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BIOIMPEDANCE ANALYSIS IN OBESITY: CLINICAL UTILITY IN ASSESSMENT, RISK STRATIFICATION, AND THERAPEUTIC MONITORING

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ABSTRACT

Background: Obesity is a complex metabolic disorder associated with an increased risk of cardiovascular disease, type 2 diabetes, and other metabolic complications. Traditional indices, such as body mass index (BMI), do not allow for an accurate assessment of body composition or the distinction between fat and fat-free mass. Bioelectrical impedance analysis (BIA) is a rapid, non-invasive tool for assessing body composition in clinical settings.
Objective: The aim of this study was to evaluate the clinical utility of BIA in the diagnosis and monitoring of obesity, including body composition assessment, identification of obesity phenotypes, diagnosis of sarcopenic obesity, stratification of cardiometabolic risk, and monitoring of the effects of dietary, pharmacological, and surgical treatment.
Materials and Methods: A narrative review was conducted of 47 scientific publications published between 1990 and 2026, most of which were from the last decade. The review included clinical trials, systematic reviews, cohort studies, and mechanistic studies on the application of BIA in obesity. The analysis focused on body composition parameters (FM, FFM, TBW, FMI, FFMI, PhA), the detection of obesity phenotypes, cardiometabolic risk, and treatment monitoring.
Results: BIA allows for the assessment of fat mass, fat-free mass, water content, and derived indices (FMI, FFMI, PhA). These parameters enable a more accurate characterization of obesity phenotypes than BMI. Data from literature reviews show that BIA supports the identification of individuals with elevated cardiometabolic risk, detects sarcopenic obesity, and monitors changes in body composition during therapy.
Conclusions: BIA is a practical, non-invasive tool that aids in the diagnosis and monitoring of obesity treatment. Despite certain methodological limitations, its reproducibility, accessibility, and ability to provide a multidimensional assessment of body composition make it a valuable complement to other clinical methods.

KEYWORDS

Bioimpedance Analysis, Obesity, Body Composition, Sarcopenic Obesity, Cardiometabolic Risk, Phase Angle

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Introduction

In clinical practice, body mass index (BMI) is most commonly used to assess the degree of obesity. Despite its simplicity and widespread use, this index has significant limitations, as it does not allow for the assessment of body composition or the distinction between fat and lean tissue. Consequently, individuals with similar BMIs may differ significantly in terms of fat mass, muscle mass, and cardiometabolic risk [1,4].

Increasing importance is being placed on methods that allow for a more precise assessment of body composition. One of the most commonly used methods in this regard is bioelectrical impedance analysis (BIA). This method is based on measuring the electrical resistance of body tissues, which allows for the estimation of parameters such as fat mass, lean mass, and total body water content [4].

Bioimpedance analysis is widely used in both clinical practice and epidemiological studies, primarily due to its non-invasive nature, relatively low cost, and the ability to obtain results quickly [4]. Studies conducted in large cohorts of obese patients confirm its usefulness in assessing body composition across a wide range of disease severity [1].

However, the accuracy of measurements obtained using the BIA method remains a significant issue. It has been shown that the accuracy of bioimpedance equations can vary depending on the study population and the degree of obesity, a factor that must be taken into account when interpreting the results [2]. Despite these limitations, bioimpedance analysis can serve as a practical alternative to more advanced methods of body composition assessment, such as dual-energy X-ray absorptiometry (DXA), particularly in clinical settings [3].

In recent years, there has also been growing interest in the use of parameters obtained from bioimpedance analysis in the assessment of cardiometabolic risk. In particular, it has been demonstrated that parameters such as body fat content can be helpful in identifying individuals at increased risk of metabolic diseases [5]. Additionally, increasing attention is being paid to the significance of the phase angle as a potential indicator of metabolic status and a prognostic marker in obese patients [6]. A modern advancement of classical bioimpedance analysis is bioimpedance vector analysis (BIVA), which enables a more advanced assessment of hydration status and body composition and is used in clinical practice [7].

2. Methodology

2.1. Study Design and Search Strategy

This study was designed as a structured narrative review of the scientific literature on the use of bioelectrical impedance analysis (BIA) in obesity, with particular focus on body composition assessment, identification of obesity phenotypes, diagnosis of sarcopenic obesity, cardiometabolic risk stratification and monitoring of treatment outcomes. The search strategy covered the following databases: PubMed, Scopus, and Web of Science, using a combination of keywords: bioelectrical impedance analysis, body composition, obesity, sarcopenic obesity, phase angle, vector analysis.

