Nutritional Assessment Platform

Multi-Frequency Bioelectrical Impedance Analysis

Standard Operating Procedures

Version 1

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Objective	To estimate body composition based on a multi-frequency impedance measurement
Population	Children from 3 years old and adults
Duration	5-15 minutes

Table of Content

1. Purpose of the measuring instrument

To estimate body composition and hydration status based on multi-frequency impedance measurements.

2. Abbreviations and algorithms

Abbreviations	Explanation and/or formula
BCM	Body cell mass
MFBIA	Multi-frequency bioelectrical impedance analysis
BIVA	Bioelectrical impedance vector analysis
BMI	Body mass index
ECW	Extracellular water
ICW	Intracellular water
PA	Phase angle (degrees) = $arctan\left(\frac{reactance}{resistance}\right) x \left(\frac{180}{\pi}\right)$
R	Resistance (Ω)
TBW	Total body water
FM	Fat mass (kg) = body weight (kg) – fat free mass (kg)
FFM	Fat free mass (kg) = body weight (kg) – fat mass (kg)
Xc	Reactance (Ω) = resistance of the cell membranes
Z	Impedance (Ω) = $\sqrt{(resistance^2 + reactance^2)}$

3. Background information and reliability

3.1 Background

Bioelectrical impedance analysis (BIA) is a double indirect, non-invasive method used to estimate body composition. It is based on the electrical conduction of alternating current through the body, in which the body's resistance plays a role. Water is a good conductor, while fat is a poor conductor. The better the conduction of alternating current through the body, the lower the resistance (R). When the current passes through a cell, the cell wall causes a short delay. This temporarily increases the electrical potential, generating enough energy to penetrate the cell wall. This short delay in energy flow is called reactance (Xc).

Impedance (Z) is the combination of resistance (R) and reactance (Xc) and is used to calculate the body's fat free mass (FFM). The phase angle (PA) is the angle between the impedance (Xc) and the resistance (R). This is a measure of both the quantity and quality of the body's cells.

A multi-frequency (MF) BIA measurement measures impedance at multiple frequencies (5 to 3000 kHz). By measuring different frequencies, a distinction can be made between intracellular water (ICW) and extracellular water (ECW). At low frequencies, the electrical current flows around the cell membranes via the ECW. At higher frequencies, the current can penetrate the cell membranes, as a result both ICW and ECW are measured (see Figure 1). The greater the range between high and low frequencies, the better this distinction can be made.

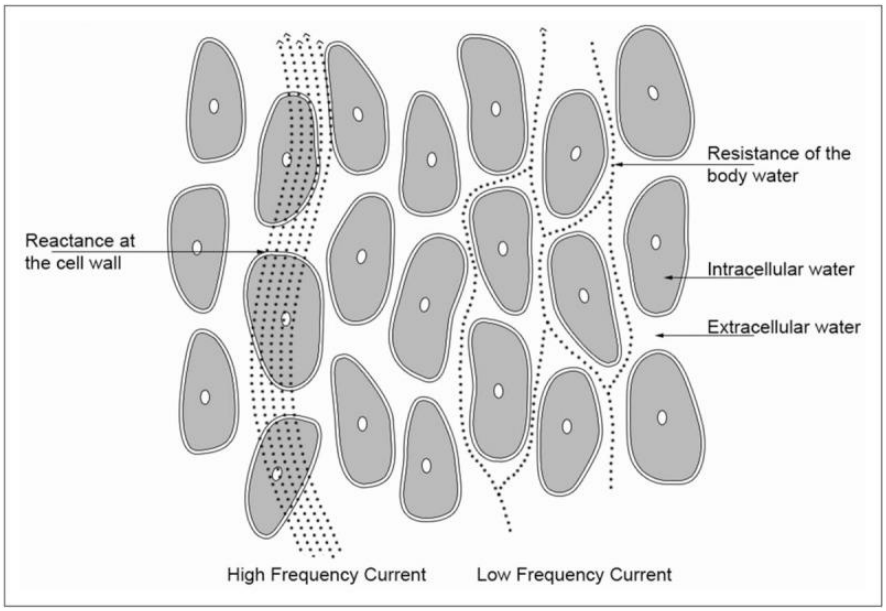


Figure 1. Principle of the MFBIA (Moonen HPFX,2021)

3.2 Reliability and validity

You **measure** the participant's reactance and resistance and **calculate** a body parameter. The algorithms used for this are not applicable to all groups. The manufacturer can be contacted to determine which population these algorithms are based on. To interpret the results of the MFBIA, you must consider the assumptions and the statistical correlation between the measurement method (impedance) and the body parameter.

