Bioelectrical impedance monitoring: Is this a bull market for electric utilities?

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If the Chairman of the United States Federal Reserve were a critical care physician today, he might pose the question, "To buy or not to buy?" That indeed is a question engaging the intensivist as we critique the utility of bioelectrical impedance analysis in the intensive care unit (ICU). The exponential increase in the number of publications on this subject during the past decade has been interpreted by some to represent significant progress in our understanding of body composition measurement. However, other clinicians argue that the technology has not provided any advancement and perhaps has brought about some controversy in the field.

Healthcare facilities have been employing bioelectrical impedance monitoring for the assessment of body composition in weight training programs and nutrition programs for a number of years. Evidence in the literature supporting bioelectrical impedance as a methodology to assess alterations in body composition and water content in healthy subjects has prompted investigations of bioelectrical impedance in patients with a variety of illnesses and conditions, including congestive heart failure, chronic obstructive pulmonary disease, cancer, and postoperative surgical patients.

Critically ill patients manifest extensive alterations in body water and composition because of extensive fluid losses and shifts. Alterations in capillary permeability can profoundly modify the fluid space geometry and contribute to the characteristic increase in ratio of extracellular water to total body water or intracellular water that is observed in the critically ill. The magnitude of the changes in fluid partitioning appears to be proportional to the severity of injury, with the greatest alteration occurring after shock or sepsis. The
consequences of fluid overload with the associated fluid redistribution can adversely affect the patient's clinical outcome, with data suggesting a direct relationship between body weight accumulation and mortality (6).

Changes in body water content are difficult to evaluate in the critically ill because of the lack of simple conventional methods to assess this variable. The predictive value of physical signs for elevated ventricular filling pressure remains inadequate (7). Both central venous pressure catheters and pulmonary artery catheters may provide information about the functional intravascular volume, but both interventions are invasive procedures associated with some morbidity and perhaps mortality. Furthermore, treatment of the critically ill patient by the intensivist is commonly guided toward maintaining systemic hemodynamics, while neglecting the effects of therapy on body water. When one considers the practical limitations of monitoring fluid balance in the individual patient, the potential application of bioelectrical impedance measurements noninvasively is intriguing.

Impedance values from healthy volunteers correlate well with body composition values derived from anthropometry, densitometry, and tritium dilution, but there is less data on the use of this methodology in the critically ill (8). The principle behind this technology is the integral association of impedance or resistance to the flow of an alternating electric current through a biological system and the fluid volume of that system. Measurement of the voltage drop of the applied current yield resistance (R) and reactance (Xc). These vectorial components, Xc and R, make up impedance (Z), the actual variable measured with the instrument. Measurement of whole body R and Xc at 50 kHz can estimate extracellular water and total body water when using any combination of R and Xc and a number of multiple regression relationships (9). If the relationship can be elucidated to determine individual fluid compartments, then bioelectrical impedance can potentially be applied to quantify not only changes in total body water and extracellular water, but, in addition, intravascular and intracellular fluid compartments.

In this issue of Critical Care Medicine, Dr. Piccoli and colleagues (10) propose an approach that might be instrumental in monitoring changes in the extracellular fluid volume of ICU patients. The study evaluates whether fluid balance measurements as determined by central venous pressure monitoring correspond to changes in bioelectrical impedance variables in an ICU population. The authors establish a graphical method for monitoring a patient's fluid balance, using bioelectrical impedance vector analysis (BIVA) methodology
and following a vectorial approach by plotting the two components of the impedance vector, R and Xc. Plotting the components of the impedance vector renders the decision of whether patients are hypervolemic, euvolemic, or hypovolemic. To validate the diagnostic utility of BIVA in an ICU population, the authors determined the accuracy of BIVA by using central venous pressure monitoring as a criterion reference. Changes in the impedance vector were compared to central venous pressure measurements, and the sensitivity of this approach was better in patients with hypervolemia. The investigators are encouraged by the good correlation between BIVA and central venous pressure in hypervolemic patients, and suggestions are made for the practical application of BIVA in the management of fluid status in ICU patients.

