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Research Article

Multifrequency Bioimpedance Functional Cut-Off Points For Noncommunicable Disease Risk In Adults In Colombia And Mexico: A Multicenter Study

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Abstract

Introduction: Chronic non-communicable diseases (NCDs) in Latin America coexist with obesity, malnutrition and sarcopenia, which requires diagnostic tools that are more sensitive than body mass index (BMI), which is insufficient to detect functional alterations.

Objective: This study evaluated the relationship between body composition measured by multifrequency bioimpedance (mfBIA) and the risk of NCDs in Colombia and Mexico, integrating bioelectrical, clinical, sociodemographic, food, and body perception variables.

Materials and methods: Using an observational, descriptive and analytical cross-sectional design, 1,800 people over 15 years of age (74.6% women; 89.7% Colombians) were evaluated, with institutional ethical approval and compliance with the Declaration of Helsinki. The mfBIA was applied under standardized scientific protocols, guaranteeing validity and reproducibility.

Results: 55.1 % had obesity (IMF), 5.6 % malnutrition (FFMI), 79.9 % functional dehydration (HSG), 31.2 % high cardiovascular risk (CHF/ICEST), 9.2 % risk of sarcopenia (ASMI) and 20.8 % risk of osteoporosis (CMO). A phase angle (AF°) < 5.5° and an impedance radius (IR) > 0.82 were associated with metabolic and cellular impairment. These conditions were correlated ($p < 0.005$) with high intake of ultra-processed foods, low dietary protein, sedentary lifestyle, low educational level, income and limited access to health services. 79.9% of the population presented body dissatisfaction, which is correlated with stress ($r = 0.32$) and weight ($r = 0.41$), especially in women and the Mexican population. Cut-off points were proposed for BMI, IMF, MIFF, MCA, HSG, CMO, AF and IR.

Conclusion: The findings support the incorporation of mfBIA into clinical and epidemiological practice, overcoming the limitations of BMI.

Keywords: Nutritional status; body composition assessment; multifrequency bioimpedance; Latin America; multicenter

Introduction

Noncommunicable diseases (NCDs) are the leading cause of morbidity and mortality in Latin America, accounting for more than 77% of annual deaths. This group includes obesity, type 2 diabetes, cardiovascular disease, sarcopenia, and cancer, all closely linked to modifiable factors such as improper diet, physical inactivity, alcohol consumption, and smoking. In this context, the accurate assessment of body composition (BC) has become relevant in the prevention, diagnosis, and management of NCDs, as it allows the identification of functional alterations before their clinical manifestation [1-3].

Multifrequency electrical bioimpedance (mfBIA) has established itself as a non-invasive, fast, safe and low-cost tool to estimate fat mass, fat-free mass, total body water and skeletal muscle mass, overcoming the limitations of body mass index (BMI) and other anthropometric methods, since it allows differentiating between intracellular and extracellular compartments, improving the estimation of hydration and active cell mass; This functional ability makes it a valuable technique for nutritional assessment in clinical and public health settings [4].

Among its main contributions are the phase angle (AF°) and the impedance radius (IR), functional parameters that reflect cellular integrity, water balance and low-grade inflammation. AF°, derived from the relationship between reactance and resistance (arctan Xc/R), is a marker of active cell mass and nutritional status, with low values associated with malnutrition, chronic inflammation and increased risk of mortality. The IR, defined as Z_{200}/Z_5, indicates water redistribution, loss of cell membrane functionality, inflammation, and metabolic risk, without relying on anthropometric algorithms or population equations. Recent studies have shown a strong inverse correlation between the two ($r = -0.850$), reinforcing their value as complementary functional biomarkers [5-7].

However, in Latin America there is still a lack of validated cut-off points for these parameters, since most models are based on Caucasian or Asian populations, which can lead to diagnostic errors in groups with different anthropometric and physiological characteristics [8].

The nutritional transition in the region has generated a double burden of malnutrition, with coexistence of obesity and malnutrition, especially in contexts of poverty and limited access to healthy food. This complexity requires more sensitive tools than BMI, which does not distinguish between fat and lean mass or consider the regional distribution of fat. In this scenario, multifrequency bioimpedance (mfBIA) is positioned as a functional alternative for the assessment of body composition, overcoming the limitations of traditional anthropometric methods. In addition, it is pertinent to highlight the relevance of mfBIA's portable equipment, useful in screening and in community contexts due to their low cost and speed, which makes them strategic allies for primary health care (PHC) and family medicine in Colombia. This orientation not only responds to the priorities of national policy, but is also aligned with the global trend towards early diagnosis and health promotion as axes to transform the conditions of the territories [2,4,9].

However, its full implementation requires cross-validation with reference methods such as DEXA, development of equations adjusted to the Latino population, and standardization of measurement protocols [10].

This research aimed to evaluate the relationship between body composition measured by mfBIA and the risk of NCDs in the population of Colombia and Mexico, in order to provide local evidence that strengthens clinical and epidemiological practice.

Methodology

Study design

An observational, prospective and exploratory study was carried out, with a descriptive and analytical approach.

Population and sample

The final sample was made up of 1,800 healthy subjects over 15 years of age, selected for convenience in urban and rural educational communities. The call was made through institutional invitations disseminated on social networks and emails addressed to employees, students and parents. Of the participants, 1,607 (89.3%) came from Colombia and 193 (10.7%) from Mexico; 74.6% were women and 62% were young adults (18–39 years).

