

## Bioimpedance Analysis as a Leading Method in Diagnosis and Evaluation of the Effectiveness of Treatment of Metabolic Syndrome

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### ABSTRACT

The article discusses the issues of diagnostics and evaluation of the effectiveness of treatment of metabolic syndrome using the method of bioimpedance analysis of body composition. The bioimpedance analyzer ABC-02 "MEDASS" was used, which allows for a comprehensive assessment of body composition: indicators of lipid, protein and water metabolism, i.e. metabolic processes, muscle, fat body mass, etc. The study involved 100 patients of fertile age with metabolic syndrome. To assess the effectiveness of the bioimpedance analysis method, a correlation analysis of the following indicators was carried out: body mass index with fat mass, with muscle mass, BMI with extracellular fluid, BMI with metabolic rate and muscle tissue fitness.

**KEYWORDS:** metabolic syndrome, insulin resistance, obesity, bioimpedance analysis of body composition, fat mass, muscle mass, extracellular fluid.

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### INTRODUCTION

Metabolic syndrome is a broad clinical condition that significantly increases risk factors for type 2 diabetes, cardiovascular diseases, and systemic metabolic complications. It is commonly identified through the coexistence of obesity, insulin resistance, hypertension, and dyslipidemia. In parallel with changing lifestyle factors and global demographic shifts, the prevalence of MS continues to rise, posing major challenges to healthcare systems worldwide. The diagnostic criteria for MS vary among international organizations; however, all share common elements like waist circumference, fasting glucose, blood pressure, and lipid profile.

Metabolic syndrome is a pathological condition that includes obesity, elevated insulin and blood glucose levels, arterial hypertension and dyslipidemia and is a global problem of our time [1]. The frequency of MS in the population is 20–40%. This symptom complex is more common in middle-aged and older people and reaches 30–40%. The presence of MS increases the risk of developing type 2 diabetes and hypertension by 3–6 times. "The prevalence of metabolic syndrome (MS) has a global tendency to increase and depends on many factors, which explains the complexity of diagnostics and approaches to prevention and therapy of this pathology. Chronological age, lifestyle, socioeconomic status, insulin resistance (IR), dyslipidemia, obesity and genetic predisposition are factors influencing the risk of development and progression of MS". The characteristics of the distribution of adipose tissue and its dysfunction are important factors in the development of insulin resistance with obesity, as well as the risk of developing cardiometabolic diseases and MS. [2]. Understanding these mechanisms is associated with advances in metabolic phenotyping. Metabolic phenotyping of obese individuals is important in relation to studying the pathophysiology of metabolic disorders, possible comorbidities, and the search for innovative strategies for the prevention and treatment of MS.

The steady growth of obesity and insulin resistance determines the need to find modern, comprehensive approaches to its diagnosis and therapy. When diagnosing obesity and choosing methods for its correction, it is fundamentally important to use reliable methods for assessing the amount of fat and muscle tissue.

Despite its broad utility, body mass index (BMI) alone has clear limitations for diagnosing and characterizing MS. Although BMI can classify individuals as overweight or obese, it does not differentiate between subcutaneous fat, visceral fat, or muscle mass. Consequently, numerous individuals may receive incomplete or even misleading assessments of their metabolic risk. The need for a more precise tool in the clinical environment underlines the relevance of bioimpedance analysis.

Using the Quetelet index is not always sufficient, since it does not provide complete information on the quantitative content of fat and muscle mass of the human body<sup>7</sup>. The use of BMI in the diagnosis of obesity and other trophic status disorders has low diagnostic sensitivity - about 50%. [3]. For these purposes, bioimpedance analysis is used in clinical medicine, allowing for an assessment of indicators that characterize the basal metabolism, active cellular mass, fat and muscle mass, as well as the total water content in the body. Bioimpedance analysis (BIA) is a diagnostic method that can be used to determine the percentage of muscle tissue, fat, water, and some other parameters of the human body. The principle of the study is to measure the resistance of various environments using a weak electric current. For example, muscle resistance is 5 times less than that of fat and 50 times less than that of bone tissue. The method is absolutely harmless to the body. Bioimpedance analysis (BIA) uses principles of electrical resistance to measure the proportion of different tissues within the body. Tissues with high water content, such as muscle, conduct electricity more readily than tissues with lower water content, such as adipose tissue. This method facilitates accurate evaluations of fat and muscle mass, total body water content, and segmental distribution of fluids. BIA also calculates phase angle, a parameter increasingly recognized as a marker of cellular health, nutritional status, and metabolic fitness.

