

The Role of Bioelectrical Impedance in Pediatric Nutritional Assessment

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Abstract Quantifying somatic compartments through bioelectrical impedance analysis (BIA) offers a clinically benign and atraumatic diagnostic alternative for evaluating a patient's physical makep, widely used to determine the nutritional status of children. This article examines the role of BIA in evaluating pediatric nutrition, reviews current research, highlights the significance of the method for early detection of nutritional disorders, and provides recommendations for its application in clinical practice. The use of BIA can facilitate the early identification and correction of nutritional imbalances, thereby improving the overall health of children. Integration of BIA into routine pediatric practice is recommended, taking into account standardized protocols and reference data.

Keywords Children, Nutritional status, Bioimpedance analysis

1. Introduction

Evaluating the nutritional status of children is essential for the early detection and management of nutritional imbalances. Conventional approaches, such as anthropometric measurements, often fail to capture the full complexity of body composition. Bioelectrical impedance analysis (BIA) provides a more accurate assessment by allowing quantification of fat mass, lean mass, and total body water. The method is based on assessing the resistance of body tissues to a low-intensity electrical current. Bioelectrical impedance analysis is safe, non-invasive, and can be readily applied in pediatric clinical practice using specialized devices that provide detailed information on the different components of the body [3,4,6].

BIA is based on the principle that various body tissues, including fat, muscle, bone, and water, exhibit distinct electrical conductivity. By analyzing these variations in electrical conductivity, the relative proportions of body tissues can be determined. In addition to standard anthropometric indicators like stature and mass, vital physiological markers — such as tissue hydration levels and the proportion of muscle to fat — are essential for a comprehensive understanding of a child's physical maturation. Standard anthropometric measurements do not always provide a complete picture. For example, a child may have a normal body weight but an excessive fat percentage and low muscle mass—these are hidden forms of developmental disorders that traditional

methods may fail to detect [5,15].

Diagnosis and Prognosis of Disorders. Clinical Significance and Predictive Potential of BIA. The application of bioelectrical impedance analysis in medical practice offers a sophisticated framework for patient assessment across several key domains:

- Constitutional Profiling: The technology facilitates the precise verification of an individual's somatotype (categorizing patients into asthenic, normosthenic, or hypersthenic types), providing a baseline for understanding their unique physiological makeup.
- Metabolic Risk Stratification: BIA is a critical tool for forecasting a predisposition toward obesity and its associated comorbidities, allowing for early preventative strategies.
- Detection of Nutritional and Developmental Deficits: This modality effectively identifies signs of protein-energy malnutrition, sarcopenia, and stunting of physical maturation, which might be overlooked during routine clinical examinations.
- Longitudinal Monitoring of Interventions: It serves as a reliable instrument for tracking dynamic fluctuations in body composition and growth metrics during both health-promotion programs and intensive therapeutic cycles.
- Multisystemic Pathological Assessment: The method enables the detection of structural abnormalities within chronic disease profiles. This is applicable across a vast clinical spectrum, including cardiology, oncology, and endocrinology, as well as disorders involving the hepatobiliary system, neural tissues, and oral health.

Objective. To examine international approaches to evaluating the nutritional status of children using bioelectrical impedance analysis (BIA).

2. Materials and Methods

A total of 18 publications were analyzed, including systematic reviews, cohort studies, prospective randomized controlled trials (RCTs), and original research focused on evaluating the nutritional status of children using bioelectrical impedance. The authors addressed several questions regarding the role of bioimpedance analysis in assessing nutritional status in children with various chronic diseases. We investigated the utility of bioelectrical impedance as a diagnostic tool for pediatric nutritional status. The study critically evaluated the method's practical reliability, including its limitations, while quantifying the exactness and repeatability of the measurement process.

3. Results and Discussion

The study of electrical conductivity in biological tissues was first reported by W. Thomson in 1880. In the 1920s, the initial instruments for measuring the impedance of cells and tissues were developed. The flow of electrical current is facilitated primarily by hydration-dense tissues like muscle due to their high electrolyte content, whereas the dense structures of bone and adipose layers act as significant insulators with minimal conductive capacity. The electrical properties of tissues are affected by factors such as the concentration and balance of ions, proteins, and electrolytes in body fluids (e.g., blood and lymph), the structural condition of the tissue itself (e.g., muscle contraction or bone density), and the presence of blood or air in organs like the kidneys or lungs. This variability enables bioimpedance analysis to provide quantitative assessments not only of individual tissues but also of entire organ systems under different physiological or pathological conditions [7].