Inclusion and exclusion criteria

Subjects over 15 years of age were included; 222 subjects were excluded because they were pregnant, had some presence of pacemakers or metal plates, amputations, or active menstruation at the time of measurement.

Ethical aspects

Participation was voluntary, with informed consent signed by adults or by parents/guardians of minors. The study was approved by an ethics committee and classified as risk-free research, in accordance with the Declaration of Helsinki, the Convention on the Rights of the Child, the ICH-GCP standards and Resolution 008430 of 1993 of the Ministry of Health of Colombia. Confidentiality was ensured through anonymization of data and storage on protected servers.

Information collection

Weight, height, and waist and hip circumferences were recorded following ISAK standards, applied by trained evaluators. Body composition was assessed using multi-frequency bioimpedance (mfBIA) with manufacturer's standardized protocol, controlled preconditions, and use of the BiodyXpert MZII (France) device, portable, wireless, quadpolar, hand-foot, multifrequency (200-5 kHz), multi-algorithm, with licensed software, and online platform. Health history and determinants (consumption of tobacco, alcohol, psychoactive substances, perception of food, physical activity, access to health, stress and exposure to pollutants) were collected by means of an adhoc questionnaire. Food consumption was measured with a validated consumption frequency questionnaire (CFCGA) and body image with the Body Shape Questionnaire (BSQ).

Data analysis

The analysis was carried out in three stages: (1) descriptive statistics with measures of central tendency, dispersion and empirical percentiles (P3 and P97); (2) normality tests (Kolmogorov-Smirnov and Shapiro-Wilk) and Pearson correlations; (3) multiple linear regression to explain BMI variability based on IMF, FA°, IR, history, stress, and food intake. Bioimpedance data were processed with Biodymanager, exported and cleaned in Microsoft Excel, and analyzed in IBM SPSS Statistics, version 25.

Validity and limitations

Validity was strengthened through standardized protocols, training of evaluators, and use of validated instruments and the same previously calibrated or new anthropometric equipment. Regarding limitations, it was observed that convenience sampling reduced the representativeness of rural, indigenous, and low-income populations; only 8.7% belonged to indigenous or Afro-descendant groups, with different patterns of fat distribution and metabolic risk. Another limitation was the absence of cross-validation with reference methods such as DXA, Bod Pod® or isotopic dilution, which prevents confirming the absolute accuracy of the estimates of fat mass and body water. Likewise, the lack of measurements of strength or physical function according to criteria EWGSOP2 could underestimate sarcopenia. Finally, the cross-sectional design restricts causal inference, limiting conclusions to observational associations.

Results and Discussion

The final sample of the study included 1,800 valid subjects, of which 1,615 (89.7%) were from Colombia and 185 (10.3%) from Mexico, with a sex distribution of 1,342 women (74.6%) and 458 men (25.4%). The mean age was 32.4 years (95% CI: 31.9-32.9), with a concentration of 62% in young adults (18-35 years), reflecting convenience sampling conducted in academic and work settings. This demographic distribution is consistent with previous studies in Latin America that also report greater female participation in health and nutrition research, although it introduces a bias that limits generalization to other age groups, especially older adults [11,12].

Determinants of health

This cohort was mainly composed of young adults, mostly single (72.8%), with a predominance of mestizos (40.9%) and high educational level (68% with technical, technological, or university training). This profile was associated with irregular physical activ-

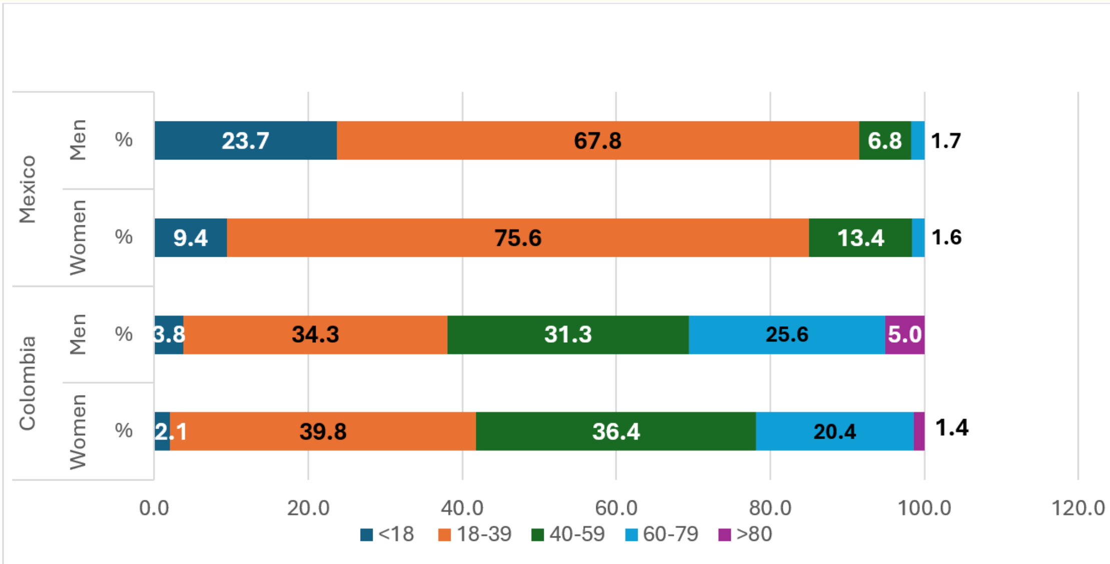

Figure 1: Distribution of the population by age, sex and country.

ity, poor food perception, and risky behaviors such as alcohol and tobacco consumption. The occupation was dominated by students (53.3%), followed by teachers and administrators, with high levels of sedentary lifestyle (75.7%), especially in women, which negatively impacted the phase angle and active cell mass. More than half reported income between 500 and 1000 USD, which conditioned access to private health services and evidenced a small group in a situation of vulnerability [13].