Bioimpedance analysis is a simple and, at the same time, very informative diagnostic method. After conducting the study, the device automatically calculates the following indicators:

The value of the basal metabolism is the minimum amount of energy that is necessary to maintain the most important functions of the body in a state of relative rest.

The value of the phase angle is an indicator that characterizes the general condition of the body, its endurance, performance, and metabolic features. The phase angle is often used to determine biological age.

The percentage of adipose tissue, muscle tissue, water, and active cellular mass. These indicators characterize the features of protein or fat metabolism, correlate with motor activity, and indicate physical development.

**In clinical practice, BIA has distinct advantages:**

**Non-Invasiveness:** BIA does not require invasive procedures, blood draws, or the use of ionizing radiation.

**Ease and Speed:** Measurements are quick, typically completed within minutes, and can be repeated over time for follow-up.

**Detailed Insights:** Parameters like basal metabolic rate, fat-free mass, total body water, and phase angle equip the clinician with critical data to guide personalized therapy.

**Broad Applicability:** From weight management programs to sports medicine and geriatrics, BIA is relevant for individuals seeking to optimize health and performance.

Recent research extends the application of BIA in various domains related to metabolic syndrome:

**Cardiovascular Risk:** Several studies have found strong associations between increased body fat mass identified via BIA and elevated cardiovascular risk indicators, including high blood pressure, dyslipidemia, and endothelial dysfunction.

**Endocrine Disorders:** Patients with endocrine imbalances such as hypothyroidism or polycystic ovary syndrome (PCOS) have demonstrated distinct bioimpedance profiles, revealing that changes in body composition often precede notable shifts in weight or BMI.

**Geriatric Population:** In older adults, BIA has proven to be an indispensable tool for diagnosing sarcopenic obesity—where increased fat mass and diminished muscle mass coincide—an essential predictor of frailty and future morbidity.

**Pediatric Relevance:** With rising childhood obesity rates, BIA can help pediatric endocrinologists identify early adiposity patterns that may later evolve into full-blown MS.

**OBJECTIVE OF THE STUDY**

To assess changes in body composition (percentage of fat mass, muscle mass, water and other body components) in women with metabolic syndrome, which helps to track the dynamics of metabolic disorders, as well as an effective approach to treatment and diagnosis.

To determine the patient's metabolic rate, hormonal status, identify metabolic diseases and establish other individual characteristics, on the basis of which an optimal weight loss program will be developed

## MATERIALS AND METHODS

The study involved 100 female patients with metabolic syndrome, who constituted the main group (n = 100). The control group also consisted of females (n = 55). Observation began from the moment of contacting a nutritionist. The average age of the sample was 28±6.5 years. In the main group, patients were divided into age categories of 18-25 years, 26-40 years, 40-45 years. The diagnosis was verified by general clinical, laboratory and instrumental research methods. Body measurement diagnostics in the main and control groups was carried out using the anthropometric method and the method of bioimpedance analysis of body composition. To assess the effectiveness of the BI method, a correlation analysis of the following indicators was carried out: body mass index with fat mass, with muscle mass, with extracellular fluid (an indicator of swelling in bioimpedance), as well as with the phase angle, which is an indicator of the metabolic rate, namely the level of muscle tissue training.

**Anthropometric and Clinical Assessments.** Standard measurements—weight, height, and waist and hip circumferences—were recorded. BMI was calculated as weight (kg) / (height). Blood pressure was measured in a resting state, and fasting blood samples were collected for serum glucose and lipid analysis. Anthropometric data alone provided a baseline but insufficient context to fully elucidate body composition.

**Bioimpedance Protocol.** Bioimpedance analysis was performed using the ABC-02 "MEDASS" analyzer. Key parameters included:

Fat Mass (FM) in kg and%;

Muscle Mass (MM) in kg and%;

Total Body Water (TBW) in liters;

Extracellular Fluid (ECF) as an indicator of edema;

Basal Metabolic Rate (BMR) in kcal/day.

Phase Angle as an indicator of cell membrane integrity and metabolic rate.

Patients were instructed to avoid eating, drinking, or intense exercise for four hours prior to measurement. Electrodes were placed on the hand, foot, or other standard positions as per manufacturer guidelines.

## RESULTS

In the main group, patients were divided into age categories: 18-25 years, 26-40 years, 40-45 years.