The search period covered publications from 1990 to 2026, including clinical trials, systematic reviews, and observational studies, with particular emphasis on studies published in the last decade. Additionally, the reference lists of selected articles were analyzed to identify additional relevant publications.

2.2. Eligibility Criteria

Inclusion criteria:

- Population: overweight or obese individuals (BMI $\geq$25 kg/m^2)
- Assessment: body composition determined by BIA (SF-BIA, MF-BIA, BIVA, phase angle analysis)
- Outcomes: body composition parameters (FM, FFM, TBW, FMI, FFMI, phase angle), detection of obesity phenotypes, cardiometabolic risk, treatment monitoring (diet, pharmacotherapy, bariatric surgery)
- Study types: original research articles, cohort studies, cross-sectional studies, clinical trials, and selected review articles or meta-analyses considered relevant for contextual interpretation.

Exclusion criteria:

- review articles without original data
- Studies focusing exclusively on laboratory technologies not available in clinical settings
- Publications not presenting BIA results related to obesity or body composition
- Conference abstracts, case reports, and articles without primary data

2.3. Data Extraction and Synthesis

Data were extracted using a standardized form, including:

- Authors, year of publication, country of study
- Study type, sample size
- Type of BIA device and measurement frequency (SF-BIA, MF-BIA, BIVA)
- Body composition parameters: FM, FFM, TBW, FMI, FFMI, phase angle
- Type of intervention: diet, pharmacotherapy (including GLP-1 RA), bariatric surgery

Study results and limitations

The collected data were subjected to a narrative synthesis, focusing on the clinical utility of BIA in the assessment of obesity, stratification of cardiometabolic risk, identification of sarcopenic obesity, and monitoring of changes in body composition during treatment.

2.4. Analytical Approach

Due to the heterogeneity of the available studies, including clinical trials, case reports, and review articles, no formal meta-analysis was conducted. Instead, a narrative synthesis approach was used to integrate and interpret the available evidence. Ultimately, 47 publications were included in the qualitative analysis.

3. Results

3.1 Assessment of Body Composition

Body composition using bioimpedance is assessed by measuring the electrical resistance (impedance) of body tissues to the flow of low-intensity current at a safe frequency. Electrodes are typically placed on the extremities (e.g., wrist and ankle), and the device measures resistance and reactance, which depend on the water and electrolyte content in the tissues. Based on these measurements, using appropriate predictive equations, total body water (TBW), fat-free mass (FFM), and fat mass (FM) [8][9][10]. This method is based on the assumption that non-fat tissues are well-hydrated and conduct electricity, while adipose tissue and bones are poor conductors. In clinical practice, both single-frequency (SF-BIA) and multi-frequency (MF-BIA) devices are used, which additionally allow for the assessment of intracellular and extracellular water distribution as well as segmental body composition analysis [9][11].

According to the American Heart Association, bioimpedance is a non-invasive, rapid, and relatively inexpensive method, but its accuracy depends on many factors, such as age, sex, hydration status, race, medical condition, and the predictive equations used. The results are most reliable when clinically validated devices and population-matched equations are used [9][11].

3.2 Comparison of SF-BIA and MF-BIA

Single-frequency bioelectrical impedance analysis (SF BIA) uses a single frequency (most commonly 50 kHz) and allows for the estimation of total body water (TBW) and fat-free mass (FFM), but does not distinguish between intracellular water (ICW) and extracellular water (ECW). SF BIA is simple, inexpensive, and widely available, but its accuracy is limited in populations with fluid imbalances, obesity, chronic diseases, and in individuals with atypical body builds. SF BIA results are highly dependent on the predictive equations used and do not always align with reference methods, especially in clinical populations [11,41,42].

Multi-frequency bioelectrical impedance analysis (MF BIA) uses several currents at different frequencies, allowing for separate estimation of ICW and ECW and a more precise assessment of fluid distribution and cellular mass. MF BIA shows higher agreement with reference methods, particularly in populations with obesity, heart failure, fluid and electrolyte imbalances, and in older adults. MF BIA also enables segmental body composition analysis and is preferred in clinical settings, especially when access to raw data (impedance, resistance, reactance, phase angle) is available[11,41].

