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REVIEW ARTICLE

Bio-electric impedance as a tool to assess hydration in critically ill patients: an integrative review

Cristiano Corrêa Batista[1,2]*

[1] Santa Casa de Misericórdia Hospital, Pelotas, Rio Grande do Sul, Brazil.
[2] Federal University of Pelotas, Rio Grande do Sul, Brazil.

Corresponding Author: Dr. Cristiano Corrêa Batista, Federal University of Pelotas, Rio Grande do Sul, Brazil.
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Abstract

Introduction: Assessing the hydration status of critically ill patients has been a difficult task over the decades. Determining how much fluid overload a patient has often helped in choosing a therapy. Methods such as bioelectrical impedance have been approached as a useful tool for this purpose. **Objective:** This study proposes to verify, through research in the literature, what is the real importance of the clinical use of bioelectrical impedance in the diagnosis of fluid overload in critically ill patients hospitalized in intensive care units. **Methods:** bibliographic search in the main scientific information databases: Scielo, PubMed, Cochrane, and Lilacs from January 2000 to July 2018. The selected languages were Spanish, Portuguese, and English. The keywords used were bioelectrical impedance, hydration, Intensive Care Unit, Intensive Care, bioelectrical impedance analysis, fluid balance, hydration overload. **Results and Conclusion:** The analysis of fluid overload in critically ill patients can be performed using multifrequency bioelectrical impedance. It is a useful tool in the diagnosis as well as in the quantification of water overload and, therefore, a corroborative method for clinical decision-making.

Keywords: Electrical Bioimpedance Analysis. Intensive Care Unit. Fluid Balance. Critically ill Patients. Phase Angle. Fluid Overload.

Introduction

In recent decades, intensive medicine has been dedicated to the development of new diagnostic tools to acquire a better and more complete insight into the volume status of critically ill patients. Several diagnostic and therapeutic methodologies are used to reduce the length of stay in the Intensive Care Units (ICU), time on mechanical ventilation, as well as their effects on morbidity and mortality **[1]**. The water management of patients admitted to intensive care is a constant challenge as their actual hydration status is difficult to be assessed at the bedside **[2]**.

Identifying the hydration status of patients, as well as quantifying this hydration, is an essential task for proper fluid and hemodynamic management. Semiological methods only estimate generic levels of hydration, for example: dehydration or hyperhydration. Hemodynamic methods identify responders and non-responders to fluid therapy. In critically ill patients, positive fluid balance has a marked influence as a risk factor for morbidity and mortality, however, very little is known about how to monitor hydration status and volume overload **[1]**.

In this sense, potential deleterious effects of a positive fluid balance range from congnitive changes and delirium, changes in cardiac contractility and myocardial electrical conduction disorders, changes in gas exchange, reduced lung compliance and increased respiratory work as well as reduced renal plasma flow and glomerular filtration rate, ileum and intestinal malabsorption, abdominal compartment syndrome, microcirculation alterations, poor wound healing and compromised lymphatic drainage. Furthermore, studies show that different types of water solutions used can also contribute to unfavorable outcomes as verified through nephrotoxic effects and increased mortality associated with the use of synthetic colloids **[2]**.

Bioelectrical impedance for analyzing the water status of critically ill patients has been studied as a useful tool to guide the water management of these patients, including both resuscitation and deresuscitation. This would be a tool to be used in monitoring the state of hydration and fluid overload. Bioimpedance can provide useful information not only in different groups of well-established patients such as: AIDS patients, hemodialysis patients or malnourished patients, but also in critically ill patients, including burn patients, trauma and septic patients undergoing fluid resuscitation **[1]**.

This study aimed to verify in the literature through bibliographic research, using the main means of scientific information available, elements that can clarify and guide the real clinical usefulness of this tool in the evaluation and guide for decision-making regarding water management of critically ill patients admitted to Intensive Care Units.