Despite the efforts of these investigators, skepticism remains regarding the applicability of impedance technology in the ICU. The poor correlation of measured central venous pressure with impedance measurement of R and Xc in euvolemic and hypovolemic patients raises significant questions concerning the clinical utility of extrapolating bioelectrical impedance methodology arbitrarily to ICU patients who may experience pathophysiologic derangements of fluid status. The relationship between impedance and total body water has been established as a statistical correlation with impedance for a particular population and is not derived from biophysical reasoning. Consequently, prediction equations are relevant only for subjects matching the reference population used in the original derivation of the equation. Potentially, large errors may occur when evaluating patients drawn from a diverse population if the clinician employs correlation equations derived from a different group of subjects.

The disturbed physiology in the ICU may alter the accuracy and clinical utility of this technology, thereby potentially overwhelming the integrity of the model on which impedance measurements are based. Multiple variables may influence the underlying principals of impedance measurements. Alterations of serum electrolytes, hematocrit, and blood flow can result in changes in Z independent of fluid volume (11). During hemodialysis, bioelectrical impedance is effected more by changes in blood composition (hematocrit, protein) then by alterations in fluid volume and may not be sensitive enough to detect volume changes in hemodialysis patients (12). Prediction formulas may not be applicable in critically ill patients with nonuniform fluid distribution among body segments. Tatara and Tsuzaki (13) reported that the human anatomy and electrode location may
influence impedance measurements. The most significant confounding variables are edema of the distal extremities, chronic venous insufficiencies, congestive heart failure, cirrhosis, hypoalbuminemia, shock impacting blood flow to the extremities, hyperthermia, and postoperative hypothermia. Localized fluid accumulations, as in ascites and pleural effusion, will cause underestimation of bioelectrical impedance because of the trunk contributing less than 10% to whole body Z (11).

The potential to measure the distribution and quantity of body water is of immense value to critical care clinicians. It remains to be seen whether the RXc graph approach can be applied to the ICU. Intensivists are fully aware that either central venous pressure and/or BIVA should be interpreted in conjunction with other clinical data and that some variance may be clinically tolerable between central venous pressure monitoring and bioelectrical impedance measurements. However, the basic clinical assumptions underlying these measurements are not yet sufficiently met to render conventionally performed bioelectrical impedance appropriate as a measure of fluid status in critically ill patients. The predictive accuracy and generalized capability of bioelectrical impedance technology in the ICU can only be established by further studies and by different investigators using large heterogeneous populations. Reference norms are needed in humans with and without disease to improve data interpretation. Studies are necessary to establish the correlation between impedance vector displacement over the RXc plane and subtle body fluid variations, i.e., how much alteration in the RXc graph is required to demonstrate changes in the clinical status of an ICU patient as determined by conventional measures. Variables influencing impedance measurements and the need for standardization of testing conditions should to be considered. Precisely what biological variable does bioelectrical impedance measure remains unknown, and its impact on patient outcome will depend on our ability to understand the implications of alteration in reactance and resistance. Because the development of fluid overload may have dire consequences for ICU patients, what we really need to study prospectively is the effect of liberal vs. conservative fluid resuscitation in the perioperative and postoperative period. Although Dr. Piccoli and colleagues (10) do not fully resolve whether BIVA is suitable in critically ill patients, the authors have provided a substantial contribution to the field.

Technology for noninvasive monitoring is improving rapidly, and there remains a recognized need for its deployment in the ICU. Therefore, any new technology that could
provide information of fluid status in a noninvasive, harmless fashion is clearly desirable. During the past decade, we have learned much about the science of technology assessment. On the basis of qualitative analysis, the pulmonary artery catheter is a technology that has been disseminated before its benefit was ever demonstrated. Consequently, systemic evaluation of its advantages has been extremely difficult to pursue. It would be a pity if bioelectrical impedance monitoring was to suffer the same fate.

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