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Bioelectrical impedance analysis values as markers to predict severity in critically ill patients

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ABSTRACT

Purpose: We investigated bioelectrical impedance analysis (BIA)-derived parameters in critically ill patients to evaluate any differences between survivors and nonsurvivors.
Methods: We calculated severity scores for 241 critically ill surgical patients (161 male and 80 female; mean age, 62.9 years) using three severity scoring systems (Acute Physiology and Chronic Health Evaluation II, Sequential Organ Failure Assessment, and Simplified Acute Physiology Score III). Body composition was measured using a portable BIA device for segmental BIA.
Results: Among the BIA values, impedance (odds ratio [OR], 0.99; $P < 0.001$), reactance (OR 0.90; $P < 0.001$), and phase angle (PhA) (OR, 0.53; $P < 0.001$) were highly statistically significant for predicting mortality in univariate and multivariate logistic regression analysis. Comparison of area under the curve (AUC) between severity scoring systems and BIA values showed statistically significant differences between reactance and PhA with all three severity scoring systems. Covariate-adjusted receiver operating characteristic curve analysis showed that compared with severity scoring, all three BIA values (impedance, reactance, and PhA) had higher AUC values.
Conclusions: PhA, impedance, and reactance determined by BIA in critically ill patients were associated with mortality outcomes and revealed stronger predictive power for mortality than severity scoring systems commonly used in an intensive care unit.

1. Introduction

Since the condition of critically ill patients can change rapidly, and their vital signs are often unstable, it is difficult to accurately predict mortality or medical outcomes. Therefore, many previous studies attempting to predict the mortality of critically ill patients used severity scoring systems such as Simplified Acute Physiology Score (SAPS), Sequential Organ Failure Assessment (SOFA), or Acute Physiology and Chronic Health Evaluation (APACHE), which use various indicators such as vital signs, blood and urine composition, and urine output. However, because these severity scoring systems often lack accuracy [1-3], efforts are being made to improve them or find more accurate and efficient methods to predict the outcomes.

For bioelectrical impedance analysis (BIA) analysis, it is generally assumed that the measured body is one cylinder. In contrast, the segmental BIA analyzer uses direct segmental measurement bioelectric impedance analysis (DSM-BIA), a patented technology, to precisely measure the body as 5 separate cylinders, four limbs and the trunk. BIA allows estimation of several factors of human body composition [4,5]. The principle of BIA involves passing a small single- or multiple-frequency alternating current (1–10 μA) through the body and measuring the resulting impedance composed of resistance, capacitive reactance, and the phase angle (PhA). As the body's electrical conductivity depends on its composition (fat and water content), the total body water (TBW), as well as the intra- and extracellular water content (ICW and ECW, respectively) can be estimated. PhA represents the phase difference between voltage and current and is related to the number of healthy cells in the body. Experimental results further allow calculation of fat mass (FM), fat-free mass (FFM), and cell mass by using a regression equation based on measuring values. Furthermore, it is possible to determine the water content and muscle mass for specific body parts such as arms, legs, and the trunk.

Abbreviations: APACHE, Acute Physiology and Chronic Health Evaluation; AUC, area under the curve; BIA, bioelectrical impedance analysis; ECW, extracellular water; FFM, fat-free mass; FM, fat mass; ICU, intensive care unit; ICW, intracellular water; PhA, phase angle; ROC, receiver operating characteristic; SAPS, Simplified Acute Physiology Score; SOFA, Sequential Organ Failure Assessment; TBW, total body water.

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As a noninvasive method, BIA is widely used in clinical settings because it provides a convenient tool to easily and quickly examine body composition at a patient's bedside [4-7]. In particular, the PhA is a useful indicator of nutritional status [8-11], and hence for the patient's overall condition [10-13].

BIA studies on critically ill patients are rare due to the concern that their severely imbalanced state of body fluids might affect BIA results [14,15]. However, some recent studies suggested the possibility of evaluating nutritional status and predicting mortality of critically ill patients using segmental BIA [7,16-20].

In the present study, we intended to gain further insight into BIA of critically ill patients and investigated the question of whether BIA is a useful tool to predict mortality of critically ill patients. For this purpose, we compared BIA data with the popular severity scoring systems SAPS III, SOFA, and APACHE II, which are commonly employed for this prediction [1-3].

2. Materials and methods

This was a prospective, open-label, observational study.

2.1. Subjects

This study was conducted from January 12 to August 3, 2015, in the surgical intensive care unit (ICU) of Ajou University Hospital, Suwon, Korea. A total of 241 critically ill surgical patients (161 male and 80 female, mean age 62.9 ± 13.1 years) over 18 years old were enrolled. Pregnant or brain dead patients were excluded. BIA analysis was performed for all patients regardless of whether they were on diet or fasting, had limb edema, anasarca, sepsis, shock, or undergoing renal replacement therapy. This study was performed after obtaining the approval of the Institutional Review Board (IRB) of Ajou University Hospital (DEV-DE4-15-115). Before inclusion in this study, informed consent was obtained from patients or their next of kin.