Methods

For this study, bibliographic searches were carried out in the main scientific medical and health information sites, available such as PubMed, Lilacs, Scielo, and Cochrane. Papers published in English, Portuguese and Spanish were researched for a period between January 2000 and July 2018. The keywords used were: *Bioelectrical Impedance Analysis, water management, ICU (intensive care unit), hydration status, fluid balance, critically ill patients, phase angle, and fluid overload.*

Discussion

The human body has 60% water, 18% protein, 16% fat, and 6% minerals. Tissue water varies from approximately 20% in fat and bone tissue and up to 85% in the kidney, liver, and blood. Bioelectrical impedance is a method based on body composition and makes it possible to detect, specifically, soft tissue hydration with approximately 2 to 3% measurement error, which is comparable to routine laboratory tests. Non-invasive assessment of body composition is crucial for routine monitoring of critically ill patients. Under proper conditions of volume control, there is an improvement in both short and long-term results. However, there are monitoring difficulties as the edema is usually not detectable until the interstitial fluid volume has increased by around 30% above normal (4 to 5 kg of body weight) and, on the other hand, a state Severe dehydration may develop before clinical signs appear **[3]**.

Also, the cumulative positive daily fluid balance is an independent predictor of worse outcomes. Therefore, bioimpedance parameters such as total body water, intracellular water, extracellular water, extra/intracellular ratio, and excess volume, along with other indices of capillary loss and water overload, have clinical potential and can be easily used in both water assessments. daily and cumulative. Understanding the different concepts involved in diagnostic assessment using this tool is a sine qua non to obtain the best information from it and, consequently, the best results. The body offers two types of resistance to electrical current: capacitive resistance (reactance) that arises from cell membranes and resistive resistance (resistance) that arises from extra and intracellular fluids **[3]**.

Besides, impedance (Z) is the term used to describe the combination of the two resistances (reactance and resistance). It represents the ratio between the insulating tissue and the conductive tissue. To obtain a good impedance measurement, five factors are essential: impedance value; height; Weight; sex, and age. Of these, sex and age are the most important to obtain the highest level of accuracy. Capacitance (C) is the storage of electrical charge by a capacitor for a short period. The measurement of capacitance in a living substance is an indicator of cell membrane health. Depending on the health status of the membrane and the number of cells, the capacitance varies and may increase or decrease. Reactance (X) is the opposition of a circuit element to changes in electrical current or voltage caused by the inductance or capacitance of the elements. This is related to cell mass **[4]**.

Also, Resistance (R) is the opposition to the passage of an electrical current through the conductor and is inversely related to water content. A conductor is a tissue that allows electricity to flow easily such as muscle and water where resistance is low and impedance is low. The insulator is a tissue that consists of cells that do not carry an electrical signal, such as fat cells, where resistance is high and impedance is high. Various electrical circuits are used to describe the behavior of biological tissues in vivo. Some involve an arrangement of resistance and capacitance in series, others in parallel, while others are more complex. A circuit that is commonly used to represent biological tissues in vivo is those in which the resistance of the extracellular fluid is arranged in parallel to the second arm of the circuit which consists of the capacitance and resistance of the intracellular fluid in series and thus the resistance. and capacitance can be measured over a frequency rate **[4]**.

Frequency is the number of repetitions per second of a complete electrical waveform. One repetition per second equals 1 Hz. A current with a frequency below 100 Hz does not pass the cell membrane. Therefore, it will only measure extracellular water. Currents above 100 HZ pass through the cell and measure total body water. Thus, the intracellular water can be calculated by the formula: AIC = ACT – AEC where AIC represents intracellular water, ACT the total body water, and AEC the extracellular water **[5]**.

In bioelectrical impedance, it is assumed that electrical conduction is faster through water and parts containing electrolytes than through fat tissue and bone mass. This happens through the resistance exerted by fat deposits along with bone tissue. Single-frequency bioimpedance generally uses a frequency of 50 Hz where current passes between the surface of electrodes placed on the hands and feet. It measures the resistive sum of extracellular water and intracellular water. Allows estimation of fat-free mass and total body water, but does not determine differences in extracellular water **[6]**.

