Body composition measurements: interpretation finally made easy for clinical use

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Purpose of review

This review presents the latest clinical applications of bioelectrical impedance analysis. It discusses the evaluation of nutritional status by using fat-free mass and body fat, percentiles of fat-free mass and body fat, height-normalized fat-free mass and body fat mass indices and a resistance/reactance vector graph.

Recent findings

Fat-free mass and body fat can be used to evaluate nutritional status by comparing individuals or groups of individuals with themselves or with reference values. Percentile distributions are also useful in determining whether individuals or groups fall within the population range. Percentile ranks can also be used to define nutritional depletion and obesity. The use of the fat-free mass and body fat mass indices has the advantage of compensating for differences in body height. The use of low, normal, high and very high fat-free mass and body fat mass indices ranges that correspond to underweight, normal, overweight and obese body mass index categories further aid in the nutritional assessment process. With vector bioelectrical impedance analysis, an individual impedance vector is compared with the 50, 75, and 95% tolerance ellipses calculated in the reference, healthy population, allowing evaluation in any clinical condition. More accurate estimates of conventional bioelectrical impedance analysis equations might be obtained in individuals with a normal impedance vector.

Summary

The assessment of fat-free mass and body fat provides valuable information about changes in body composition with weight gain or loss and physical activity, and during ageing. The use of percentiles and height-normalized fat-free mass and body fat permit the classification of patients as under or overnourished.

Keywords

bioelectrical impedance analysis, bioimpedance vector, body composition, fat-free mass, body fat, nutritional assessment

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Abbreviations

BFMI	body fat mass index
BIA	bioelectrical impedance analysis
BIS	bioimpedance spectroscopy
BMI	body mass index
FFM	fat-free mass
FFMI	fat-free mass index
TBW	total body water

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Introduction

Recent findings have shown that there is an association between body composition and morbidity and mortality [1,2]. Kyle *et al.* [3•] found that a low fat-free mass index (FFMI) and a high body fat mass index (BFMI) were associated with increased lengths of hospital stay. The studies pointed to the importance of determining fat and lean body masses by direct measures, rather than relying on the body mass index (BMI) only when describing obesity and malnutrition-related mortality risk and clinical outcome. There is thus a real interest in determining the respective contribution of the lean and the fat masses to the body mass.

This review discusses recent clinical applications of bioelectrical impedance analysis (BIA). In particular, it discusses the evaluation of nutritional status by using traditional and recently developed parameters derived from BIA.

The classification of under or overweight historically has utilized the comparison of a measured body weight with a threshold of a criterion standard or reference value. Reference values were generally based on observed population distributions of measured weight (e.g. descriptive statistical distributions), such as the National Health and Examination Surveys (NHANES), whereas criterion standards were dependent on the relation of weight to morbidity or mortality outcomes (e.g. health outcomes), such as the Metropolitan Life Insurance Company tables [4]. The most often used criteria to designate under or overweight is a weight normalized for standing height. However, BMI is insensitive to body fatness, particularly at low BMI, as well as with above-normal muscle development. On the other hand, body composition measurements [e.g. fat-free mass (FFM) and body fat] permit a more precise evaluation of the nutritional status.

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Bioelectrical impedance analysis

BIA is an easy, safe, non-invasive, and convenient method to determine the lean and fat body compartments. A prerequisite of BIA is that the equations used to transform the measured resistance and reactance into predicted FFM or total body water (TBW) are adapted to the individuals measured and have been tested for validity in the populations for which they are intended. In these conditions, BIA equations are very accurate in the estimation of FFM and TBW. The use of 'general' prediction equations across different age and ethnic groups without previous testing of their validity should thus be avoided. Early BIA equations were validated in inadequate populations, as demonstrated in respiratory insufficiency patients [5]. Large variations were shown in the results that precluded the clinical interpretation of many formulae published in the literature.

Fluid imbalances remain a significant limitation to the use of BIA equations in clinical evaluation. Regional fluid accumulation influences the accuracy of the BIA measurement. Although single-frequency BIA is not valid under conditions of significantly altered hydration, this does not negate its use to predict absolute FFM or TBW in normally hydrated individuals. Both single and multiple-frequency BIA equations become inaccurate when the extra to intracellular ratio is altered as a result of disease and treatment (e.g. diuretics, dialysis, etc.) [6].