Assumptions:

- The body is composed of 5 cylinders of uniform cross-section. The two arms, two legs, and trunk are considered 5 cylinders.

- The body consists of a constant portion of water. This is only true with a normal hydration status*.

* In cases of hydration abnormalities, MFBIA is suitable, unlike SF-BIA, where measurements are not recommended when the hydration status is abnormal. MFBIA allows you to assess hydration status because it distinguishes between intracellular water (ICW) and extracellular water (ECW). This makes it possible to track measurements over time and assess changes in body composition, and to determine whether these are caused by changes in fat, fat-free mass, or water.

Advantages:

The measurement is relatively inexpensive, non-invasive, and in many cases, the MFBIA device is portable. It provides insight into body composition, which can be monitored over time. MFBIA has several additional advantages compared with SF BIA (see SOP SF BIA). It can distinguish between ICW and ECW, providing information about hydration status. For some MFBIA devices, a fluid correction can even be calculated (see, for example, the Inbody s10 SOP). In addition, most MFBIA devices measure both sides of the body using 8 points, making it possible to perform segmental analyses.

Disadvantages:

MFBIA is a double indirect method, and there are many factors that influence the outcome. Therefore, it is less reliable and valid than indirect methods such as DXA and ADP.

Factors influencing MFBIA outcome: (Schotman J., 2021; Kyle, U.G., 2004; Earthman, C.P,2015.)

1. Cylinder diameter
   The thinner the cylinder (with a smaller diameter), the greater the resistance. Therefore, the trunk (with a larger diameter) has less influence on body resistance. Consequently, MFBIA can detect changes in limb resistance more effectively than changes in abdominal fat.
2. Composition of the compartments
3. Temperature
4. Cell membrane quality
5. Height and weight measurement
6. Placement of the electrodes
7. Poor contact between the electrode and the skin

Due to: lotion use, wounds, and/or hair on the hands or feet.

8. Pressure ulcer, wounds
9. Time spent lying down before the measurement
10. Movement prior to measurement
11. Fluid balance, including menstruation
12. Full bladder

    A full bladder affects weight but not measured resistance. A full bladder (and therefore a higher weight) results in a higher fat mass in the formula. You can ask the participant to urinate before the measurement or, if necessary, use a weight measured in the morning with an empty bladder.
13. Metal in or on the body
14. Implants (except dental implants), IV
15. Position

    Position (lying, standing, or sitting) affects BIA results based on fluid distribution. For most MFBIAs, lying down is the recommended position because body fluids are better distributed, making the measurement more stable and reliable. It also reduces the influence of gravity on fluid distribution. The lying position is used in the ESPEN guideline and in determining most reference values and formulas. However, if measuring while lying down is not feasible, it is also possible to measure in a standing or sitting position. Some MFBIAs are designed for standing measurements. The phase angle is then approximately 1 degree lower, and the algorithms are adjusted for the standing measurement. It is important to maintain the same position for each measurement so that you can compare the results accurately.
16. Eating and drinking

    The European Society for Clinical Nutrition and Metabolism (ESPEN) guideline recommends/prescribes performing BIA measurements in a fasting state, with at least 2 hours recommended in a clinical setting and 8 hours in a research setting (Kyle, U.G., 2004). Because it is undesirable to ask patients with malnutrition and/or sarcopenia to fast, and there is no robust literature supporting this strategy in the guideline, Korzilius et al. conducted a study (Korzilius, J.W., 2023). The authors' conclusion was consistent with the ESPEN guideline, in which they found that eating affects BIA measurements, but these remain within clinically acceptable limits when a standardized breakfast is used. These findings were confirmed in a study by Hollander-Kraaijeveld et al., in which a similar approach was applied to a group of patients with cystic fibrosis (Hollander-Kraaijeveld, F.M., 2020). Both studies concluded that it is not necessary to perform BIA measurements in a fasting state.

In conclusion: To use MFBIA, it is essential to work in a standardized manner as much as possible to minimize the influences of different factors. To interpret MFBIA data, the

context and circumstances of the measurement must be considered. If measurements are taken under controlled and standardized conditions, BIA is sufficiently valid to compare patients with themselves over a certain period of time.

4. Target audience

Children aged 3 years and older, and adults.