For multifrequency bioimpedance, an empirical linear regression model is used, but it includes impedance at multiple frequencies (0, 1, 5, 50, 100, 200 to 500 kHz) to assess fat-free mass, total body water, water intracellular and extracellular. It is more accurate and less biased in predicting extracellular water in critically ill patients than single frequency bioimpedance. The single frequency bioimpedance is more accurate for measuring total body water **[5,6]**.

In bioimpedance, an alternating current with low and high frequency is introduced into the human body to assess the body's electrical conductivity along with resistance (impedance). Subsequently, capacitance is the parameter that delays the current, falling behind the voltage which results in a phase shift. This change, which is geometrically measured as the angular transformation of the capacitance radius to the resistance, is called the Phase Angle. The Phase Angle represents the relationship between resistance and reactance. The Phase Angle is the determinant of the relative contribution of the fluid (resistance) and the cell membrane (capacitance) of the human body. This is positively correlated with capacitance and negatively correlated with resistance. It also reflects the distribution of water between the intra- and extracellular spaces **[5]**.

A Phase Angle of zero degrees is an indicator of the absence of cell membrane, while a 90-degree angle represents a capacitive circuit representing only membranes with no liquid at all. Cell membranes cause a delay in current passage time compared to the time it passes through extracellular water. Therefore, a high Phase Angle is consistent with high reactance, a large amount of cell membrane residues, and body cell mass is seen in healthy patients, whereas in critically ill patients they tend to have a lower Phase Angle **[6]**. This demonstrates that the Phase Angle is an indicator of cell mass as well as nutritional risk. High Phase Angle scores reflect a property of cell membrane function, whereas a lower Phase Angle is characteristic of both decreased cell-matrix component and cell apoptosis. Inappropriate values of the Phase Angle characterize pathological states where membrane integrity and fluid balance are worsened **[7]**.

Although bioimpedance is a simple, non-invasive, fast, portable, reproducible test and a convenient method to measure body composition and net distribution with little physical demand, it is still unclear whether it is accurate enough for clinical use in critically ill patients. In this sense, the analysis of bioimpedance with multiple frequencies is emphasized as it is less influenced by hyperhydration states **[5]**.

A study carried out by Forni et al. **[8]** in 2015 performed 344 measurements in 61 mechanically ventilated patients. They identified 23% as dehydrated, 36% as normohydrated, and 41% as hyper hydrated upon admission to the ICU. Changes in volumetric status between 1 and 2 liters could not be detected in all patients. Even changes in more than 2 liters with cumulative balances were reflected in the bioimpedance vector assessment only in those hyper hydrated patients where fluid removal was achieved. Interestingly, lactate levels correlated with volumetric status and changes in water balance but not with bioimpedance assessment. This leads to an understanding of the possible limitation of bioimpedance in critically ill patients. The estimation of hydration status is related to fat-free mass, which means muscle mass (in the limbs).

Proteolysis in critical illness results in rapid muscle loss from the earliest days. In critical illness, fluid change can be considerable and rapid, not necessarily isotonic. In this aspect, vector analysis, such as the Phase Angle, may play a greater role in the assessment of these patients. Fluid homeostasis in patients admitted to intensive care units is complex and requires in-depth knowledge of the dynamics of fluid and electrolyte balance. use the therapy restrictive fluid can improve adverse outcomes in patients who are under liberal fluid therapy and consequently have a fluid overload. Bioelectrical impedance has been used to measure tissue resistivity, as well as to determine the volume of extracellular fluid and total body water. By measuring the body's conductivity, Bioimpedance provides data that is directly proportional to water composition.

