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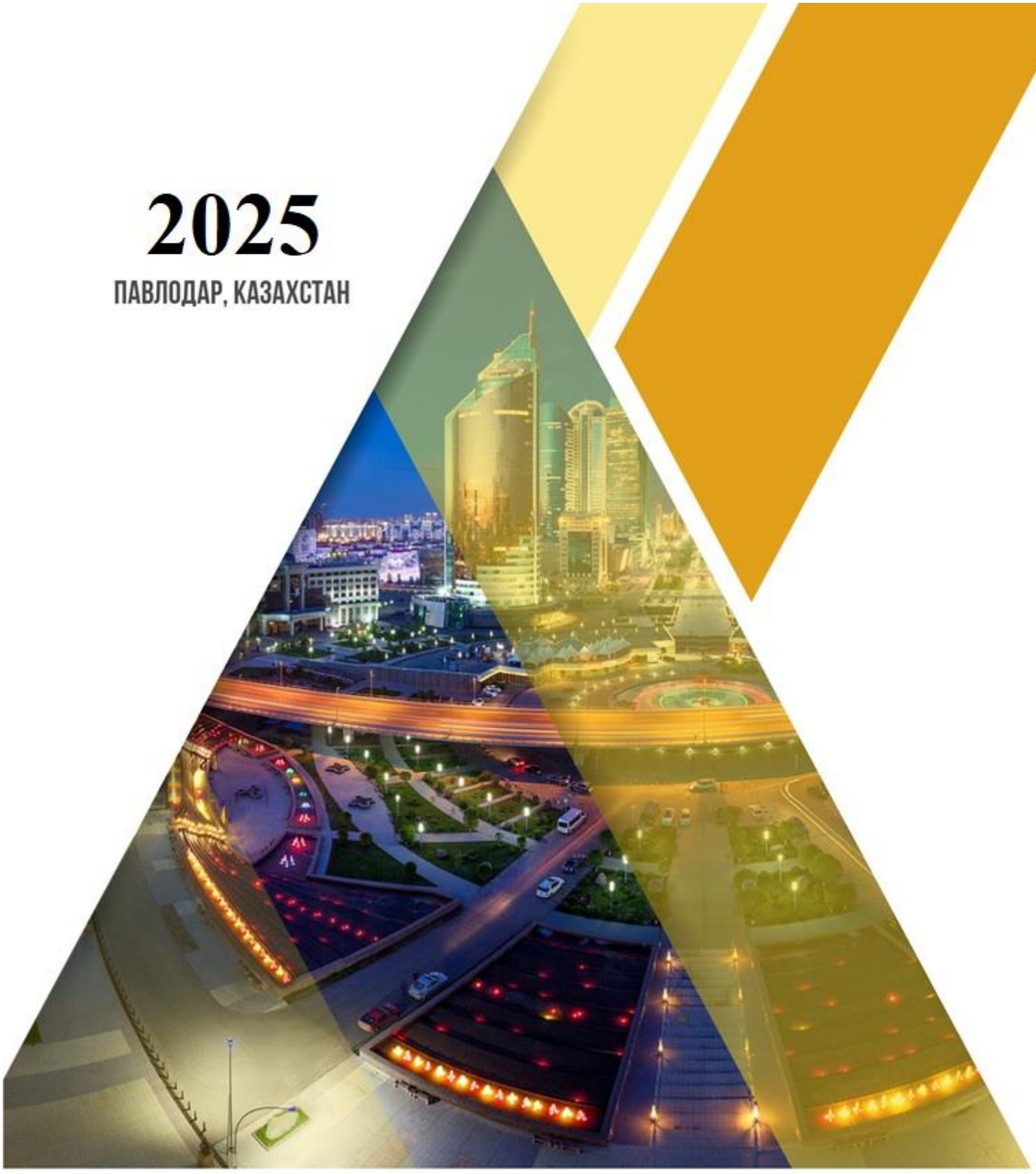

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Application of bioimpedance analysis in patients with chronic kidney disease for fluid management and nutritional status assessment.

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Keywords: Bioimpedance analysis, chronic kidney disease, fluid overload, dry weight, nutritional status, hemodialysis, body composition, bioelectrical impedance vector analysis.