4.1 Indications

- As a parameter in the diagnosis of nutritional status (e.g., malnutrition and sarcopenia or sarcopenic obesity)
- To monitor changes in body composition during nutritional interventions
- For segmental body composition analysis (if applicable, depending on the MFBIA device used)
- As a variable in the calculation of protein requirements (Dekker, I. 2021)
- To assess hydration status

4.2 Contraindications

There is no contraindication for MFBIA.
Many manufacturers of MFBIA devices list a pacemaker as a contraindication in their manuals due to concerns about pacemaker malfunction. However, theoretically, it is unlikely that an electrical current of 5-1000 kHz will interfere with the pacemaker because:

- These high frequencies are far removed from the cardiac frequency (20 Hz)
- Bandpass filters are built into the pacemaker to attenuate high-frequency currents.

In collaboration with the Dutch Working Group on Cardiology Dietitians, a literature review was conducted (Zweers, H. 2023). This concluded that MFBIA is safe with a pacemaker or implantable Cardioverter defibrillator and that there is no scientific evidence to justify maintaining the contraindication for MFBIA with a pacemaker.
There is also no contraindication for a Deep Brain Stimulator used to treat Parkinson's disease. The reason this is safe is because the current does not pass through the brain but only through the limbs and trunk.

4.3 Less reliable for; (Schotman J., 2021; Kyle, U.G., 2004; Earthman, C.P,2015.)

The factors listed below reduce the validity of the MFBIA measurement. The measurement itself is not dangerous, and sometimes it can still be useful to perform the MFBIA measurement, especially since there are few suitable alternatives. However, when MFBIA is less reliable, the results must be interpreted with caution. Comparing results with reference values or calculating protein requirements based on estimated FFM is less reliable. Monitoring body composition over time is often possible if the measurement error is systematic and standardized.

- Pregnancy
  Pregnancy affects body composition, and there are no algorithms available for pregnancy.
- Fever
  Fever increases body temperature, which can lead to a reduction in resistance. This may result in an underestimation of fat mass (FM) and an overestimation of FFM.
- Abnormal body mass index (BMI)
  Due to the lack of suitable algorithms, MFBIA is less valid for low or high BMIs. Because of the inaccuracy of MFBIA in obesity, it is valuable to include waist circumference in addition to MFBIA to monitor changes in abdominal fat. The reason for the lack of suitable algorithms for low BMIs is that the algorithms have been validated in a healthy population, where low BMIs are very rare. The lack of reliable algorithms for morbid obesity is due to several challenges in validating such algorithms:
  - There are no reference values available for patients with morbid obesity because the DXA examination table and the BodPod are too small, making the reference measurement impossible.
  - Abdominal fat is underestimated because the trunk represents only 10% of the total resistance.
  - When a patient has many skinfolds, the body shape no longer meets the cylinder assumption required for a reliable MFBIA measurement.
- Abnormal height
  For people with dwarfism or very tall people (>2 meters), MFBIA is less reliable because the algorithms used for MF BIA include height as a variable. These algorithms have not been validated for people with abnormal heights.
- Amputations
  Height and weight play a significant role in the formulas used for MFBIA. Limb amputations (amputations of only a finger or toe have a negligible effect) affect these variables, making the results of the MFBIA less reliable. It is not recommended to perform BIA on patients with amputations for determining protein requirements or

diagnosing malnutrition or sarcopenia. Cut-off points and reference values are not applicable. However, BIA allows for comparison of patients with themselves over time.

4.4 Less useful for;

- Patients in palliative phase
  The Nutrition Assessment Platform considers it of little use to perform MFBIA measurements in patients in the palliative phase. Tracking the decline in FFM and PA offers little added value because there are no therapeutic options for improvement.

5. Safety

MFBIA is safe and painless to use. The test administrator should be trained in its use and interpretation.

6. Description of the measuring instrument

To choose a MFBIA device, you can consider several aspects. For example, the population on which the algorithm is based must be known. The formula should be based on the largest possible group with the greatest possible BMI variation. The test population should be a good approximation of the Dutch population.

In addition, the following considerations should be taken into account: What is the budget? Does the device use electrodes or clamps? Is the device mobile? Is segmental analysis possible (8-point measurement)? Is it desirable to be able to perform a fluid correction (for example, in dialysis)?

Please note that this SOP is not written specifically for any particular device. The consumer guide provides insight into the characteristics of various MF BIAs, which can help in selecting a suitable device for the specific setting in which it will be used.