**TABLE I. AGE DISTRIBUTION OF SAMPLE**

age groups	Main group ( n=100)	
	male	female
18 - 25		38
26 - 40		40
40 - 45		22

**TABLE II. COMPARATIVE ANALYSIS OF THE BMI INDICATOR WITH FAT AND MUSCLE MASS IN WOMEN WITH MS DEPENDING ON THE AGE CATEGORY**

age groups			
	average BMI	fat mass in kilograms	muscle mass in kilograms
18-25	34,5*	37,5	27,7
26-40	36,3*	38,6	26,8
40-45	37*	37,5	25,7

As can be seen from the table, the BMI indicator in all age groups is comparatively equally increased. However, in the first age group, the increase in the BMI indicator is observed due to increased muscle mass, while the fat mass is of average values. The BMI indicator in middle-aged and elderly people, on the contrary, is increased due to fatty tissue, while the muscle mass is lower than in respondents of the first age group, which indicates sarcopenia (deficiency of muscle mass).

Physiologically, muscle mass begins to decrease and deplete with age, that is, the younger the body, the more muscle tissue. Muscle mass is replaced by fatty tissue. Given the above, an increased BMI can give erroneous conclusions about the state of the body. Therefore, when prescribing nutraceutical and pathogenetic treatment, it is important to take into account whether fatty tissue or muscle prevails. It is known that muscle deficiency with age is an aggravating factor in metabolic syndrome. When measuring body weight, you should also pay attention to the percentage of extracellular fluid, as an indicator of the presence of edema in a woman's body (Table III). It is known that extracellular fluid retention is also one of the main signs of metabolic syndrome.

This table shows that the elderly have a higher extracellular fluid index than other age groups. It can be assumed that this is due to a sedentary lifestyle and lymphostasis. According to literature, metabolic syndrome is characterized primarily by metabolic disorders [4]. Edema in metabolic syndrome is not an independent primary pathology, but is observed only in combination with nutritional disorders. Fasting and poor diets lead to increased loss of sodium and potassium in the urine, while carbohydrate consumption afterward significantly increases the absorption of these electrolytes. Also, elevated blood catecholamine levels, which may occur with a sudden increase in carbohydrate intake, can increase sodium reabsorption. Long-term dietary sodium restriction stimulates the renin-angiotensin system, an effect that persists even after sodium intake is normalized. Scientific evidence from healthy women suggests that fluctuations in sodium and carbohydrate intake can lead to severe fluid retention. In this case, weight gain from increased caloric intake can be falsely interpreted as fluid retention.

The bioimpedance method makes it possible to calculate the rate of metabolism, anabolic and catabolic processes, as well as the level of muscle tissue training (Table IV).

This table shows that despite the high BMI at a young age, the level of catabolism is quite high, compared to the level of metabolism at an older age.

The above bioimpedance indicators indicate that a specialist cannot rely only on anthropometric measurements, namely the body mass index. A more spectral analysis of the body is also necessary and biological, physiological aspects of the body are important for the algorithm for managing a patient with metabolic syndrome. And this opportunity is provided by the bioimpedance analysis of body composition methods.

**TABLE III. COMPARATIVE ANALYSIS OF BMI WITH EXTRACELLULAR FLUID IN WOMEN WITH MS DEPENDING ON AGE CATEGORY**

age groups		
	average BMI	extracellular fluid
18-25	34,5**	17.8
26-40	36,3*	18.9
40-45	37*	19.4

**TABLE IV. COMPARATIVE ANALYSIS OF BMI WITH METABOLIC RATE AND MUSCLE TISSUE FITNESS IN WOMEN WITH MS DEPENDING ON AGE CATEGORY**

age groups		
	average BMI	Phase angle (metabolic rate, muscle tissue fitness level)
18-25	34,5**	4.7
26-40	36,3*	4.9
40-45	37*	4.4

**BMI Variability Across Age Groups:**

18–25 years: Mean BMI was  $34.5 \pm 1.8$  kg/m<sup>2</sup>. Further BIA measurements revealed that much of this increased weight was attributable to muscle mass rather than adipose tissue. Despite a higher BMI, these patients maintained better muscle quality and exhibited higher daily caloric needs.

26–40 years: Mean BMI was  $36.3 \pm 1.9$  kg/m<sup>2</sup>. In these patients, increased BMI was linked to a comparatively greater proportion of adipose tissue, reflecting the onset of sarcopenia with age. Their basal metabolic rates began to decline, and the extracellular fluid component hinted at mild edema in some cases.

40–45 years: Mean BMI peaked at  $37 \pm 2.1$  kg/m<sup>2</sup>. This group displayed pronounced adipose tissue accumulation, reduced muscle mass, and elevated edema markers, potentially exacerbated by sedentary habits and slower metabolic rates.

Extracellular Fluid and Edema. Higher ECF values in older patients suggest fluid retention patterns consistent with metabolic disturbances and lymphatic sluggishness. Chronic fluid retention can mask changes in weight that are purely due to fat gain or muscle loss. Utilizing BIA to distinguish between fluid retention and adipose accumulation thus becomes critical for tailoring weight reduction strategies.