Habits and lifestyles

Lifestyle habits showed direct influence on bioelectrical parameters: perceived stress was negatively correlated with FA°, while occasional alcohol and tobacco consumption was associated with lower cellular hydration and fat redistribution. Regular access to health services was related to better hydration indicators and lower impedance, reinforcing the importance of primary care and the biopsychosocial approach in nutritional assessment.

In terms of diet, the frequency of consumption questionnaire revealed a pattern characterized by caloric excess, high consumption of ultra-processed foods, low fiber intake, and protein imbalance. The average BMR was 1389 kcal/day, with estimated energy requirements of 1910 kcal/day, but an actual intake of 2150 kcal/day, which represents an excess of 12.5%, higher in young men. This imbalance was associated with overweight, central adiposity and insulin resistance. In Colombia, carbohydrate intake predominated (52.1%), while in Mexico there was a high consumption of fats (40.3%), with excess saturated fats and high intake of sugary drinks. Young adults consumed an average of 2300 kcal/day, of which 42% came from ultra-processed foods. Men exceeded the recommended thresholds for protein and fat, while women had lower energy intake and a higher prevalence of unsupervised restrictive diets. These findings reflect the nutritional transition in Latin America, marked by food globalization and the increase in the consumption of ultra-processed foods, generating the double burden of malnutrition: obesity and coexisting deficiencies. (14)

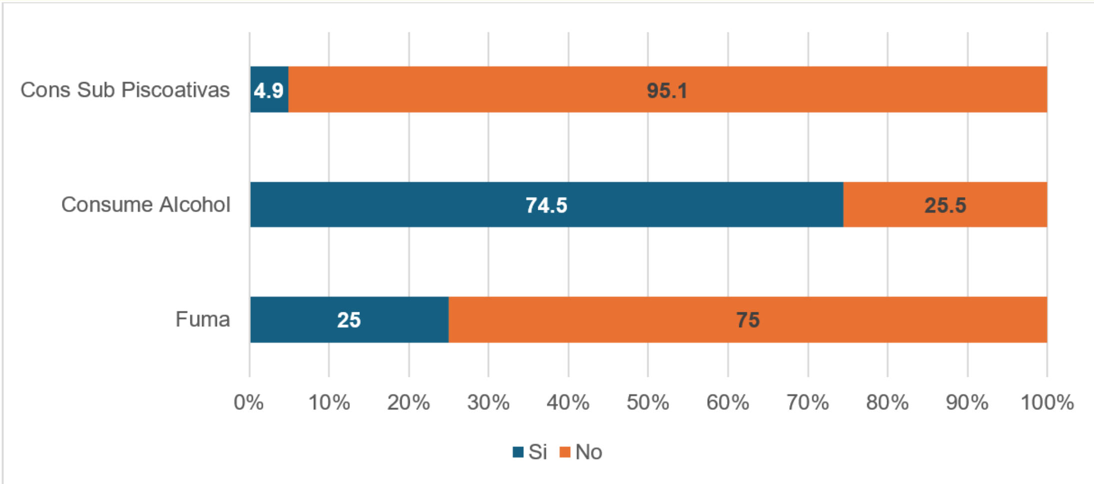

Figure 2: Distribution of the population according to consumption of addictive substances.

Nutritious	Average intake	% of total	Comparison with recommendations
Energy (kcal/day)	2150	12,5%	About RCT
Protein (g/day)	68,3	12,7%	Below 1.2 g/kg/day
Fat (g/day)	89,2	37,1%	>30% recommended
Carbohydrates (g/day)	286,5	50,2%	High in added sugars

Table 1: Estimated calorie and nutrient intake from the Food Frequency Questionnaire (CFCGA).

Source: Own elaboration.

Body image perception

Body image perception was identified as a key psychological component in nutritional and functional assessment, especially in young people. Of the 486 participants, 284 adequately completed the Body Shape Questionnaire (BSQ); 37% had high dissatisfaction (>110 points), with a mean of 96.7 ± 14.2, reflecting moderate general dissatisfaction, but with a significant group at risk of behavioural alterations related to food and psychological well-being.

72% of women reported high dissatisfaction compared to 28% of men, in agreement with studies on greater aesthetic pressure in young women. Mexican women [15]. scored higher than Colombian women, suggesting differentiated cultural and media influence. Young adults (26–40 years) showed the highest levels of dissatisfaction, associated with greater social and occupational exposure, as well as with the conflict between aesthetic expectations and physiological changes typical of early adulthood [16].

Participants with high BSQ scores had a lower phase angle and higher impedance index, suggesting a possible relationship between negative body perception and cellular functional impairment. Although it does not imply causation, the literature indicates that body dissatisfaction can induce extreme dietary behaviors, sedentary lifestyle, or overtraining, with negative effects on active cell mass and intracellular hydration. These findings reinforce the importance of including psychological instruments in body composition studies, given that self-image influences eating behavior, adherence to treatments, and the risk of mental disorders [16].

