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Review Article

Nursing Section

Importance of Bio-electrical Impedance for Measurement of Body Fluid Status in Chronic Kidney Disease Patients on Maintenance Haemodialysis: A Narrative Review

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ABSTRACT

Assessing the precise body water status in patients with renal disorders is crucial for their health. It has been reported that chronic fluid overload is present even in the early stages of renal insufficiency. If volume overload in a patient with chronic renal failure is not controlled, serious problems such as pulmonary oedema, cardiac remodelling, and diastolic heart failure can develop. Bio-electrical Impedance Analysis (BIA) has emerged as one of the most useful tools, although randomised clinical studies are lacking to support its universal use. Early management of hydration may improve clinical outcomes, as it allows for personalised dialysis prescriptions and nutritional support. BIA practice is utilised as non invasive health monitoring for Body Composition (BC). BIA is a practical and inexpensive method. Moreover, BIA parameters estimated for disease prognosis analysis have been found to be reasonably predictable for both patient status and healthcare. Additionally, BIA is a simple, accurate, portable, quick, easy, and low-cost method. In patients with End-stage Renal Disease (ESRD) undergoing maintenance Haemodialysis (HD) treatment, excessive fluid volume is considered a risk factor for death. Furthermore, fluid elimination to achieve Dry Weight (DW) is a crucial component of HD treatment for ESRD patients. DW is an important concept related to patients undergoing HD. Conventional methods seem to be time-consuming and operator-dependent. BIA is a new and simple method that has been reported to accurately estimate DW. Estimating the dry weight of HD patients is a challenging task. Many tools are available, but not every HD centre has access to them. Several strategies have been used to develop a more standardised method of assessing dry weight in HD patients. The Bio-impedance Spectroscopy (BIS) device has been validated against gold standard methods of volume assessment. Body composition monitoring appears to be a helpful diagnostic tool that reasonably complements existing clinical methods in assessing the DW of HD patients. BIS identifies Fluid Overload (FO) as a virtual "Over Hydration (OH)" compartment, which is calculated from the difference between the measured extracellular volume and the predicted values based on a fixed hydration of lean and adipose tissue mass.

Keywords: Bio-electrical impedance analysis, Chronic renal failure, Dry weight, Fluid overload, Oedema

INTRODUCTION

The BIA method has been used as a non invasive way to measure the constituents of the human body. Commercial medical devices using BIA have become popular due to their convenience and safety. It is possible to measure segmental human body composition of water, muscle, and fat mass, and even cardiac output using BIA. BIA is a method that measures the change in reactance and resistance of the current passing through body fluid with solute to measure body components and their distribution. Multifrequency BIA (MFBIA) can separately measure extracellular and Intracellular Water (ICW). Low-frequency current, which cannot cross the cell membrane, is used to measure Extracellular Water (ECW), and high-frequency current, which can pass through the cell membrane, is used to measure ICW. BIA is also used for total body water (TBW) and ICW/ECW ratio measurement with multifrequency. BIA is a useful tool to estimate adequate ultrafiltration for dialysis patients [1].

Chronic Kidney Disease (CKD) is the gradual and irreversible loss of kidney function. If an adult's Glomerular Filtration Rate (GFR) is 60 mL/min/1.73 m^2 or below, it indicates that at least half of normal kidney function has been lost. CKD is categorised into five stages based on GFR. The first three stages [1-3], ranging from mild to moderate, may require dialysis, while stages [4,5] are considered severe [2]. In renal disease, waste builds up in the body due to kidney damage and inadequate blood filtration. ESRD refers to total and irreversible kidney failure that can only be managed through dialysis or a kidney transplant [2].

The CKD is considered a public health issue, with approximately 50 million people worldwide affected. Certain populations, such as African Americans, American Indians, Hispanics, and South Asians, including individuals from Pakistan, Sri Lanka, Bangladesh, and India, have a higher likelihood of developing CKD. In Pakistan, 75 (25.60%) out of 293 (97%) individuals were found to have CKD. Most CKD patients require replacement therapies such as HD, peritoneal dialysis, or kidney transplantation, with HD being the most common form of treatment [3].