7. Cleaning and maintenance

7.1 Cleaning

Disposable adhesives (electrodes or Biatrodes™) should be discarded after each use.

7.2 Maintenance

For maintenance instructions, please refer to the MFBIA analyzer manual or follow the applicable guidelines in your own work environment. Generally, MFBIA analyzers require little maintenance. The cables of the MFBIA analyzer are the most vulnerable components.

8. Method

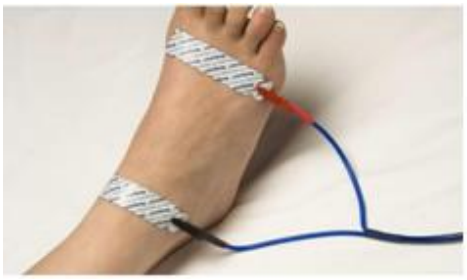
8.1 Supplies

- MFBIA device. See the MFBIA device manual for variant-specific features, such as separate electrode stickers.
- Cleaning alcohol and/or disposable paper towels
- A quiet room with a bed and an ambient temperature between 20-25°C.

8.2 Preparation

- When planning the measurement, instruct the participant in advance about the measurement and ask the participant to avoid physical exertion before the measurement.
- Ask the participant to urinate before the measurement (or use the weight measured in the morning with an empty bladder (Geranda.E.C.Slager, 2025)).
- Ask the participant to remove their jewelry and keys from their pockets. Earrings and piercings are permitted, but please note their use. A belt may remain on as long as it does not touch the skin.
- Measure the height and weight according to the standard operating procedures (SOP's). Correct the measured weight for clothing and, if applicable, shoes.
- Let the participant lie down 5-10 minutes before the measurement.
- Ask about factors that influence the results of the MFBIA or check them in the medical record.
- Make sure that the participant's body does not touch metal or conductive objects, such as a bed rail or chair back.
- Check the participant's position. When taking a measurement in the lying position: Make sure the legs are at a 45-degree angle and the arms at a 30-degree angle. If the upper legs touch each other and the upper arms touch the trunk (often the case with obesity), then use a towel or other insulating material between the thighs and between the arm and the truck. When taking a measurement while sitting: Make sure the participant sits upright with the legs uncrossed and the hands away from the body. Make sure the participant sits upright, away from the backrest, with their feet placed on insulating material. For standing measurements on MFBIA devices intended for this purpose, see the instruction manual of the device in question.
- Check the cables. They should not be run close to high-voltage equipment, such as computer monitors. The cables should not be twisted or bent.
- If the skin is oily, for example, due to the use of cream or body lotion, clean the skin beforehand to remove the grease. For this, you can use alcohol-based cleaning wipes; these do not need to be from a specific brand. Please note that the wipes do not contain

protective oil. The most important thing is that the electrodes make good contact with the skin and that they are used in a standardized manner. If necessary, remove excess hair by shaving it. For a MF measurement with electrodes**:** Place the electrodes on a normal area of skin, avoiding areas with many moles, scars, wounds, and/or hair. Place the electrodes as shown in figures 1 and 2. If there is no normal piece of skin available on the front of the hand or foot, the electrodes can be placed at the same height on the back, for example in the case of an IV (Geranda.E.C.Slager, 2024).



Hand (Figure 1)

- Place the voltage electrode (on many MF-BIA devices and in figure 3 this is the black electrode) on the wrist between the wrist bones.
- Position the injecting electrode (on many MF-BIA devices and in Figure 3 this is the red electrode) under the knob of the middle finger in a straight line above the voltage electrode.

Foot (Figure 2)

- Place the tension electrode (black) on the ankle between the ankle bones.
- Position the injecting electrode (red) on the foot, 1 cm below the second toe.

There should be at least 5 cm of space between the two electrodes (at least 3 cm in children), and the position of the voltage electrode is always fixed on the bump. In children and in persons where this distance is less than 5 cm, the injecting electrode (red) should be placed on the fingers. When taking repeated measurements, it is essential that the electrodes are placed in the same location. Therefore, it can be useful to always keep the same distance, for example 5-7 cm or the distance corresponding to your badge or the plastic sheet on which the electrodes are attached or the name badge. Check that there is no friction on the electrodes because the cables are not hanging freely.

Specifically for children: It is of great importance to give them a clear explanation of what will happen before the measurement begins. If the child is anxious, it may be useful to first

perform the measurement on one of the parents/caregivers. If necessary, the assistance of a pedagogical employee can be requested.