Body composition

The mean height was 1.65 ± 0.09 m, with significant differences between men (1.71 ± 0.08 m) and women (1.60 ± 0.06 m), values lower than those reported in global studies, attributable to genetic, nutritional and sociodemographic factors specific to the region. The sex gap coincides with that described in Brazil and Mexico, where an average difference of 10–12 cm has been documented, linked to a history of child malnutrition and inequalities in access to food [17,18]. The average body weight was 77.3 ± 16.1 kg (men 83.5 ± 13.4 kg; women 72.1 ± 14.8 kg), figures slightly higher than those reported by PAHO/FAO (74.0 kg) and similar to the national surveys of Mexico (75.2 ± 13.8 kg) and Colombia (74.9 ± 14.2 kg). [19,20]. Body composition showed a predominance of fat mass (30.1 kg), equivalent to 39.0% of total weight, a percentage that exceeds the healthy ranges recommended for both sexes. This finding shows a high prevalence of functional adiposity, which limits the usefulness of body mass index as the only indicator of metabolic risk.

Variable	Mean	Hours of deviation
Crude Fat Mass (g)	30,1	8,9
MGBVR	16	4,3
Fat-Free Mass (MLG) (kg)	47,2	8,5
Agua Corporal Total (ACT) (L)	34,1	6,2
Fat-free hydration (HSG) (%)	70,1	2,2
Skeletal Muscle Mass (MME) (kg)	24,4	5,2
Active Cell Mass (ACM) (kg)	29,2	5,6
Skeletal Muscle Mass of the limbs (MMEM) (kg)	18,6	4
Metabolic Protein Mass (MPM) (kg)	8,8	2
Total Protein Mass (TPM) (kg)	10,5	2,2
Bone Mineral Content (BMC) (kg)	2,2	0,5
Non-Bone Mineral Content (NOMC) (kg)	0,3	0,5
Extracellular Solids (SE) (kg)	4	0,8

Table 2: General descriptions of body composition.

Fat mass

The average fat mass was 30.1 kg, equivalent to 39.0% of total body weight, exceeding the recommended healthy ranges and reflecting a high prevalence of functional adiposity. When using BMI as the only criterion, 62.6% of the participants were classified as overweight, but with low sensitivity (16.2%) and specificity (26.8%) to detect functional adiposity, in accordance with what was reported in Latin American populations [21,22].

The fat mass index (FAT) improved diagnostic discrimination: 31.6 % of the subjects were classified as functionally obese, 52.9 % in normal ranges, and 15.6 % with low fat mass, a category absent in the BMI but clinically relevant. These findings coincide with what was described by Gómez (2022), who showed that the IMF reduces misclassification and improves the prediction of metabolic risk. The positive correlation between FMI and impedance radius (IR), and negative correlation with phase angle (AF°), supports the usefulness of multifrequency bioimpedance to detect cellular alterations not captured by conventional anthropometry [23].

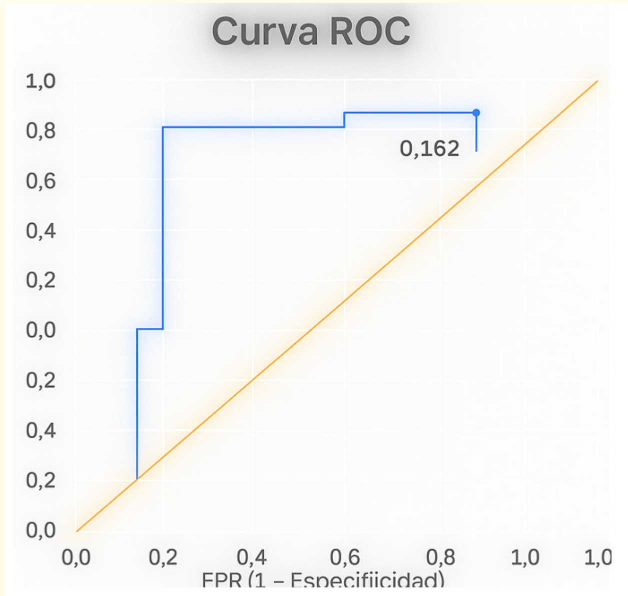

Figure 3: BMI vs IMF ROC Curve.

The distribution of the IMF showed marked differences by sex: in women, a mean of 9.62 kg/m^2 with positive bias and leptocurtic kurtosis; in men, an average of 5.45 kg/m^2 with less dispersion. These non-normal characteristics justify the definition of sex-specific cuts. The P25–P75 percentiles (6.70–11.20 kg/m^2 in women; 3.60–7.10 kg/m^2 in men) correspond to healthy functional ranges, while the P95 percentiles (15.70 and 11.60 kg/m^2, respectively) identify the threshold of elevated metabolic risk [24].

Functional classification	Mujeres (kg/m^2)	Men (kg/m^2)
Under IMF	<6.7	<3.6
Healthy range	6.7 – 11.2	3.6 – 7.1
Overweight	11.3 – 15.6	7.2 – 11.5
Obesity	>15.7	>11.6

Table 3: IMF's proposed functional classification, by sex.

Source: Original data obtained in this study, processed by descriptive analysis and percentiles in SPSS v25.

PAHO/FAO reports population means of FMI (9.8 kg/m^2 in women; 5.2 kg/m^2 in men) similar to our central percentiles, although without capturing risk subgroups. Data from the ENSIN 2018 in Colombia and the ENSANUT 2018 in Mexico show comparable values, which supports the regional applicability of the proposed cuts [1,19,20].