Currently, a variety of techniques are employed to evaluate body composition and the amount and distribution of fat and fat-free mass. Somatic assessment relies on a combination of clinical physical examinations and the systematic gathering of morphometric data—specifically evaluating abdominal girth, subcutaneous fat layers, and body mass ratios—to effectively quantify an individual's physical makeup (such as hydrostatic densitometry, air displacement plethysmography, underwater weighing, and photon scanning), as well as biophysical approaches, such as bioelectrical impedance analysis, infrared reflectance, neutron activation analysis, radioisotope-based techniques, radiological imaging, ultrasonography, and magnetic resonance imaging and spectroscopy. In routine clinical settings, however, methods that are simple, cost-effective, efficient, and safe are generally preferred. Although MRI and CT scans are the established benchmarks for the precise mapping of internal and superficial adipose tissues, their

routine clinical utilization is frequently impeded by logistical complexities and the absence of a compelling necessity. Dual-energy X-ray absorptiometry (DEXA) is an accurate, reference, and effective method with minimal radiation exposure, making it relatively safe for use in children. However, DEXA is costly and labor-intensive. In this context, bioimpedance analysis is a modern, effective, and easy-to-use method suitable for large-scale studies of body composition, allowing measurements as percentages of different body components. Through bioelectrical impedance analysis (BIA), researchers can derive critical metrics such as active cell mass (ACM), lipid content, lean body mass, and total hydration levels, alongside the impedance phase angle (PA). Skeletal structures, visceral organs, and neural networks, along with systemic fluids, comprise the fat-free mass (FFM)—a metric that serves as a structurally consistent reflection of an individual's genetic blueprint. Conversely, the active cell mass (ACM) functions as the body's metabolic engine, encompassing the protein-dense, physiologically dynamic elements of both internal organs and muscle tissue. Active cell mass (ACM) serves as a physiological indicator of a person's metabolic engagement and physical exertion, where reduced levels often signify observed in cases of reduced mobility or hypodynamia. Research also indicates that both insufficient and excessive ACM can be associated with heightened feelings of hunger, particularly among children with overweight or obesity [5,6]. Total body water comprises intracellular (16–22%) and extracellular (30–50%) fluids. Its proportion declines with age: in full-term newborns, total body water accounts for approximately 75% of body weight, decreasing to around 65% by one year of age and remaining relatively stable until the onset of puberty [7].

Gorban V.V. et al. (2016) investigated the preventive potential of bioimpedance analysis (BIA) and heart rate variability in outpatient practice among young adults aged 18–25 years. Early functional changes in body composition and their association with subclinical autonomic imbalance were identified [8,9].

Kozlova L.V. et al. provided an analysis of studies on the application of BIA in Russia and worldwide in epidemiological screening to assess nutritional status. Currently, in Russia, bioimpedance analysis has become a routine method used in Health Centers. The use of simple anthropometric measures and indices provides low diagnostic sensitivity (50% for obesity diagnosis based on body mass index) when assessing nutritional status, leading to a high rate of false-negative results. Median values of body fat percentage measured by BIA in the population aged 5–25 years examined in Health Centers were compared with the results of studies conducted in England, the USA, Turkey, and South Korea [12]. Belkina E.I. and Kuznetsova T.A., together with a mobile Health Center team, examined 319 schoolchildren aged 6–17 years in schools of the Oryol region. The authors concluded that BIA allows for a differentiated assessment of body composition in children, taking into account age- and sex-specific characteristics. Due to the low specificity of body mass index (BMI) indicators, they recommended additionally using fat

and fat-free body component indices derived from BIA when evaluating children's nutritional status [2].

Research performed by Perevalov and Lir utilized bioimpedance technology to evaluate the somatic status of toddlers. By analyzing the body composition of subjects in the 3–4 year age bracket, the investigators successfully delineated distinct developmental and growth trajectories inherent to early childhood [13].

Tissue compartments were quantified through the application of bioelectrical impedance analysis in children and adolescents aged 5–18 years who were in remission from oncological diseases (group 1), those undergoing chemotherapy or in the early post-hematopoietic stem cell transplantation period (group 2), and children with non-neoplastic gastrointestinal diseases (group 3) [11]. A pronounced protein depletion was observed in children of group 2, accompanied by an increased percentage of body fat. Excess fat content was also noted in group 1 children, despite normal fat-free mass. The authors developed new formulas for calculating resting energy expenditure [11]. Additionally, A.Yu. Vashura et al. (2011) reported that in children during the early post-transplantation period (up to day +100), nutritional status is significantly impaired, characterized by a disproportionate increase in adipose tissue relative to depleted lean mass, a condition that demands urgent dietary intervention [16].