In clinical practice, MF BIA provides greater accuracy and broader diagnostic capabilities than SF BIA, particularly in populations with fluid imbalances or extreme BMI values. However, both types of devices require standardized procedures and the use of validated predictive equations, and results should not be used interchangeably between different devices [11,41,42,43].

3.3 BIA vs. DXA

Compared to dual-energy X-ray absorptiometry (DXA), considered the gold standard, BIA shows good agreement in populations with moderate obesity; however, in individuals with high BMI, there may be overestimation or underestimation of fat mass and appendicular skeletal muscle mass{skeletal muscle mass in the limbs} [3,2,1]. The advantages of BIA include the ability to monitor patients frequently, low cost, and the absence of ionizing radiation, making it a practical tool in both clinical and population-based studies [4,27]. BIA vector analysis (BIVA) and the phase angle (PhA) parameter additionally allow for the assessment of muscle quality and hydration status, which is particularly useful in the diagnosis of sarcopenia and sarcopenic obesity—areas where DXA does not provide information on muscle cellular properties [20,6,7]. Despite certain limitations, BIA is a valuable tool complementary to DXA, particularly in monitoring changes in body composition in obesity and following therapeutic interventions, such as bariatric surgery or pharmacological treatment [30,32,28].

3.4 Clinical Applications of BIA

Bioelectrical impedance analysis (BIA) is widely used in medicine to assess hydration status, body composition, and metabolic risk, with particular emphasis on nephrology, cardiology, oncology, intensive care, geriatrics, and sports medicine [10,44]. In nephrology, BIA allows for monitoring hydration in patients with chronic kidney disease and during dialysis, and a lower phase angle is associated with increased mortality and heart failure [44]. In cardiology and heart failure, BIA/BIVA enables the differentiation of causes of dyspnea, assessment of fluid overload, and monitoring of decongestion; shorter vectors indicate fluid overload, while longer ones indicate dehydration [7,45]. In intensive care, BIA aids in assessing hydration status and rapid muscle wasting, particularly when traditional methods fail due to fluid disturbances [46]. In oncology patients, BIA is used to detect sarcopenia and cachexia and to predict survival; the phase angle is an independent predictor of mortality and postoperative complications [40,45]. In geriatrics, BIA enables the detection of sarcopenia and malnutrition, and bibliometric studies indicate that "sarcopenia" and "phase angle" are currently significant areas of research [14,15,47]. In obesity and sports medicine, the method enables the assessment of body composition, visceral fat, and hydration status, serving as a convenient tool for monitoring changes in patients and athletes [44][47].

3.5 Diagnosis of sarcopenic obesity:

Sarcopenic obesity is a complex phenotype of body composition disorders characterized by the simultaneous presence of excess body fat and reduced muscle mass and function. According to the current expert consensus of the European Society for Clinical Nutrition and Metabolism (ESPEN) and the European Association for the Study of Obesity (EASO), its diagnosis requires a comprehensive assessment of both the adipose and muscle components of the body, which goes beyond the capabilities of traditional anthropometric indices [12]. In this context, bioelectrical impedance analysis (BIA) plays a significant role as an accessible, non-invasive, and widely applicable diagnostic tool that enables the simultaneous assessment of both components [12,18].

The importance of BIA in the diagnosis of sarcopenic obesity stems from its ability to identify body composition abnormalities that remain undetected using classical assessment methods [12]. Parameters obtained using this method, such as muscle mass and its reference indices, allow for the detection of reduced muscle mass even in individuals with high body weight, which is crucial for early diagnosis [18]. At the same time, it has been demonstrated that the prevalence of sarcopenic obesity and its association with metabolic disorders, such as insulin resistance, are significantly dependent on the diagnostic methods used [13,21].

Particular diagnostic value in bioimpedance analysis is attributed to the phase angle, which reflects the integrity of cell membranes and the metabolic state of tissues [14]. Numerous studies indicate that reduced values of this parameter are associated with an increased risk of sarcopenia and sarcopenic obesity [14,16], and its diagnostic utility has been confirmed in systematic reviews and meta-analyses [15]. An extension of classical bioimpedance analysis is vector analysis (BIVA), which enables a more advanced assessment of hydration status and tissue structure, as well as the identification of characteristic bioelectrical patterns in patients with sarcopenic obesity [19,20]. Recent data indicate that the use of BIVA may further increase diagnostic sensitivity in this patient group [17].