A study carried out in 2013 by Basso et al. **[9]**, aimed to evaluate the effect of measuring hydration status measured by bioelectrical impedance vector analysis on mortality in critically ill patients. In particular, to investigate the hydration status of patients admitted to the ICU and how this measure varied during hospitalization, following the current practice of water management. The study demonstrated a significant correlation between mortality in the ICU and maximum hydration. Each added percentage point of maximum hydration was associated with a death probability of 2.64%. A similar correlation was found between ICU mortality and average hydration. Where a single point increase in mean hydration corresponded to a 2.9% increase in the probability of death. The author states that the bioimpedance vector analysis can allow the direct assessment of the hydration status of patients admitted to the ICU, with an instantaneous measure, and this could overcome the probability of errors in the fluid balance records. He also states that there would be an additional advantage in which serial measurements could establish an ideal weight target, which would allow guiding the management with dialysis therapy or continuous ultrafiltration.

Another study carried out by Sakaguchi et al. **[10]** in 2015 aimed to develop and validate a method to quantify the degree of fluid accumulation in patients with decompensated heart failure, using multifrequency bioimpedance to support water management. The study involved 130 patients with decompensated heart failure referred to intensive care. The results showed a significant positive correlation observed between extracellular water reduction and body weight loss. In addition, the ratio of measured versus predicted extracellular water at discharge was found to be an independent prognostic factor for patients with decompensated heart failure. The transition from compensated to decompensated heart failure was accompanied by fluid retention. The author concluded by noting that extracellular water measured by multifrequency bioimpedance is a useful quantitative marker for fluid accumulation in patients with decompensated heart failure and the ratio of measured versus predicted extracellular water is an independent prognostic factor at discharge.

In 2016, a study by Samoni et al. **[11]** evaluated the impact of hyperhydration on critically ill patients, comparing their assessments by electrical bioimpedance (vector analysis) to cumulative fluid balance records. The study showed a significant association between mortality in the ICU and severe hyperhydration measured by bioimpedance. The lean body mass hydration scale obtained through bioimpedance vector analysis in predicting the risk of mortality in ICU patients was better than conventional methods of water balance recording. Furthermore, bioimpedance analysis proved to be safe, easy to use, and suitable for use at the bedside. According to Wabel **[12]** in 2009, the absolute amount of extracellular water is not only influenced by the state of hydration, but also by the underlying body composition. Body composition measurements such as intracellular water, fat mass, or bodyweight should also be checked when counted in determining the normohydration target, and bioimpedance could provide such information at the bedside and could be used for clinical management.

In 2015 Jones et al. **[13]** conducted a prospective, clinically blinded, observational study to assess the hydration status of adult patients admitted to intensive care units using bioimpedance vector analysis. This study demonstrated a significant but weak correlation between changes in fluid balance and changes in hydration measured by bioimpedance, as well as no correlation with changes in lactate and no correlation with changes in central venous pressure (CVP). However, it demonstrated an increase in hydration status in patients who had calculated fluid accumulation greater than 1 liter. Furthermore, a statistically significant decrease in hydration was observed after an average fluid loss of 2.4 liters. The author suggests that bioimpedance can add useful information to guide water management in critically ill patients.

This is also corroborated by Piccoli **[3]** in 2010, where he compared the hydration status measured by bioimpedance and central venous pressure (CVP) in 121 patients admitted to the ICU. The combined assessment of tissue hydration through bioimpedance and central filling pressure measured by PVC provides a useful clinical assessment tool in the planning of fluid therapy in ICU patients, especially in those patients with low levels of central venous pressure.

Conclusion

Severely ill patients admitted to intensive care have their water content altered. Quantitative measurement of your hydration status can contribute to better clinical management. Bioelectrical impedance is still under analysis in relation to its real contribution to the water management of patients with this clinical condition. However, there are several arguments in the literature towards its usefulness at the bedside. It is a low-cost tool, easy to move, and easy to use. Probably, Bioelectrical Impedance associated with other clinical methods of water assessment, both semiological and hemodynamic, brings elements that can contribute exponentially to medical decision-making at the bedside. Routine analysis, quantifying hydration through bioelectrical impedance, allows for a better understanding of the fluid balance of critically ill patients admitted to intensive care. It not only directly assists in your clinical management but also has the ability to open up avenues for new studies involving body composition in this particular group of patients.

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Conflict of interest
The authors declare no conflict of interest.

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