Table 1 shows the measured and calculated parameters and various methods of clinical interpretation. Resistance and reactance (or impedance magnitude and phase angle) are measured by the BIA analyser and then used to estimate FFM, body fat, TBW or body cell mass. This review discusses the evaluation of nutritional status by using FFM and body fat, percentiles of FFM and body fat, the height-normalized FFMI and BFMI and the vector BIA graph with a resistance–reactance graph. The review limits itself to single-frequency (50 kHz) BIA and does not include a discussion of body cell mass, total body, intra or extracellular water.

Fat-free mass and body fat

FFM and body fat can be used to evaluate the nutritional status by comparing individuals or groups of individuals with themselves (as an absolute value or percentage change) or with reference values (Table 1). Kyle and colleagues [7,8••,9••] evaluated the nutritional status by FFM and body fat and clinical assessment (by subjective global assessment) of 995 patients at hospital admission. FFM was significantly lower and body fat significantly higher in patients than in controls [7], and this was true for both 'acutely' and 'chronically' ill (symptoms for less than or greater than 7 days, respectively) subjects [8••]. Furthermore, FFM was significantly lower in severely depleted (by subjective global assessment) men and women and moderately depleted women ($P<0.001$) and body fat was significantly higher ($P<0.05$) in well-nourished patients than in volunteers [9••]. Patients older than 60 years had lower FFM and higher body fat values than did patients less than 60 years or age of volunteers ($P<0.001$) [9••].

Percentiles for fat-free mass and body fat

Percentile distributions are useful in determining whether or not an individual falls within the population range. Percentile ranks, such as the 10th and 90th percentiles ($P<10$, $P>90$), can be used to define nutritional depletion and obesity. However, percentile cut-off points are age, sex and population-specific, assume that the average in the population is desirable, and are vulnerable to changes over time as the population distribution changes (ethnic, lifestyle, genetic, etc.). For example, a comparison of ethnic differences in a 2411 sample of Japanese men and women [10] showed that height was 3–4%, weight 11–12%, BMI

Table 1. Measured and calculated quantities, obtained by bioelectrical impedance analysis or bioelectrical spectroscopy, and criteria used for clinical interpretation

Measured at various frequencies[a,b]	Calculated using regression equations	Criteria for clinical interpretation
Resistance and reactance[b,c]	Fat-free mass	Absolute or relative values of mass/volume (kg, l or %)
	Fat-free mass index	Percentiles ($P<10$, …, $P>90$) of univariate or bivariate distributions
Impedance magnitude and phase angle[d]	Body fat	calculated variables (e.g. FFMI, BFMI)
	Body fat mass index	measured vector components (e.g. *R*, *Xc*, phase angle)
	Body cell mass	bivariate impedance vector measurements (e.g. *RXc* graph)
	Total body water	Nutritional status category:
	Intra and extracellular water	low, normal, high, very high FFMI or BFMI

BFMI, Body fat mass index; FFMI, fat-free mass index.[a]50 kHz is the most common frequency. Frequencies can vary from 1 to 1000 kHz. [b]Two of the four measures are necessary for the calculation of body composition parameters, referring to either [c]rectangular or [d]polar vector coordinates.

1–3%, FFM 18–20%, and body fat was 1–2% lower than in 5225 Swiss men and women [11]. On the other hand, the percentage body fat was 10–12% higher in Japanese who had lower BMIs than Swiss men and women. Deurenberg-Yap *et al.* [12] also found higher percentages of body fat at lower BMIs in other Asian populations (Chinese, Malay, Singaporian Indians).

Differences in percentile ranks were also noted when comparing Danish and Swiss individuals. Although the median BMIs were not remarkably different in Danish than in Swiss individuals, the median FFM was higher in taller and heavier Danish individuals, and the greatest differences (higher weight, FFM and body fat) were noted at the highest percentile. Percentile distributions must thus be developed in the population for which they are used.

However, percentile classifications permit the evaluation of the nutritional status of patients. Kyle *et al.* [7] found a significantly higher prevalence (31.2%) of $FFM_{P<10}$ in patients at hospital admission compared with healthy volunteers (9.9%), and noted that prevalence of malnutrition was underestimated by a BMI of less than 20 kg/m^2 (17.3% of patients) or serum albumin (14.9%). The prevalence was higher in patients admitted to medical (35.4%) than to surgical (30.4%) or trauma services (12.1%). Furthermore, the authors found that 72.9% of patients with a BMI of less than 20.0 kg/m^2 fell below $P<10$, compared with 32.9% of controls. In addition, 31% of patients with a BMI of 20–24.9 kg/m^2 compared with 12% of volunteers fell below $FFM_{P<10}$. Therefore a higher proportion of patients than controls and almost a third of patients with normal BMIs were 'malnourished' by definition $FFM_{P<10}$. Differences were also noted when patients were classified as 'acutely' or 'chronically' ill [8••]. Thirty-seven per cent of chronically ill and 24.7% of acutely ill patients were below $FFM_{P<10}$.