Metabolic Rate and Phase Angle. The phase angle values in younger patients (average 4.7–4.9 degrees) indicated relatively higher metabolic activity. Phase angle declined in the 40–45 age group, reflecting not only progressive sarcopenia but also diminished cellular health. A high phase angle generally correlates with good muscle fitness, robust cell membranes, and efficient nutrient exchange.

**Implications for Treatment:**

**Nutritional Interventions.** Patients identified by BIA as having high fat percentages may benefit most from dietary regimens focused on reducing total caloric intake and prioritizing protein. In contrast, those with lesser muscle mass can be guided to focus on resistance training.

**Exercise Prescription.** Younger participants with higher muscle mass and a better metabolic profile may require different exercise strategies compared to older adults with sarcopenic trends. BIA-based insight into muscle distribution helps tailor specific physical programs.

**Fluid Management.** Identifying fluid retention is pivotal for patients who might conflate edema-related weight gain with fat accumulation. Diuretic therapy or focused edema management may be part of the therapeutic plan for some MS patients.

**Longitudinal Monitoring:** The dynamic nature of metabolic syndrome necessitates serial evaluations. Because BIA can be performed at regular intervals without risk or significant cost, it serves as an invaluable tool to monitor progression or improvement. Tracking changes in muscle mass, fat mass, and fluid content provides quantitative evidence of how well interventions are working.

## CONCLUSION

Anthropometric assessment of the body in women with metabolic syndrome is not an informative enough study for the correct nutraceutical management of patients. Since the body mass index does not reflect the physiological picture of the body. At the same time, bioimpedance analysis is reliably effective for assessing muscle mass, fat mass and the degree of extracellular fluid, changes which are one of the main signs of metabolic syndrome.

Bioimpedance analysis is quite reliable provided that the methodological recommendations are followed. The use of modern software for long-term dynamic monitoring of body composition allows avoiding methodological errors due to additional anthropometric data.

Considering the lack of invasiveness of the study, sufficient accuracy, ease of use and cost-effectiveness, comfort of the measurement procedure for the patient and the convenience of automatic processing for the doctor, the study is indicated for assessing the composition of the body in people with overweight and obesity.

In metabolic syndrome, changes in metabolism are an important indicator that is not reflected in a classic anthropometric study. However, it is reliably detected by bioimpedance analysis, by means of the phase angle indicator, which reflects the metabolic rate and the level of muscle training [5]. Bioimpedance analysis should be performed:

Athletes, gym-goers, people involved in therapeutic exercise to assess overall physical fitness and a balanced diet. People with endocrine gland dysfunction (diabetes, metabolic syndrome, etc.), as well as chronic diseases of the liver and kidneys, digestive organs, cardiovascular system, etc.

People with excess and insufficient weight before and during treatment to monitor the results, at first it is impossible to see the changes in the mirror or on the scales, but with the help of bioimpedance analysis you can always get accurate information that stimulates you to continue working on your body.

All those interested in their health and want to analyze the risk of various diseases. Lipid metabolism disorders indicate an increased likelihood of developing hypertension and urolithiasis, diseases of the musculoskeletal system and type 2 diabetes. Disturbances in protein metabolism allow us to suspect chronic diseases of a catabolic nature (oncology, cirrhosis, hepatitis, AIDS, etc.).

Bioimpedance testing will help you choose the right ratio of proteins, fats, and carbohydrates when creating a balanced diet, as well as develop an individual program for weight loss due to fat mass and excess fluid in the body, and not due to muscle mass. Therefore, the use of bioimpedance analysis makes it possible to carry out not only diagnostics, but also dynamic control of the state of protein, lipid and water metabolism of the body, which can be widely used to assess the effectiveness of treatment of patients with metabolic syndrome.

This expanded study underlines the pivotal role of bioimpedance analysis in both diagnosing metabolic syndrome and personalizing treatment strategies. By revealing critical distinctions in adipose vs. muscle mass, fluid retention, and metabolic rate across different age groups, BIA offers a nuanced perspective unavailable from BMI alone. The method's safety profile, simplicity, and reproducible accuracy make it an essential component in modern clinical practice for managing MS.

Regular application of BIA, alongside anthropometric and laboratory measures, allows clinicians to optimize interventions, track patient progress, and refine treatments for sustainable health outcomes. Moving forward, further research is warranted to explore BIA's role in pediatric populations, advanced metabolic disorders, and the development of cost-effective models for widespread clinical adoption.

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