Bioimpedance-based obesity predictive model

The multiple linear regression model that integrated multifrequency bioimpedance parameters (IMF, AF°, IR), personal and family history, perceived stress, and food consumption explained 68% of the BMI variability ($R^2 = .68$; RMSE = 2.1 kg/m^2; $p < .001$), overcoming the limitations of anthropometry-only approaches. Among the most robust predictors, the FMI ($\beta = .41$; $p < .001$) stood out, confirming its role as an intermediate marker between body composition and clinical diagnosis [25].

FA ($\beta = -.34$; $p = .001$) and RI ($\beta = -.29$; $p = .002$) showed inverse associations with BMI, evidencing the relationship between cellular integrity, metabolic efficiency, and adiposity. On the behavioral level, perceived stress (β = .08; p = .03), consumption of saturated fats (β = .13; p = .005) and sugars (β = .10; p = .01) contributed significantly to the model, underlining the influence of psychosocial and dietary factors on the accumulation of body fat [26,27].

Family (β = .11; p = .01) and personal (β = .09; p = .02) history reflected the genetic predisposition to obesity, while the inclusion of variables such as bone mineral content (β = –.07; p = .04) and age (β = .02; p = .01) enriched the nutritional characterization. Together, this multidimensional approach transcends traditional anthropometric measures and provides early indicators of metabolic risk, suggesting that lean mass preservation, diet optimization, and psychosocial stress management are key strategies in obesity prevention [28].

Variable	β (Coefficient)	OR / Pending	Significance (p)	Importance (%)
IMF	0.41	↑ IMC	0,001	20%
OF°	-0.34	↓ IMC	0.001	15%
AND	-0.29	↓ IMC	0.002	13%
FFMI	-0.18	↓ IMC	0.003	9%
Saturated Fats	0.13	↑ IMC	0.005	9%
ASMI	-0.12	↓ IMC	0.02	8%
ANPER	0.11	↑ IMC	0.01	7%
CMOVC	-0.07	↓ IMC	0.04	6%
ANFAM	0.09	↑ IMC	0.02	6%
Stress	0.08	↑ IMC	0.03	5%
Age	0.02	↑ IMC	0.01	4%
Sugars	0.10	↑ IMC	0.01	4%

Table 4: Summary of the predictive model of clinical and preclinical obesity based on BIA.

Metabolic and cardiovascular risk

The waist-hip ratio (CHF) has established itself as a sensitive marker of cardiovascular risk by reflecting visceral adiposity, linked to atherogenesis, insulin resistance, and endothelial dysfunction. In this cohort, 54.8% had some degree of risk and 31.2% were in the elevated category, with average CHF above the WHO cut-off points in both sexes, reinforcing the need for interventions aimed at reducing abdominal fat [29].

The waist-to-height ratio (SCI) was shown to be a robust predictor of cardiometabolic risk, identifying high prevalences in Colombians (24.5%) and Mexicans (16.7%), even in the absence of obesity due to BMI. The ECI was more sensitive in women (23.6% vs. 5.7% in men), which coincides with studies that highlight its greater predictive capacity in women, while the ICC is more accurate in men [30].

The logistic regression model that integrated ICC, ECI, and lifestyle variables reached an AUC of 0.89, with sensitivity of 80% and specificity of 86%, surpassing the performances reported by Zhang et al. (2021) and Heo and Lee (2025). The inclusion of factors such as consumption of saturated fats and sugars, exercise, and access to health services improved the discriminative capacity, facilitating its application in clinical and community contexts. [31,32].

Variable	Coefficient β	OR (Odds Ratio)	p-value
ICC	1.23	3.42	0.001
ICE	1.04	2.83	0.002
Sex	-0.68	0.50	0.002
Age	0.03	1.03	0.006
Weight kg	0.06	1.06	0.003
Saturated Fats	0.22	1.24	0.001
Sugars	0.20	1.22	0.002
Exercise	-0.27	0.76	0.0002
Access to health services	-0.19	0.83	0.01

Table 5: Results of the Logistic Regression Model of Cardiometabolic Risk by CHF and ECI.

Unlike these studies, this research integrated anthropometric indices of central adiposity (ICC and ICE), lifestyle variables, and access to health services, which not only improved discriminative capacity, but also facilitates its application in clinical and community settings without requiring complex biochemical analyses.

Fat-Free Mass (MLG)

The MLG is not a homogeneous compartment, but a set of structural and functional components essential for metabolic health. It was broken down into total body water, body protein, and mineral content.

Agua Corporal Total (ACT)

The human body is mainly composed of water (approximately 70% in men and 65% in women). However, not all of this amount participates directly in metabolic processes, since between 10 and 15% of body water is found in adipocytes, where it fulfills specific functions for fat tissue itself. For this reason, when assessing hydration status and detecting dehydration, it is more appropriate to work with fat-free hydration (HSG), which reflects the water contained in metabolically active compartments. In this cohort of 1800 Colombian adults, the HSG showed differences by sex: 69.6% in women and 71.4% in men, values below the reference range (73%–76%), indicating a prevalence of subclinical dehydration close to 80%.

Functional cut-off points based on population percentiles were proposed, with six categories differentiated by sex. An HSG < 63% in women or < 67% in men defined severe functional dehydration, associated with intracellular water loss and elevated metabolic risk. Only 20.1% of women and 32.7% of men were in the appropriate physiological range, underscoring the magnitude of the problem. Values greater than 75% in women or 76% in men suggest fluid overload and extracellular redistribution.