8.3 Measurement

- Instruct the participant to lie down relaxed and not to move, talk or tense any muscles during the measurement.
- Turn on the MFBIA meter and follow the instructions of the measuring device.
- After the measurement, disconnect the participant and remove the electrodes.

Specifically for children: After the measurement, a reward can be provided based on a savings system (for example Franniez, champion beads, diploma of bravery).

8.4 Processing of the results

Follow the instructions of the respective MFBIA device; it will display an output showing the calculated body composition parameters based on the algorithm compared to the reference values. The reference values used can be requested from the manufacturer. **Please note** whether the reference values are BMI dependent or not. This is important when assessing if someone has low muscle mass or not according to the current cut-off points in the GLIM criteria (Cederhorm, 2025). People with overweight and obesity rarely meet the criteria for low muscle mass. Of course, it is possible that people with overweight and obesity have relatively low muscle mass and to assess this you need BMI-dependent reference values (For example, SECA has it but not Inbody). If your MFBIA device does not have BMI-dependent cut-off points, you can still look at the water ratio and the BIVA gram. A relatively low ICW and low BCM also indicate relatively low muscle mass (see assessing hydration status).

Phase angle (PA)

The phase angle is a measure of cell health and nutritional status, calculated from an electrical measurement (BIA) as the angle between reactance and resistance. A higher phase angle indicates better cell membrane integrity and fat free mass, while a low phase angle indicates malnutrition, disease and increased risk of mortality. The phase angle can be used to monitor cellular health, muscle quality and nutritional status. The phase angle is calculated as arctan (reactance(R) /resistance (Xc)) x (180 / π). The phase angle in healthy people usually varies between 5 and 7, where athletes can sometimes have values around 9 and sick people have a lower phase angle of around 4 (Bosy-Westphal, A., 2006; Norman, K., 2012). For reference values of the phase angle, the Bosy-Westphal reference is used (Bosy-Westphal, 2006).

Bioelectrical impedance vector analysis (BIVA)

BIVA provides insight into fluid balance and body cell mass (BCM). BCM is a measure of active tissue, mainly muscle mass and organs. BIVA allows the raw results of the BIA measured at 50 kHz on the right side of the body (the same as the SF BIA) (resistance and reactance) to be interpreted without using population-specific algorithms (Earthman, C.P,2015). In a graph, resistance/length^2 is plotted on the x-axis against reactance/length^2 on the y-axis. Using BIVA software, supplied by the MF BIA manufacturer, in the output this can be displayed as a point (vector point) on a BIVA nomogram (Figure 5).

In the BIVA nomogram, three ellipses are visible, corresponding to the 50th, 75th and 95th vector percentiles of a reference population. This reference population is composed of healthy individuals. Specific nomograms are currently being developed for certain diseases, as well as for neonates and young children (Norman, K.,2012; Buffa, R., 2014.). The ellipses in a nomogram are sex and height specific. The nomograms and reference population provided by the MFBIA equipment manufacturers are based on their own reference population. As a result, nomograms vary between manufacturers.

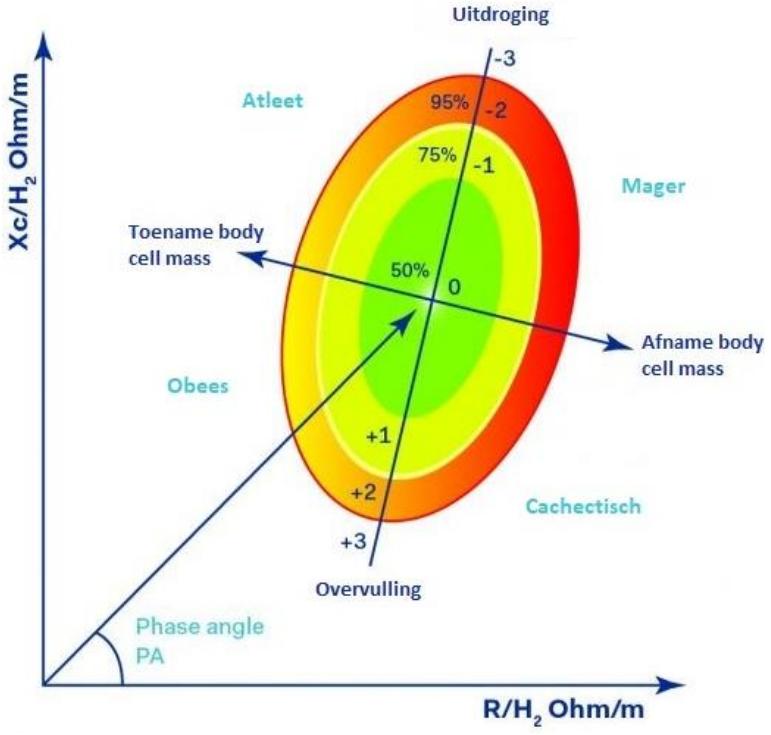


Figure 5: BIVA nomogram (NtVD, 2017)