3.6 Risk stratification in obesity

Bioelectrical impedance analysis (BIA) plays an increasingly important role in health risk stratification among overweight and obese individuals, enabling a more precise assessment of body composition than traditional anthropometric indices. Unlike body mass index (BMI), BIA allows for differentiation between the body's fat and fat-free components, which is crucial for identifying individuals at increased cardiometabolic risk [4,26]. Population-based studies have shown that parameters obtained using the BIA method can effectively identify individuals with excessive body fat and increased metabolic risk, even within the same BMI category [5].

Particular importance in risk stratification is attributed to qualitative parameters, such as the phase angle, which reflects the integrity of cell membranes and the functional state of tissues. It has been demonstrated that phase angle values differ significantly between groups with varying degrees of obesity, which may indicate its potential utility in assessing health risk and the severity of metabolic disorders [22]. Additionally, bioimpedance vector analysis (BIVA) enables the identification of characteristic bioelectrical patterns associated with different BMI categories as well as hydration status and tissue distribution, which has been confirmed in both adult and pediatric populations [23,24].

The application of BIA in large cohorts of obese patients has demonstrated its usefulness in differentiating obesity phenotypes and identifying patients at increased risk of complications, although limitations arising from the accuracy of the predictive equations used in this method must be taken into account [1,2]. Despite these limitations, BIA remains a particularly useful tool in epidemiological studies and clinical practice, where it enables not only the assessment of body composition but also risk stratification in large populations [4,27]. In recent years, advances in analytical methods, including the use of machine learning algorithms based on BIA data, have further enhanced the ability to precisely classify the degree of obesity and assess health risks, pointing to the growing potential of this method in personalized medicine [25].

3.7 Limitations of BIA in Risk Stratification

Despite the growing importance of bioelectrical impedance analysis (BIA) in risk stratification among individuals with obesity, this method has significant limitations that must be considered when interpreting results. One of the key issues is that measurement accuracy depends on the predictive equations used, whose validity may vary depending on the study population, including the degree of obesity, age, and sex [2]. In particular, it has been shown that in the obese population, errors in body composition estimation may be greater, which limits the precision of risk assessment at the individual level [2].

An additional limitation is the influence of hydration status on measurement results, which can lead to misinterpretation of body composition parameters, especially in cross-sectional studies and in clinical settings where controlling this factor is difficult [4,27]. This variability is particularly significant in the context of advanced analyses, such as BIVA, where the interpretation of bioimpedance vectors is directly related to the distribution of body fluids [23,24].

Limitations also apply to qualitative parameters, such as the phase angle, whose values may be modified by factors not directly related to body composition, including age, inflammation, or physical activity levels, which may affect its usefulness in unambiguous risk stratification [22]. Furthermore, although BIA enables the assessment of body composition at the population level, its use in precise individual diagnostics requires caution and consideration of the clinical context [4]. Despite the rapid development of analytical methods, including the use of machine learning algorithms, their application in clinical practice remains limited due to the need for validation across different populations and the lack of standardization of analytical procedures [25]. Therefore, despite the high utility of BIA in risk stratification at the population level, its interpretation should always be performed with consideration of methodological limitations and in conjunction with other diagnostic tools [4,27].

3.8 Monitoring obesity treatment using bioelectrical impedance analysis as an innovative clinical tool

Unlike classic anthropometric indices, such as body mass index (BMI), BIA allows for a multidimensional assessment of body composition, including fat mass, lean mass, and total body water content. This makes the method particularly useful in modern, technology-based models of care for patients with obesity [31,37].

Dietary Therapy

In dietary treatment, BIA enables the monitoring of qualitative changes in body composition, including the distinction between fat loss and lean mass loss. This is crucial for optimizing nutritional interventions and reducing the risk of adverse metabolic effects. Studies indicate that BIA can be effectively used to track changes in body composition during weight loss, although its accuracy depends on the degree of obesity and the predictive equations used [29,31]. From a technological perspective, this method is applicable in both clinical practice and remote patient monitoring systems.