In the US, there are over 661,000 individuals with renal failure, of whom 468,000 are receiving dialysis and 193,000 have received working kidney transplants [4]. In India, 9-13% of HD patients die within a year. Dialysis patients have adjusted all-cause death rates that are 6.3-8.2 times higher than those of the general population [5]. HD is the most common treatment for ESRD, involving the removal of toxins and excess water [6]. Chronic fluid volume overload is a common complication in HD patients and is directly linked to hypertension, increased arterial stiffness, left ventricular hypertrophy, heart failure, and ultimately higher mortality and morbidity [7]. Volume overload is the most frequent cause of hypertension in dialysis patients and may independently contribute to poor cardiovascular outcomes. Increased mortality and hydration status are independently linked in ESRD patients. A total of 90% of individuals undergoing HD successfully maintain their BP without the need for antihypertensive medications by limiting volume overload [8]. In patients receiving dialysis, chronic volume overload is linked to left ventricular hypertrophy and high cardiovascular mortality. Therefore, it is crucial for these individuals to assess their body fluid condition [8].

A significant prognostic factor for these patients is their volume status. Dialysis patients who are OH can develop congestive heart failure, and mortality rates are also increased. On the other hand, patients receiving HD frequently experience volume depletion and hypotension caused by dialysis, which are independent risk factors for death [9]. Dehydration in HD patients is often accompanied by hypotension and unpleasant symptoms such as tinnitus and vertigo. Dehydration can also worsen vascular access thrombosis, dysrhythmias, and cardiac or neurological ischaemic events. Therefore, it is critical to calculate the post dialysis target weight for patients receiving HD [10].

Researchers have concluded that abnormalities in fluid status, particularly extracellular fluid overload, are associated with an increased mortality rate. Although the importance of achieving normovolaemia is not discussed, it appears notoriously difficult to achieve in clinical practice. This is due to the difficulty in removing fluid gain attributed to the intermittency of the treatment and the inappropriate adherence to a strict salt-restricted diet within the limited time allocated for dialysis treatment. Easily applicable technology like BIS may aid in identifying patients with extracellular fluid overload at risk for adverse outcomes, while measurements of absolute blood volume may predict tolerance to dialysis treatment [11].

Accurate assessment of volume status is necessary to regulate volume, but it is a challenging task in dialysis patients. Clinical markers such as BP, pulse rate, and oedema do not accurately indicate volume status. Clinical oedema may not be visible, and some volume may remain in the body. DW is the lowest weight that can be tolerated without developing signs of hypovolaemia, or the weight at which a patient receiving dialysis does not have oedema or hypertension without taking a BP-lowering medication [12]. However, due to the aforementioned issues, nephrologists find it difficult to determine DW. Techniques for calculating DW have been proposed, including those that make use of biological indicators such as levels of atrial or brain natriuretic peptide, the size of the inferior vena cava on ultrasound, and monitoring BV. Unfortunately, estimates of DW produced using these techniques are inaccurate. The following dilution techniques are considered as reference techniques for calculating bodily fluid volumes: deuterium for all bodily fluids TBW, bromide for ECW, and radioactive potassium isotope (40K) for ICW [13].

Although these techniques have the potential to be accurate, they are invasive since blood samples are required, and they are costly because mass spectrometry and the cost of the isotope must be used. Moreover, they cannot be used to measure volume variations over a brief period of time due to the preservation of residual tracer, and they cannot be repeated at short intervals. As a result, BIA, a straightforward, non invasive, and affordable technique, is frequently utilised instead. BIA can be used to quantify TBW, ICW, and ECW. This method is precise and provides accurate estimates of TBW and ECW [14].

Despite significant advancements in dialysis technology, technicians still struggle to maintain haemodynamic stability during haemodialysis. As a result, patients may experience both hypervolaemia and hypovolaemia-related side-effects such as ventricular hypertrophy and pulmonary oedema, as well as hypotension and muscle cramps due to hypovolaemia. Accurate assessment of hydration status and determination of DW play crucial roles in the care of patients receiving HD [14].

Bioimpedance examines the electrical resistance and reactance of human tissue. Measurable tissue characteristics include FO, lean tissue mass that is ordinarily hydrated, and adipose tissue mass that is normally hydrated. Although attempts have been made to measure the volume status and DW of patients receiving dialysis using BIA, the majority of DW examinations are still carried out clinically [15].

In order to calculate resistance values and estimate body water content and composition, BIA uses alternating current to flow across the electrical characteristics of the human body. BIA is classified into single-frequency, multi-frequency, and BIS based on the number of frequencies employed. It is further categorised as whole-body or segmental BIA, depending on whether the entire body is divided into segments. BIA can be used to quantify the contents of ECW, ICW, and TBW. By assessing volume overload using the ratios of ECW to TBW and ECW to body weight, it is possible to calculate DW [16].