The causes of this functional dehydration are multifactorial: low water consumption, high intake of coffee and alcohol, insensitive losses due to environmental heat and exercise without adequate fluid replacement. From a clinical perspective, correcting cellular hydration has an immediate impact on muscle functionality, cognitive concentration and thermal regulation.

Proteins

On the other hand, metabolic protein mass (MPM) (8.8 ± 2 kg) and total protein mass (TPM) (10.5 ± 2.2 kg) were within the ranges expected for healthy adults, in line with the five-level body composition model validated by Lukaski., *et al.* (1986), which underlines the structural and functional role of proteins [33].

Functional category	Women (%)	Men (%)	Clinical Interpreting
Severe functional dehydration	< 63.0	< 67.0	High metabolic risk, possible cellular hypohydration
Subclinical water instability	63.0 to 65.0	67.0 to 68.1	Mild water deficit, requires follow-up
Suboptimal hydration	65.1 to 68.0	68.2 to 69.4	Marginal water intake, possible functional alteration
Adequate physiological range	68.1 to 71.6	69.5 to 72.7	Preserved water balance, stable functionality
Hyperhydration without overload	71.7 to 75.0	72.8 to 76.0	Excellent compartmentalization, no clinical signs
Suspected water overload	> 75.0	> 76.0	Possible extracellular excess, evaluate clinical status

Table 6: Functional classification of fat-free hydration (HSG) according to cellular stability and metabolic prognosis.

Source: Own elaboration based on the sample.

Mineral content (CMO)

Osteoporosis is an osteometabolic disease characterized by decreased bone mineral density (BMD) and deterioration of microarchitecture, which increases the risk of fractures in the vertebrae, hip and wrist. Marena (2021) defines it as a BMD 2.5 standard deviations below the average for healthy young adults (T-score < –2.5). It is estimated that it affects more than 500 million people in the world, with a global prevalence of 18.3%, higher in women (23.1%) than in men (11.7%), and that in people over 65 years of age it can exceed 27% in women [34,35].

Although dual X-ray absorptiometry (DXA) remains the standard diagnosis, studies have shown that CMO estimated by multifrequency bioimpedance can act as a functional predictor of osteoporotic risk, by indirectly reflecting total bone mass and its relationship to other body compartments. In this cohort, 20.8% of participants were at high risk of osteoporosis, a finding consistent with global data and reinforcing the value of BIA as a functional screening tool. In women, the mean BMC was 2.07 kg (95% CI: 2.06–2.09), with asymmetric and leptocurtic distribution, while in men it reached 2.71 kg (95% CI: 2.66–2.76), with a more symmetrical and phyllocurtic distribution. These differences justify cut-off points differentiated by sex. The low percentiles (p3 and p10) identified subgroups with critical mineral reserve, while the intermediate range (p25–p75) defined the functional window and the high percentiles (p90–p97) reflected optimal reserve [36].

Functional category	Women (kg)	Men (kg)	Clinical Interpreting
Severe mineral risk	< 1.3	< 2.2	Severe Osteopenia, High Structural Risk - DEXA Urgent
Bone vulnerability	1.3 to 1.7	2.2 to 2.4	Suboptimal density, requires preventive follow-up. Urgent DEXA
Low structural range	1.8 to 1.9	2.5 to 2.9	Possible functional mineral deficit
Adequate structural range	2.0 to 2.6	3.0 to 3.4	Sufficient structural reserve, preserved functionality
High functional mineral reserve	2.7 to 3.0	3.5 to 3.7	Excellent density, low metabolic risk
Structural hypermineralization	> 3.0	> 3.7	Superior physical potential, optimal reserve

Table 7: Functional classification of CMO by sex.

Source: Own elaboration.

The predictive model of CMO by diet showed that the consumption of low-fat dairy products had the strongest association, confirming its role as a primary source of calcium and vitamin D. Positive effects were also observed for eggs, oily fish and whole grains, while white fish and nuts were negatively associated, possibly due to low nutritional density or excess fat. Physical activity presented a significant positive association, confirming its role as a mechanical stimulus for bone remodeling. Finally, the growing burden of fragility fractures in Latin America—with hip fracture rates ranging from 108 to 276 per 100,000 in those over 50 years of age and high prevalence in Mexico and Colombia—underscores the urgency of applying local referrals and using BIA as an accessible tool for early stratification and prioritization of densitometry in vulnerable subgroups [37-39].

Fat-free mass index (FFMI)

The FFMI quantifies the fat-free mass (kg) adjusted for height (m^2), offering a direct estimate of lean mass relative to the body. Unlike the body mass index (BMI), the FFMI more accurately discriminates the muscle component, which is essential for assessing nutritional and functional status. Its diagnostic value lies in the fact that the loss of fat-free mass is a reliable marker of clinical malnutrition, defined as deterioration of body composition accompanied by functional deficit, with an impact on immunity, scarring and tolerance to medical treatments [40].

Malnutrition is not limited to underweight; it can occur in individuals with normal or high BMI when there is loss or redistribution of lean mass. Globally, the prevalence of malnutrition in adults (BMI < 18.5 kg/m^2) reaches 8.5% in men and 13.4% in women (WHO, 2022), in Latin America and the Caribbean, 131 million people cannot afford a healthy diet, which favors functional deficiencies not detected by BMI [41].

From a database of 1,800 Colombian and Mexican subjects, FFMI percentile tables were developed: in men, the 5th percentile was 14.1 kg/m^2 and in women 16.2 kg/m^2. These values are lower than those reported in Switzerland (17.3 and 15.3 kg/m^2, respectively) and different from those in Mexico (15.8 and 14.9 kg/m^2), which underscores the need for local references.