Pharmacotherapy

In the context of pharmacological treatment of obesity, particularly with the use of GLP-1 receptor agonists, BIA enables the assessment of the nature of weight loss through the analysis of changes in fat and fat-free tissue components. Available data indicate that semaglutide-based therapies lead to significant weight loss, accompanied by measurable changes in body composition that can be captured using bioimpedance methods [28,32,33]. According to current clinical guidelines, assessing the quality of weight loss is a key component of monitoring the efficacy of pharmacological treatment, which justifies the inclusion of BIA in routine clinical practice [34].

Bariatric Surgery

BIA is also widely used in monitoring patients who have undergone bariatric surgery, where dynamic and complex changes in body composition occur. This method allows for the assessment of fat loss, changes in lean body mass, and shifts in body water distribution, which are of significant importance for the course of postoperative treatment. Studies confirm the usefulness of BIA in assessing changes in body fat percentage and hydration following bariatric procedures [28,30,35,36], although interpretation of results requires caution in the early postoperative period due to fluctuations in hydration status. From an innovative perspective, BIA can support the development of personalized care models and digital monitoring systems for patients following surgical procedures.

Advanced parameters and data interpretation

The phase angle and vector impedance analysis (BIVA) reflect cellular integrity, hydration status, and the body's overall metabolic status. These parameters are gaining increasing importance as potential biomarkers in assessing prognosis and personalizing obesity therapy [6,39,40]. Their integration with clinical data is a key element in the development of precision medicine.

Limitations and technological aspects

Despite its numerous advantages, the use of BIA is associated with limitations arising from the influence of hydration status, body composition, and the selection of predictive equations on the accuracy of measurements. These factors may particularly affect the reliability of results in patients with severe obesity and during periods of rapid physiological changes [31,37].

BIA should be considered a complementary tool rather than an alternative to reference methods such as DXA. At the same time, the development of new technologies, including advanced analytical algorithms and wearable devices, may in the future increase the precision and scope of application of this method in clinical practice [38].

4. Discussion

4.1. Implications for Clinical Practice

Bioelectrical impedance analysis (BIA) is becoming an increasingly useful tool for assessing body composition in overweight and obese patients. Unlike body mass index (BMI), which is merely a simplified anthropometric indicator and does not provide information on the proportions of individual body components, BIA allows for a distinction between fat mass and fat-free mass. This enables a more precise characterization of obesity phenotypes, which is of significant clinical importance. Individuals with similar BMI values may, in fact, differ significantly in terms of body fat content, muscle mass, hydration, and cardiometabolic risk. In clinical practice, this means that body weight or BMI alone do not always reflect a patient's actual metabolic status. Derived parameters obtained using the BIA method, such as body fat percentage, fat mass index (FMI), fat-free mass index (FFMI), total body water, and phase angle, are of particular clinical value. These indicators can provide additional information regarding nutritional status, tissue quality, muscle mass, and potential metabolic risk. The use of BIA therefore allows not only for a quantitative assessment of body composition but also for a more functional interpretation of the patient's condition. This is particularly significant in the modern approach to obesity treatment, where the goal of therapy is not solely weight reduction but also improving body composition quality, preserving muscle mass, and reducing metabolic and cardiovascular risk.

Bioimpedance analysis also appears particularly useful in identifying sarcopenic obesity, a phenotype characterized by the coexistence of excess adipose tissue and reduced muscle mass and/or function. This condition is associated with an increased risk of disability, insulin resistance, functional impairments, metabolic complications, and a poorer clinical prognosis. Traditional anthropometric indices do not allow for reliable detection of this condition; therefore, BIA can serve as a valuable, easily accessible, and scalable tool to aid in the early identification of patients requiring more individualized dietary, exercise, and therapeutic management.

Another significant advantage of BIA is the ability to monitor changes in body composition over time, which is particularly important during obesity treatment. Weight loss does not always indicate a beneficial therapeutic effect if it is accompanied by excessive loss of lean body mass or adverse changes in hydration. BIA allows for distinguishing whether weight loss is primarily due to a reduction in body fat or to the loss of muscle and other lean body components. As a result, this method can support more informed clinical decision-making and the optimization of therapeutic interventions.