2.2. Severity scoring systems

SAPS III, SOFA, and APACHE II scores were calculated based on test results or clinical features obtained within 24 h after admission to the ICU.

2.3. BIA measurement

Body composition was measured using a portable BIA device for segmental BIA (InBody S10®, InBody Corp., Seoul, South Korea), using 50-kHz alternating current. The InBody S10 body composition analyzer is designed for patients over 3 years of age who are immobile or who are amputees, with touch-type electrodes or with adhesive-type electrodes and produces results within 2 min. With each InBody S10 test, a full-page results sheet is printed detailing the whole-body and segmental (right and left arms and legs and trunk) muscle, fat, and water values such as total body water (TBW), ICW, ECW, ECW/TBW, lean body mass, FM, skeletal muscle mass, and whole-body and segmental PhA, impedance, and reactance at each segment and frequency.

After a patient's admission to the ICU, the measurements were performed twice weekly (Monday and Thursday) in the afternoon between 2 and 4 pm because the researcher who measured BIA was available only at this time. BIA measurements were performed while patients were lying on the bed with their arms and legs spread out. Because it is usually difficult to apply touch-type electrodes to ICU patients due to intravascular lines and dressing covering these lines, we used adhesive-type electrodes. Eight adhesive electrodes were used: one on the most distal part of the third metacarpal bone of each hand, one on each wrist, one on the most distal part of the second metatarsal bone in each foot, and one on the central part of each ankle. In contrast with other BIA devices used for patients who are standing, the InBody S10 cannot measure height and body weight while the patient is lying down. Before pressing the measurement button, manual input of patient information such as age, height, and weight is needed. We used the actual body weight of each patient which was measured by scale in the ICU bed on their exam date. To prevent any errors caused by improper patient postures or inappropriate attachment of the electrodes, photographs were taken and reviewed by co-investigators.

2.4. Nutritional assessment

Nutritional assessment was performed for patients with a medium or high risk of malnutrition. Risk factors at the time of admission included 1) unexpected weight loss during the past month; 2) dysphagia; 3) starvation for >3 days; 4) anorexia for >2 weeks; 5) tube feeding; 6) human immunodeficiency virus infection, chronic kidney disease, liver cirrhosis, hepatic encephalopathy, congenital metabolic disease, sores, multiple trauma, burns on >10% of the body surface; g) old age; h) extremely low body mass index; and i) abnormal serum albumin level. Depending on the result of the nutritional assessment, patients were categorized as either well-nourished or malnourished.

2.5. Statistical analysis

The first BIA measurement values from patients admitted to the ICU were used for comparisons with severity scores. All continuous data are expressed as the arithmetic mean values ± standard deviation; other data are reported as number (percentage). The normality of each variable was tested using the Kolmogorov–Smirnov test. Student's *t*-tests were used for comparisons between survivors and nonsurvivors. Univariate logistic regression analysis with a forward stepwise approach and multivariate logistic regression analysis were performed to investigate correlations of BIA data and severity scores with respect to their ability to predict mortality. Receiver operating characteristic (ROC) curves were generated and areas under the curves (AUCs) calculated.

ROC curves and AUCs were compared using the DeLong method [21]. *P*-values of <0.05 were considered statistically significant.

All of the statistical analysis was performed using R software version 3.2.0 (R Foundation for Statistical Computing, Vienna, Austria).

3. Results

Patient characteristics are shown in Table 1. Height and weight were 164.4 ± 8.9 cm (range, 140–186 cm) and 64.7 ± 14.7 kg (range, 33–135 kg), respectively. The most common cause of admission was abdominal surgery due to malignant tumors (23.2%), followed by open-heart surgery (17.4%). Malnourished patients accounted for 17.0%, and patients with a shock status needing vasopressors accounted for 60.6%. In-hospital mortality was 19.9%.

The mean time interval from ICU admission to the BIA measurement used for this analysis was 2.3 ± 1.8 days (range, 0–5 days). A comparative analysis was performed between the severity scores and BIA values for survivors and nonsurvivors. The established scoring systems (SAPS III, SOFA, and APACHE II) showed a statistically significant correlation with the difference between survivors and nonsurvivors (Table 1). Among the BIA values, PhA ($P < 0.001$), impedance ($P < 0.001$), and reactance ($P < 0.001$) were statistically different between the two groups. Although ECW, TBW, ECW/TBW, and FM also showed weak statistical significance, all other BIA data were unrelated to patient mortality.

A univariate logistic regression analysis was performed to assess the predictive power of several characteristics (Table 2). All three severity scores exhibited significant predictive power for mortality. Among the BIA values, impedance (odds ratio [OR], 0.99; $P < 0.001$), reactance (OR 0.90; $P < 0.001$), and PhA (OR, 0.53; $P < 0.001$) were highly statistically significant for predicting mortality, whereas ECW, TBW, ECW/TBW, TBW/FFM, and waist to hip ratio displayed somewhat lower predictive power, similar to the severity scoring systems. The three BIA