 | 16 | 16 |
| (M, 75 yrs) | N | 4.5 | 5 | 4.5 | 18 | Total |
| #4 | P | 2.5 | 2.5 | 3 | 10 | 42 |
| (F, 85 yrs) | N | 2.5 | 4 | 3 | 14 | Severe |
| #10 | P | None | none | none | none | 54 |
| (F, 85 yrs) | N | 3.5 | 6.5 | 5 | 16 | Moderate |
| #11 | P | None | none | none | none | 16 |
| (F, 75 yrs) | N | 3 | 5 | 4 | 18 | Total |
| #20 | P | None | none | none | none | 39 |
| (F, 73 yrs) | N | 1.5 | 4 | 3.4 | 11 | Severe |

P: Paretic; N: Non-pretic

was higher than that in non-paretic side, whereas θin paretic region was lower θin non-paretic region. In addition, the characteristic frequency in paretic region was higher than that in non-paretic region, suggesting the deteriorated integrity of cell membrane. Furthermore, BIVA parameters was analyzed for paretic and non-paretic regions of 5 severe stroke patients with upper extremity hemiplegia. The impedance vectors (positions) of BIVA for 5 severe stroke patients with upper extremity hemiplegia migrated sideway downward due to reduced BCM (also muscle mass) and cell integrity.

Occupational assessment (pinch and hand grip strength, and ADL by MBI) was performed for 5 severe stroke patients with upper extremity hemiplegia. Pinch (Tip, Lateral and, Palmar) and hand grip strength in paretic region were lower those in non-paretic region. In particular, pinch and hand grip strength were nil in the paretic region of 3 severe hemiplegic patients (# 10, #11, and #20). ADL score was as follows: 16 (Total) for #2, 42 (Severe) for #4, 54 (Moderate) for #10, 16 (Total) for #11, and 39 (Severe) for #20. Male patient (#2) exhibited lower ADL score although body composition, impedance parameters, and pinch and hand grip strength were relatively excellent than other patients.

In this study, the paralysis of severe stroke patients with upper extremity hemiplegia was quantitatively distinguished quantitatively impedance parameters (PM, θ, *fc*, and BIVA), which was in good agreement with occupational assessment (pinch and hand grip strength, and ADL by MBI). The limitation of this study was as follows. The number of severe stroke patients with upper extremity hemiplegia was limited in the experiments. When the subjects are categorized by gender, age, and disease states, and the impedance measurement are performed for long time intervals in the rehabilitation therapy, impedance characteristics could be quantitatively distinguished as a more confident manner.


## ACKNOWLEDGEMENT

This work was financially supported from the basic research project (NO. 2013R1A2A2A04015325) by the National Research Foundation of Korea via the funds of Ministry of Education, Korea in 2013.


## REFERENCES


1) Adamson J, Beswick A, Ebrahim S: Is stroke the most common cause of disability? J Stroke Cerebrovasc Dis, 2004, 13: 171–177. [Medline] [CrossRef]
2) Jun HJ, Kim KJ, Chun IA, et al.: The relationship between stroke patients' socio-economic conditions and their quality of life: the 2010 Korean community health survey. J Phys Ther Sci, 2015, 27: 781–784. [Medline] [CrossRef]
3) Mercier L, Audet T, Hébert R, et al.: Impact of motor, cognitive, and perceptual disorders on ability to perform activities of daily living after stroke. Stroke, 2001, 32: 2602–2608. [Medline] [CrossRef]
4) Kwakkel G, Kollen B: Predicting improvement in the upper paretic limb after stroke: a longitudinal prospective study. Restor Neurol Neurosci, 2007, 25: 453–460. [Medline]
5) Cho KH, Lee WH: Effects of inpatient rehabilitation on functional recovery of stroke patients: a comparison of chronic stroke patients with and without cognitive impairment. J Phys Ther Sci, 2012, 24: 245–248. [CrossRef]
6) Thomasset MA: [Bioelectric properties of tissue. Impedance measurement in clinical medicine. Significance of curves obtained]. Lyon Med, 1962, 94: 107–118. [Medline]
7) Lingwood BE, Colditz PB, Ward LC: Biomedical applications of electrical impedance analysis. Proc. of ISSAP, 1999, 1: 367–370.
8) Lukaski HC: Methods for the assessment of human body composition: traditional and new. Am J Clin Nutr, 1987, 46: 537–556. [Medline]
9) Ward LC: Segmental bioelectrical impedance analysis: an update. Lippincott Williams & Wilkins, 2012, pp 424–429.
10) Lukaski HC: Biological indexes considered in the derivation of the bioelectrical impedance analysis. Am J Clin Nutr, 1996, 64: 397S–404S. [Medline]
11) Lukaski HC, Singer MG: Phase angle as a prognostic indicator in cancer AAAI Spring Symp. Technical Reports, 2011, SS-11–04: 37–40.
12) Gupta D, Lammersfeld CA, Vashi PG, et al.: Bioelectrical impedance phase angle as a prognostic indicator in breast cancer. BMC Cancer, 2008, 8: 249. [Medline] [CrossRef]
13) Norman K, Pirlich M, Sorensen J, et al.: Bioimpedance vector analysis as a measure of muscle function. Clin Nutr, 2009, 28: 78–82. [Medline] [CrossRef]
14) Buffa R, Floris G, Marini E: Assessment of nutritional status in free-living elderly individuals by bioelectrical impedance vector analysis. Nutrition, 2009, 25: 3–5. [Medline] [CrossRef]
15) Lukaski HC: Biological indexes considered in the derivation of the bioelectrical impedance analysis. Am J Clin Nutr, 1996, 64: 397S–404S. [Medline]
16) Kim JH, Kim SS, Kim SH, et al.: Comparing the whole body impedance of the young and the elderly using BIMS. J Sens Sci Tech, 2016, 25: 20–26. [CrossRef]
17) http://www.bodystat.com/home/online-brochure/predictionMarker (Accessed Feb. 10, 2016)
18) Bosy-Westphal A, Danielzik S, Dörhöfer RP, et al.: Phase angle from bioelectrical impedance analysis: population reference values by age, sex, and body mass index. JPEN J Parenter Enteral Nutr, 2006, 30: 309–316. [Medline] [CrossRef]
19) http://www.bodystat.com/support/news/what-is-phase-angle (Accessed Feb. 15, 2016)
20) Piccoli A, Rossi B, Pillon L, et al.: A new method for monitoring body fluid variation by bioimpedance analysis: the RXc graph. Kidney Int, 1994, 46: 534–539. [Medline] [CrossRef]
21) Norman K, Stobäus N, Pirlich M, et al.: Bioelectrical phase angle and impedance vector analysis—clinical relevance and applicability of impedance parameters. Clin Nutr, 2012, 31: 854–861. [Medline] [CrossRef]
22) Toso S, Piccoli A, Gusella M, et al.: Bioimpedance vector pattern in cancer patients without disease versus locally advanced or disseminated disease. Nutrition, 2003, 19: 510–514. [Medline] [CrossRef]
23) Castillo Martínez L, Colín Ramírez E, Orea Tejeda A, et al.: Bioelectrical impedance and strength measurements in patients with heart failure: comparison with functional class. Nutrition, 2007, 23: 412–418. [Medline] [CrossRef]
24) https://otassessments.wordpress.com/dynamometry/pinch-strength/(Accessed Mar. 12, 2016)