4.2. Prognostic Potential and Significance in Personalized Medicine

Beyond its diagnostic applications, bioimpedance analysis may also have prognostic significance in the treatment of obesity and its complications. Of particular interest are raw and qualitative bioelectrical parameters, such as the phase angle and bioimpedance vector analysis (BIVA), which may reflect the integrity of cell membranes, tissue quality, nutritional status, and the body's overall physiological reserve. Unlike simple quantitative indices, these parameters can provide information not only about body composition itself but also about the patient's functional and metabolic status. Available data suggest that changes in BIA parameters during dietary or pharmacological treatment or following bariatric surgery may correlate with improved insulin sensitivity, reduced inflammation, enhanced functional capacity, and a lower cardiovascular risk. This is particularly significant in the era of modern obesity therapies, such as GLP-1 receptor agonists, incretin therapies, and bariatric treatment, where increasing emphasis is placed not only on the extent of weight loss but also on its quality. In this context, BIA can serve as a tool to support a more precise assessment of treatment response.

In the future, the clinical potential of BIA may be further enhanced through integration with modern digital technologies, such as wearable devices, mobile apps, and telemedicine systems. Combining BIA data with clinical data, physical activity, metabolic parameters, and machine learning algorithms may in the future enable the creation of more personalized risk models and treatment response models. Although these applications are currently largely in the development stage, they point to the growing role of BIA in the field of precision medicine.

4.3. Limitations of the Current Evidence

Bioimpedance analysis has significant limitations that must be considered when interpreting results. The accuracy of measurements depends on numerous biological and technical factors, such as hydration status, food and fluid intake, level of physical activity, age, sex, comorbidities, and the type of predictive equations used. These factors can significantly affect the reliability of results, particularly in individuals with severe obesity or water-electrolyte imbalances. Another limitation is the lack of full agreement between BIA results and reference methods, such as dual-energy X-ray absorptiometry (DXA). Different BIA devices may generate results that are not fully comparable, due to differences in measurement frequencies, electrode placement, algorithms used, and whether total or segmental analysis is performed. For this reason, BIA should not be considered a direct substitute for reference methods in every clinical situation, especially when very high measurement precision is required. Available studies exhibit significant heterogeneity in terms of study populations, device types, cutoff points used, and defined endpoints. This limits the ability to directly compare results and hinders the full standardization of BIA use in clinical practice. Therefore, the interpretation of results should always take into account the broader clinical context and, if possible, be combined with anthropometric, biochemical, and functional assessments.

4.4. Directions for Future Research

Future research should focus primarily on standardizing measurement procedures and developing more precise, population-specific predictive equations for individuals with obesity. It is also necessary to further define clinically useful cutoff values for parameters such as phase angle, FMI, FFMI, and indices derived from BIVA analysis across different obesity phenotypes and therapeutic contexts. An important direction for further research remains the evaluation of BIA's utility in monitoring modern obesity therapies, including treatment with GLP-1 receptor agonists, dual-component therapies, and emerging methods of bariatric surgery. Longitudinal studies are particularly needed to determine whether changes in body composition parameters obtained via BIA actually translate into long-term metabolic, cardiovascular, and functional benefits.

The integration of BIA with digital technologies and AI-supported systems remains a promising area. Such an approach could, in the future, improve the capabilities of remote patient monitoring, facilitate the personalization of therapy, and increase the effectiveness of care for patients with obesity. If these solutions are properly validated, BIA may gain even greater significance as a practical tool supporting daily clinical care.

Conclusions

Bioelectrical impedance analysis is a practical and clinically useful tool for assessing body composition in patients with obesity. Compared to BMI alone, it allows for a more detailed assessment of body fat percentage, lean body mass, hydration, and derived parameters relevant to metabolic health.

Parameters obtained from BIA, such as body fat percentage, fat mass index, fat-free mass index, and phase angle, can aid in the identification of obesity phenotypes, the stratification of cardiometabolic risk, and the diagnosis of sarcopenic obesity. This method is also used to monitor changes in body composition during dietary, pharmacological, and surgical treatment, enabling a more comprehensive assessment of response to therapy.

Despite certain methodological limitations and a lack of full agreement with reference methods such as DXA, bioimpedance analysis remains a valuable complementary tool in modern care for patients with obesity. Its accessibility, reproducibility, and ability to provide a multidimensional assessment of body composition make it particularly useful both in daily clinical practice and in monitoring the long-term effects of treatment.

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