Sex	Malnutrition	Low functional	Normality	High functional	Possible Steroid Use
Man	≤ 14.1	>14.1 to ≤16.5	>16.5 to ≤19.5	>19.5 to ≤22.9	>22.9
Woman	≤ 16.2	>16.2 to ≤18.3	>18.3 to ≤21.9	>21.9 to ≤24.3	>24.3

Table 8: Functional classification of the FFMI by sex for the Latino population.

Source: Authors' elaboration based on the doctoral DB, processed in SPSS vr 19.

Applying these cut-off points, 5.6% of participants were classified with FFMI ≤ P5, a figure comparable to the 4% observed in Sweden, validating the cross-cultural relevance of the approach. A functional classification is proposed that distinguishes malnutrition (≤ P5), low functional (> P5–P25), normality (> P25–P75), high functional (> P75–P95) and possible use cases of anabolics (> P95), optimizing the detection of nutritional states and the identification of non-physiological hypertrophy.

FFMI values above the 95th percentile (>22.9 kg/m^2 in men and >24.3 kg/m^2 in women) have been linked to a degree of lean mass that is difficult to achieve naturally. Classical studies showed that athletes with documented testosterone consumption exhibit FFMI up to 3 kg/m^2 above healthy controls, and that an FFMI > 25 kg/m^2 is rarely observed in a doping-free population [42]. In this sample, 2.4% of men and 1.1% of women exceeded these thresholds, suggesting the need to investigate a history of ergogenic drug use before classifying them as physiological hypertrophy. This approach improves diagnostic accuracy, but it must be complemented with detailed anamnesis, hormonal measurements, and control of variables such as protein supplementation.

Muscle Mass

On the other hand, the mfBIA allowed the evaluation of data related to muscle mass, including skeletal muscle mass (SMM), skeletal limb muscle mass (MMEM), and the Appendicular Skeletal Mass Index (ASMI).

Skeletal Muscle Mass (SMM)

In this cohort, the mean MME was 24.4 ± 5.2 kg, with clear differences by sex: 28.1 kg in men and 21.5 kg in women. This finding is concerning in a predominantly young population and could be related to low strength physical activity or insufficient protein intake. The observed dimorphism reflects both hormonal influence and activity patterns and muscle fiber distribution. MME plays a functional role that transcends strength: it regulates basal metabolism, facilitates glucose uptake and acts as an endocrine organ through the release of myokines with anti-inflammatory and anabolic effects. Its reduction decreases resting energy expenditure, favors the accumulation of visceral fat and alters glycolipid homeostasis, predisposing to insulin resistance and metabolic syndrome, even in subjects with normal BMI [43].

Appendicular Skeletal Muscle Mass (of the limbs) (MMEM)

The MMEM was 18.6 ± 4.0 kg, constituting the main reservoir of locomotor power. Its positive correlation with phase angle (AF°) (r = 0.533) reinforces its value as an indicator of cellular integrity. AF°, reflecting the ability of membranes to retain intracellular water, is associated with active cell mass and metabolic functionality. Studies have shown that muscle loss is accompanied by decreased AF°, increased impedance index (IR), and increased risk of subclinical inflammation. Muscle mass assessment using mfBIA allows subclinical losses to be detected before they translate into reduced strength or performance, and offers dynamic monitoring of the response to nutritional and training interventions [5,44].

Appendicular Skeletal Mass Index (ASMI)

The ASMI corresponds to the lean mass of the limbs adjusted for height and, together with the AF°, constitutes a diagnostic criterion for sarcopenia according to the Global Leadership Initiative on Sarcopenia. Sarcopenia is defined as a progressive and generalized loss of muscle mass, strength and physical performance, linked to aging, inactivity and chronic inflammation, with a higher risk of falls, dependence and mortality, its global prevalence ranges between 10–16% in people over 60 years of age, reaching higher figures in Latin America, such as 19.1% in older adults and up to 39.6% in people over 80 years of age in Chile [45,46].

In this cohort of 1,800 participants, the ASMI showed slight positive asymmetry and greater dispersion in men. Based on population percentiles, sex-differentiated cut-off points were established: ASMI ≤ P5 (≤ 5.2 kg/m^2 in men; ≤ 6.3 kg/m^2 in women) to define functional sarcopenia; P25–P75 as normal range; P75–P95 as elevated muscle development; and > P95 as a possible atypical hypertrophy, which in the absence of structured training forces the use of ergogenics or measurement errors to be ruled out. Local validation of these thresholds improves diagnostic accuracy in Latin American populations, avoiding extrapolations from non-representative international references.

Sex	Sarcopenia	Low Range	Normality	High	Possible anabolic hypertrophy
Man	≤ 5.2	>5.2 to ≤6.3	>6.3 to ≤7.8	>7.8 to ≤9.3	>9.3
Woman	≤ 6.3	>6.3 to ≤7.5	>7.5 to ≤9.0	>9.0 to ≤10.6	>10.6

Table 9: Functional classification of ASMI by sex.

Source: Empirical distribution according to population sample.