Bio-electrical Impedance

Principles: The electrical characteristics of biological tissue form the foundation for BIA. When a weak alternating electric current is introduced into the body, highly conductive bodily tissues conduct electricity. Current travels through cell membranes in two ways: directly through fluid and indirectly. Low-frequency current passes through extracellular fluid but does not pass through cells [17].

Benefits: BIA provides more precise estimates compared to anthropometric approaches and is easy, safe, and non invasive.The practical benefits of bioimpedance measures have led to their rapid growth. The equipment is lightweight and non intrusive [18].

Proper fluid management is crucial for patients receiving HD, and determining their DW is essential for effective treatment [7]. However, accurately assessing DW and the volume that needs to be eliminated during each dialysis session for a specific patient using BIA remains a clinical challenge that has not been fully resolved [15]. Some patients with a normal percentage of ECW relative to total body weight, particularly those close to the lower limit for normal individuals, may experience dehydration following HD due to excessive fluid removal [19]. The problems of excessive and inadequate hydration and intradialytic morbid events highlight the fact that achieving optimal DW correction is not always prompt or accurate [20]. In clinical practice, accurately assessing DW is a significant and challenging issue. The DW is defined as the lowest weight after HD at which the patient would not experience symptoms such as hypotension and oedema, and would not require antihypertensive medication. Maintaining fluid balance reduces the risk of Cardiovascular Disease (CVD) and helps manage blood pressure. Typically, DW is subjectively determined at HD facilities based on the patient's signs and symptoms [21].

Inadequate volume control may be a major factor contributing to low survival rates and high mortality among HD patients. Although bioimpedance measurement has the potential to improve fluid management, the technique has not yet been widely implemented, and many dialysis facilities lack an established fluid management policy [7]. Determining hydration status and achieving a healthy DW in dialysis patients is challenging. Morbidity and mortality, primarily caused by Cardiovascular Disease (CVD), remain unacceptably high, and poor volume control is increasingly recognised as a major contributing factor. Therefore, finding feasible and reliable instruments for determining DW is a priority in research, as there is no gold standard for this purpose [22].

Bioelectrical Impedance Analysis (BIA) and its efficacy: BIA has been described as a body composition assessment technique since the 1970s. It is based on the resistance (R) and reactance (Xc) of the biological environment to alternating electric current. BIA has been applied in various clinical conditions, including liver disease, kidney failure, heart disease, trauma, pre- and postsurgical periods, and starvation. It is particularly valued for its practicality and bedside usability compared to other body composition procedures. BIA is a quick, safe, non invasive, and cost-effective method for assessing body composition and nutritional status in both healthy individuals and patients [23].

Researchers have considered BIA a reliable technique for evaluating DW in HD patients. Underestimating DW can lead to inappropriate prescriptions for ultrafiltration, which may exacerbate HD-related morbidities [24]. Recent randomised controlled trials have shown that when BIS is used to guide DW adjustments, HD patients experience regression in left ventricular mass index, reduced blood pressure, decreased arterial stiffness, and improved survival [25]. The importance of proper fluid volume management in HD patients is well recognised, and various technologies, with BIS being the most well-researched, are now available to assist in fluid status measurement [26].

Observational studies have linked OH to mortality in dialysis patients. Clinically, assessing fluid status is challenging because it can lead to either persistent OH, characterised by significant weight gain between dialysis sessions, hypertension, left ventricular hypertrophy, and peripheral and pulmonary oedema, or hypovolaemia, resulting in intradialytic hypotension and loss of residual renal function. Traditional techniques such as checking for oedema or "probing the DW," which involves removing fluid until hypotension occurs, are increasingly recognised as ineffective. Gold standard techniques like isotope dilution, while more accurate, have proven to be costly, time-consuming, and unsuitable for widespread use in clinical settings. In light of these limitations, bioimpedance has been developed as a non invasive, bedside approach to assist in the clinical evaluation of fluid status and body composition [27].

The BIA is considered a valuable tool for detecting important changes in Body Composition (BC) due to altered hydration, including changes in lean mass, fluid accumulation, and loss. BIA can accurately assess water distribution between the ICW and ECW compartments in patients with CKD. Therefore, BIA holds promise in predicting creatinine performance as a diagnostic tool for CKD [24].

In clinics, postdialysis DW is often assessed through a trial-and-error approach. This conventional method relies on the patient's interdialytic weight gain and clinical symptoms, requiring skilled personnel and subjective judgment. However, this approach is time-consuming, operator-dependent, and may yield inconsistent results [28]. To overcome these limitations, various advanced techniques, including BIA, have been developed to produce more accurate and operator-independent outcomes [29]. BIA is a novel and straightforward technique that utilises low-amplitude alternating electrical current to indirectly assess body composition. While this method has been evaluated in several studies, further research is needed before it can be universally accepted as a reliable method [30].