In their 2024 study, Setko et al. demonstrated that BIA-derived data—specifically active cell mass and fat/muscle proportions—enables the development of individual-specific nutrition plans. By focusing on these distinct metabolic characteristics, the method offers a more effective way to prevent dietary disorders among the student population compared to generalized approaches [14].

Xiong Z.H., Zheng X.M., Zhang G.Y., Wu M.J., and Qu Y. (2022), in an investigation of the relationships between BIA parameters and clinical outcomes in critically ill children, it was found that the bioelectrical impedance phase angle (PA) serves as an independent predictor of 90-day mortality in this population. Low PA values were associated with prolonged duration of mechanical ventilation in children [18]. It has been reported that PA measured by BIA is a reliable indicator of morbidity and mortality in various diseases. PA reflects the integrity of cell membranes and hydration status and depends on the clinical course of the pathological process. Low PA values indicate cell membrane damage and reduced capacity for energy storage and metabolic activity. A strong correlation has been identified between PA values and nutritional status, particularly in predicting the risk of worsening nutritional and clinical status [18].

Więch P., Sałacińska I., Bączek M., and Bazaliński D. (2024) studied the nutritional status of healthy children aged 7–15 years ($n = 550$) using bioelectrical impedance and anthropometric measurements and found that "...variables such as age and sex significantly influence individual body composition components. This observation highlights the necessity of employing multiple methods to assess the nutritional status of healthy children." They noted that

"...while nearly 50% of the pediatric cohort maintained a caloric surplus leading to elevated body weight, a significant divergence was observed as only one-fifth of these cases involved a genuine expansion of adipose tissue. This contrast underscores the diagnostic inadequacy of the Body Mass Index (BMI); by relying solely on external volumetric measures, it fails to account for essential internal physiological transformations, including the accretion of bone minerals, myofibrillar growth, and cellular proliferation" [17].

A systematic review of the literature published up to June 30, 2020, in MEDLINE, Scopus, EMBASE, and CENTRAL regarding the use of BIA in the pediatric population—specifically in the population of newborns. A systematic review encompassing infants and children under the age of two revealed 15 distinct investigations, which collectively yielded 46 predictive formulas; these models were specifically segmented to distinguish between the physiological profiles of neonates under six months and the developmental stages of those in the 6-to-24-month bracket. Lyons-Reid J. et al. (2021) noted that "...current scientific literature in this domain is frequently undermined by systematic errors and a notable scarcity of data derived from healthy pediatric cohorts. While contemporary evidence suggests that bioelectrical impedance analysis (BIA) achieves a level of estimative precision on par with alternative body composition diagnostics, its clinical superiority over straightforward anthropometric regression formulas appears negligible during the earliest stages of infancy" [10].

Almeida Y.L., Costa Maia C.S., Barros N.E., et al. (2021) established that "...among various methods for assessing and monitoring body composition, BIA demonstrates good accuracy and reliability, as well as characteristics favorable for clinical use: it is portable, practical, inexpensive, and non-invasive." The authors proposed vector analysis of BIA, "...by projecting height-normalized resistance and reactance vectors onto a Cartesian plane, this diagnostic framework produces elliptical tolerance zones that function as a physiological map. This approach facilitates a semi-quantitative appraisal of tissue distribution—specifically delineating the balance between total body hydration and the ratio of adipose to lean mass—thereby clarifying the spatial arrangement of various somatic compartments" [1].

4. Conclusions

The clinical value of bioimpedance technology in pediatric healthcare has been reaffirmed by recent investigative data. For example, a study conducted at the Shanghai Children's Medical Center The findings indicate that BIA enables the assessment of nutritional status in children and adolescents, supporting the detection of subclinical obesity and other body composition abnormalities. Further studies corroborate that BIA is an effective method for the early identification of obesity-related and metabolic risk factors in pediatric populations. The advantages of the method include safety (absence of radiation), speed (results obtained within 1–2 minutes), non-invasiveness and painless application, the

possibility of regular monitoring, high informational value, and suitability for routine use in pediatric practice.

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