Health, nutrition, and cellular integrity

Phase angle (AF°) and impedance radius (IR) have established themselves as two of the most robust bioelectrical markers derived from multifrequency bioimpedance (mfBIA), with growing clinical and epidemiological applications. Both are obtained from the relationship between resistance (R) and reactance (Xc), so they do not depend on weight or water algorithms. The AF° reflects the integrity of cell membranes and the active cell mass, while the IR defined as the quotient between the impedance at 200 kHz and 5 kHz represents the ratio between resistive and reactive components of the tissue, being inversely proportional to the cellular functional state, reflecting water imbalance, low-grade inflammation and cellular integrity [5,26], in this cohort it showed a strong inverse correlation with AF° ($r = -0.85$; $p < 0.001$), in addition to being positively associated with fat mass and negatively with fat-free mass, CAM and ASMI, confirming its role as a marker of subclinical inflammation and fluid redistribution [26].

Local cut-off points were established for FA and IR in Colombian and Mexican populations, with functional categories based on percentiles (p3, p10, p25, p50, p75, p90, p97). For AF°, the critical limits were < 5.4° in women and < 6.0° in men, coinciding with values associated with functional malnutrition and worse prognosis in ICU. The normal functional range ranged from 6.2–7.5° in women to 6.8–7.6° in men, consistent with values described in healthy young adults [47,48].

Category	Women	Men	Main physiological value	Clinical/Prognostic Implication
Severe cellular dysfunction	< 5.4	< 6.0	Very compromised membrane integrity. Active mass loss, chronic inflammation	↑ ICU mortality risk; ↑ Systemic complications. It needs urgent intervention; Poor nutritional prognosis
Functional malnutrition	5,4–5,6	6,0–6,2	Moderate decrease in cellular bioelectrical activity. Onset of lean functional loss	Risk of progressive clinical deterioration; requires support. Close monitoring; Possible transition to critical status
Lower functional range	5,7–6,1	: 6,3–6,7	AF° below the average, without reaching a critical level. Decreased cell function without severe impairment	Vulnerable State; risk of metabolic complications. Needs nutritional optimization and tracking
Normal functional range	6,2–7,5	6,8–7,6	Adequate electrical homeostasis, preserved cellular function. Functional and metabolic balance	Good overall prognosis; Compatible with clinical stability. Ideal for population comparison
High cellular functionality	7,6–8,3	7,7–8,3	FA above the 75th percentile, with predominant active mass. Optimal membrane function; Excellent cellular hydration	Good prognosis, low inflammatory risk. Supports effective recovery and clinical stability
Functional hypertrophy	> 8.3	> 8.3	Increased anabolic potential; Atypically high AF°. Association with athletes or subjects with optimal cellular function	High physical performance indicator; Higher metabolic reserve. Low clinical risk; Excellent functional prognosis

Table 10: Functional Classification of Phase Angle (AF°) by Sex, Cell Function, and Clinical Prognosis.

Source: Authors' elaboration based on percentile data.

In the case of IR, values < 0.740 in women and < 0.730 in men defined optimal cellular integrity, while > 0.870 and > 0.830, respectively, corresponded to severe reactive dysfunction. This classification into six strata facilitates the detection of subclinical inflammation and water imbalance, providing a functional framework adapted to Latin American physiology [6].

Functional category	Women (IR)	Men (IR)	Clinical Interpreting
Integrity optimal	< 0.741	< 0.731	High reactive mass, adequate cell hydration
Functional water balance	0.741 to 0.760	0.731 to 0.744	Preserved integrity, no inflammatory signs
Acceptable physiological margin	0.761 to 0.781	0.745 to 0.764	Low functional limit, possible cellular vulnerability
Initial reactive dysfunction	0.782 to 0.826	0.765 to 0.797	Early indicator of water imbalance, subclinical metabolic risk
Moderate cellular engagement	0.827 to 0.869	0.798 to 0.829	Diminished integrity, suspected low-grade inflammation
Severe reactive dysfunction	> 0.870	> 0.830	Functional evidence of inflammation, loss of reactive mass

Table 11: Functional Impedance Radius (IR) Classification by Sex by Cell Integrity and Subclinical Inflammation.

Source: Authors' elaboration based on percentile data.

Comparison with recent predictive models shows the advantage of incorporating bioelectrical biomarkers. While Zhang et al. (2021) reported an AUC of 0.782 for metabolic syndrome using biochemical and demographic variables, our model that includes AF° and IR reached an AUC of 0.89, with sensitivity of 83% and specificity of 89%. Similarly, Heo and Lee (2025) obtained an AUC of 0.819 using HOMA-IR and sociodemographic data, without considering cell membrane parameters or fluid balance [32,49].

These results demonstrate that the proposed cut-off points not only standardize the interpretation of FA and IR, but also improve the prediction of metabolic risk in primary care and population-based studies. Among the limitations, the cross-sectional and multicenter nature of the sample is recognized, which prevents the evaluation of the temporal stability of the thresholds. Future longitudinal research should validate these cut-off points in specific cohorts—such as cancer or geriatric patients—and explore their relationship with long-term clinical outcomes. It is also recommended to compare these percentiles with international benchmarks in the child and adolescent population, in order to expand their applicability in public health programs.

Conclusions

The mfBIA proved to be a functionally superior tool to BMI to assess the risk of NCDs in the Latino population, detecting alterations using parameters such as AF° and IR. Empirical cut-off points associated with obesity (IMF), malnutrition (FFMI), risk of sarcopenia (ASMI) and risk of osteoporosis (CMO) were proposed. However, these findings should be interpreted considering the limitations: convenience sample (young/female), absence of validation with DEXA, and diagnoses based solely on mfBIA indices. Despite this, evidence supports its incorporation into regional clinical practice and public health programs, promoting a more accurate, functional, and contextualized nutritional assessment for Latin America; provided that it is complemented with future studies in more diverse populations.

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