Interpretation of results in BIVA nomogram

With multiple measurements over time, shifts can occur in both vertical and horizontal directions.

The nearly vertical axis (longitudinal axis) represents hydration status. As hydration status increases, the vector point moves downwards, while as hydration status decreases, the vector point moves upwards. There is a state of dehydration if the vector point is above the 75th percentile on the longitudinal axis. If it is outside the 75th percentile at the bottom, then there is overhydration.

The nearly horizontal axis (width axis) represents BCM. As the BCM decreases, the vector point moves to the right, and with an increase it shifts to the left. If the vector point is located far to the right, the BCM is low, indicating little active tissue and likely low muscle mass. If the vector point is located far to the left, there is a lot of active tissue and probably high muscle mass.

Hydration status assessment

For this, you use the BIVA plot, the ECW/TBW ratio or impedance ratio, and segmental analysis in combination with relevant medical data about your patient.

ECW/TBW ratio

The ECW ratio, also known as water ratio, indicates the ratio between ECW and Total Body Water (TBW). Here, the TBW is composed of ICW + ECW. If this ratio is high, it could be due to:

1) Overhydration (high ECW) thus edema in the legs. If edema is the cause of a high ECW/TBW ratio, you can search for explanatory causes in the medical record such as low albumin, renal failure, or heart failure. For example, clinical patients immediately after surgery are often overfilled with infusions. In segmental analysis, this can often be seen in mobile patients as high FFM in the legs compared to the trunk and arms. If the ECW is high due to edema, the BIVA plot indicates that the patient is overhydrated (the vector is at the bottom of the vertical axis). With the MFBIAs from Inbody® and the BIS from Fresenius®, you can apply a correction to body weight, FFM and muscle mass after detecting overhydration. For this, please see the brand specific SOP. In other MFBIAs it is not possible to apply this correction, which means that in the presence of edema, fat-free mass (FFM) and muscle mass are overestimated. If you want to use the FFM to calculate the protein requirement for someone with edema in the legs, you must consider that the FFM is overestimated. It is then appropriate to adjust the protein requirement slightly downwards based on the FFM. In practice, the overestimation of the FFM in cases of leg edema is usually no more than 2 kg. For example, with a recommendation of 1.5 grams of protein per kilogram of FFM, this means a maximum deviation of approximately 3 grams of protein.

2) Low ICW may result from low muscle mass, as seen in cachexia, sarcopenia, malnutrition, or in patients with muscle disease. With a low ICW as the cause of the high ECW/TBW ratio, you do not see a higher FFM in the legs on the segmental analysis. When comparing muscle mass with reference values, the muscle mass is low. In overweight people, you can often only see this if you use BMI specific references. If the high ECW/TBW ratio is due to a low ICW, then the hydration status in the BIVA plot is usually normal, and the BCM is low (the dot on the right of the horizontal axis). In this case, correcting weight for fluids is useless.

Impedance ratio

Some MFBIAs, for example Bodystat, work with an impedance ratio, also called a prediction marker. Here the resistance at 200 kHz (measure for TBW) is divided by the resistance at 5 kHz (measure for ECW). The closer this impedance ratio gets to 1.0, the more the resistance determination is influenced by ECW. The aim is a ratio <0.8. The impedance ratio allows you to estimate whether you have a reliable BIA measurement or whether the measurement has been affected by fluids. See also video of bodystat.

Fluid accumulation in the abdomen or trunk is more difficult to assess with the BIA, because the resistance of the trunk accounts for only a limited portion of the total body resistance. The extra weight due to fluid in the trunk, such as in ascites, polycystic kidney disease and pleural effusion, is incorrectly classified as fat mass. This does not lead to an overestimation of fat-free mass and muscle mass, as with edema in the legs, but rather to an overestimation of fat mass.

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