Introduction

Chronic Kidney Disease (CKD), especially its end-stage (ESRD) requiring renal replacement therapy, is associated with significant morbidity and mortality. Two critical and interconnected management challenges in this population are the accurate assessment of hydration status and nutritional status. Fluid overload (FO) is a strong independent predictor of cardiovascular events and all-cause mortality in dialysis patients. Conversely, underestimation of dry weight leads to intradialytic complications. Clinical assessment of dry weight is often imprecise. Malnutrition and protein-energy wasting (PEW) are equally prevalent and detrimental, complicating the clinical picture. Traditional tools like clinical examination, body mass index (BMI), and serum albumin have limitations in differentiating between fat, muscle mass, and fluid compartments. Bioimpedance analysis (BIA) is a non-invasive, reproducible, and relatively inexpensive bedside technique that estimates body composition by measuring the resistance and reactance of the body to a low-level alternating electrical current. It provides quantitative data on total body water (TBW), extracellular water (ECW), intracellular water (ICW), and body cell mass (BCM). This thesis explores the application and utility of various BIA methodologies in the comprehensive management of patients with CKD.

Aim of the Study:

The primary aim of this study is to evaluate the effectiveness of multifrequency bioimpedance spectroscopy (BIS) and bioelectrical impedance vector analysis (BIVA) in guiding dry weight assessment and improving cardiovascular outcomes in hemodialysis patients. A secondary aim is to assess the

role of BIA in diagnosing and monitoring protein-energy wasting (PEW) and sarcopenia in the non-dialysis CKD population.

Materials and Methods:

A prospective, observational cohort study was conducted over 18 months. The study included two groups:

1. Group HD (n=75): Adult patients with ESRD on maintenance thrice-weekly hemodialysis.

2. Group CKD 3-4 (n=75): Patients with stage 3-4 CKD not on dialysis.

All participants underwent a baseline assessment including medical history, physical examination, and laboratory tests (creatinine, eGFR, albumin, prealbumin). Bioimpedance measurements were performed:

For Group HD: Pre- and post-dialysis using a multifrequency BIS device (e.g., Body Composition Monitor, Fresenius). Parameters recorded: Overhydration (OH), ECW/TBW ratio, lean tissue index (LTI), fat tissue index (FTI).

For Group CKD 3-4: In a hydrated, stable state using a single-frequency BIA device for body composition (phase angle, BCM, fat-free mass) and BIVA (plotting resistance/height vs. reactance/height on the R-Xc graph).

In Group HD, the bioimpedance-derived OH value was provided to the treating nephrologist to aid in dry weight prescription, but the final decision was clinical. Patients were followed for the occurrence of predefined endpoints: hospitalization for cardiovascular events (heart failure, arrhythmia) or death. In Group CKD 3-4, BIA parameters were correlated with nutritional markers and handgrip strength. Statistical analysis was performed using SPSS v.26, employing t-tests, correlation analysis (Pearson's), survival analysis (Kaplan-Meier, Cox regression), and multivariate analysis.

Results and Discussion:

In Group HD, baseline BIS revealed significant fluid overload (OH > 2.5L) in 48% of patients, despite being at their clinically assessed dry weight. A strong positive correlation was found between the pre-dialysis ECW/TBW ratio and systolic blood pressure ($r=0.72$, $p<0.01$) and NT-proBNP levels ($r=0.68$, $p<0.01$).

Patients guided by BIS-titrated dry weight (achieving OH between -1.0L to +1.0L) showed a significant reduction in interdialytic weight gain and antihypertensive medication use compared to the control period ($p<0.05$). Kaplan-Meier analysis demonstrated that patients with persistent FO (OH > 2.0L) had significantly lower cardiovascular event-free survival (Log-rank test, $p=0.003$). Cox regression identified high OH as an independent risk factor for events (HR 1.85, CI 1.2-2.9).

In Group CKD 3-4, BIVA revealed that 35% of patients were outside the 75% tolerance ellipse, indicating alterations in hydration and/or cell mass. A low phase angle (< 5°) was present in 25% of patients and showed a strong correlation with low handgrip strength ($r=0.65$, $p<0.01$) and low serum prealbumin levels ($r=0.58$, $p<0.01$), identifying patients with PEW/sarcopenia. Single-frequency BIA estimates of fat-free mass index (FFMI) were more sensitive than BMI in detecting muscle mass depletion.

Discussion: The results confirm that clinical assessment frequently underestimates fluid overload in dialysis patients. BIA provides an objective, quantitative measure that can safely guide ultrafiltration therapy, potentially reducing cardiovascular burden. The correlation between BIA parameters (OH, ECW/TBW) and cardiac biomarkers validates its physiological relevance. In non-dialysis CKD, BIA and particularly BIVA and phase angle, serve as early markers of nutritional risk and sarcopenia, preceding changes in conventional serum markers. The phase angle emerges as a global indicator of cellular health and nutritional status. Limitations include the need for population-specific reference values, the influence of electrolyte shifts, and the fact that BIA estimates rather than directly measures compartments. Nevertheless, as a complementary tool, BIA enhances the precision of fluid and nutritional management in CKD, moving towards a more personalized medicine approach.

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