The accuracy of BIA has been investigated in dialysis patients, and research suggests that it can effectively detect precise volume status. In children undergoing HD, the BIS device, known as Body Composition Monitor (BCM), has demonstrated superior accuracy and agreement in assessing fluid status compared to the InBody S10 device [31]. BIA devices are increasingly being used in clinical settings, including the estimation of DW in dialysis patients. Volume overload is a common occurrence in patients undergoing HD or Peritoneal Dialysis (PD), and BIA devices can aid in diagnosing and reducing volume overload, leading to decreased blood pressure and left ventricular hypertrophy. Additionally, by identifying volume status and adjusting DW in patients with depleted volume, adverse effects can be minimised. The accuracy of measuring OH is of utmost importance [15].

When measuring fluid volume in maintenance HD patients, BIA evaluation of ECW can be a reliable method for calculating DW [32].

The BIA is a preferred method for determining DW in HD patients due to its simplicity and affordability. Different BIA techniques have been discussed to accurately evaluate fluid volume distributions and calculate DW. Multi-frequency BIA (MFBIA) may be better than single-frequency BIA (ICV) in differentiating between Extracellular Volume (ECV) and intracellular volume [15].

The annual mortality rate among chronic HD patients is approximately 18%, with about half of the deaths attributed to cardiovascular causes. Congestive heart failure is a common reason for hospitalisation, with volume excess likely playing a significant role [32].

Assessing fluid status is crucial in dialysis patients, but establishing solid endpoints for euvolaemia is challenging in everyday clinical practice [7]. Chen et al., utilised the ECW% (ECW as a percentage of weight) to calculate DW using whole-body BIA. They considered ECW% >25% in female patients and >28% in male patients as excessive, based on the 100^{th} percentile of healthy individuals.

Patients with high BP had significantly higher ECW% compared to those with normal BP (24.29%±3.56% vs. 21.50%±2.38%). All patients with excessive ECW% had high BP, but not all patients with high BP had excessive ECW%. None of the patients with normal BP had high ECW%. Decreasing DW resulted in a significant drop in ECW% and BP. Among symptomatic normotensive individuals, 75% experienced an increase in DW and a reduction in symptoms [33]. Cardiovascular disease (CVD) is the leading cause of morbidity and mortality in HD patients with ESRD[9].

Indicators such as left ventricular hypertrophy, left ventricular dysfunction, and hypertension are associated with cardiovascular dysfunction in HD patients. Hypertension is a significant contributor to cardiovascular and cerebrovascular morbidity and mortality in the general population. Excessive DW is considered a risk factor that can lead to cardiac dysfunction and, indirectly, sudden death [34].

BIA has been proven to be a practical, non invasive, and cost-effective method for assessing DW. It provides accurate results, is portable, quick, easy to use, and low cost. BIA parameters have shown to be beneficial in predicting disease prognosis and patient healthcare status [24].

Through an extensive review of the literature, several research gaps have been identified:

1. The problems of OH and underhydration, as well as intradialytic morbid events, highlight the challenges in achieving optimal correction of DW accurately and in a timely manner.
2. Many dialysis facilities lack an established fluid management policy, and the implementation of such policies is still limited.
3. Accurately assessing DW in clinical practice remains a significant and challenging issue.
4. Inadequate volume management may be a major contributing factor to the low survival rates and high mortality among HD patients.
5. Research focused on practical and reliable methods for calculating DW is of utmost importance, as there is no absolute standard for this purpose.
6. Achieving appropriate DW and assessing hydration status in dialysis patients is a complex issue.

These research gaps highlight the need for further studies to address the challenges in determining and managing DW in dialysis patients effectively.

CONCLUSION(S)

Bioelectrical impedance is an easy, safe, and non invasive method. The application of the new biofluid impedance technique can be taught to nurses, and an operating manual can be prepared and shared with them. This would enable them to educate other staff members, patients, and their family members, thereby contributing to enhancing and promoting the quality of care. In a home setting, where biofluid impedance devices are predominantly used on a daily basis, patients and caregivers can be trained to use these techniques effectively, improving their skills and reducing the time required for caregiving. Biofluid bioimpedance can be valuable for patients, doctors, nurses, and family caregivers in measuring body fluid volume and preventing complications. Training on handling and operating the device can be an integral part of the practical curriculum for healthcare professionals.

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