The prevalence of $FFM_{P<10}$ was also evaluated in Berlin (399 men, 26.4 ± 4.4 kg/m^2; 368 women, 25.7 ± 5.2 kg/m^2) compared with Geneva patients (525 men, 24.3 ± 3.9 kg/m^2; 470 women, 23.4 ± 4.5 kg/m^2) and healthy volunteers (924 men, 24.8 ± 2.9 kg/m^2; 838 women, 24.0 ± 3.8 kg/m^2) [13•]. The prevalence of $FFM_{P<10}$ was higher in Geneva (31.3%) than in Berlin patients (17.3%) and than in volunteers (9.5%). A higher prevalence of adiposity (body $fat_{P>90}$) was noted in Berlin (40.8%) than in Geneva patients (26.5%) and than in volunteers (11.0%). Berlin and Geneva patients thus had a higher prevalence of low FFM and high body fat than volunteers. In summary, the higher BMI in Berlin patients appeared to protect patients from FFM depletion, but increased the prevalence of high body fat compared with Geneva patients.

Height-normalized indices of body composition: fat-free mass and body fat mass indices

FFMI and BFMI have the advantage of compensating for differences in height. Just as BMI is useful in evaluating the excess or deficit in body weight of individuals of different heights, so are FFMI and BFMI (kg/m^2) potentially useful in evaluating body composition parameters in individuals who differ in height. Furthermore, FFMI and BFMI can identify individuals with normal BMI, but who are at potential risk because of decreased FFM or elevated body fat. Similarly, FFMI can identify body builders who have an elevated BMI without being obese or having excess body fat. Comparisons in body composition between older and younger individuals and between ethnic and racial groups may be facilitated with the use of FFMI and BFMI.

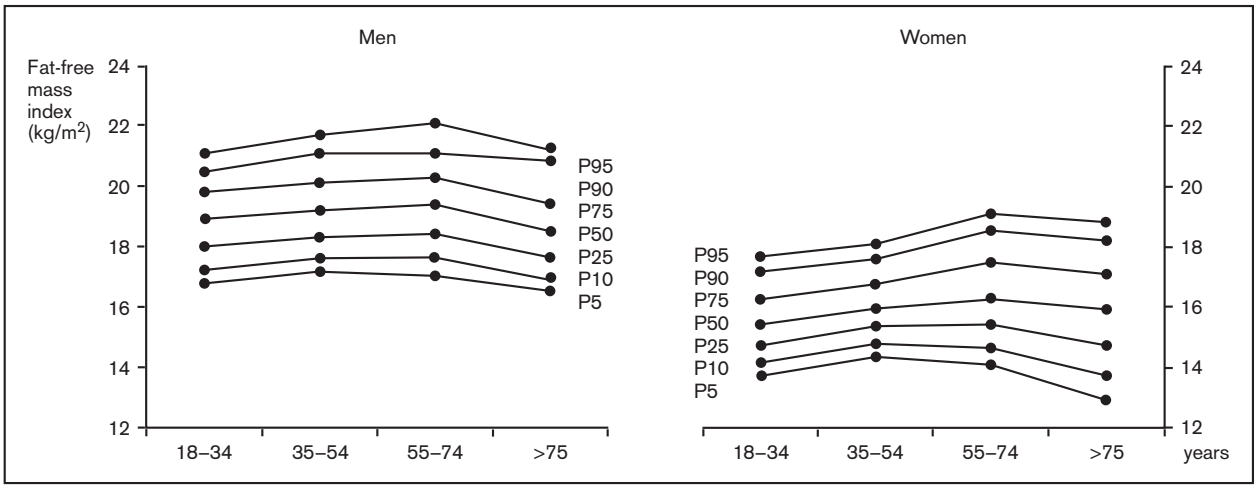
Figure 1 (adapted from Schutz *et al.* [14••]) shows percentiles of FFMI with age. FFMI is stable until 75 years and is lower thereafter. These results contradict previous findings of lower FFM after 50 years in men and women [10,15]. However, lower FFM is partly caused by shorter height of older individuals [10,11]. The differences are eliminated by the FFMI, and any differences in FFMI would reflect true lower FFM. Figure 2 (adapted from Schutz *et al.* [14••]) shows that BFMI increases with age in both men and women.

Kyle *et al.* [16] determined FFMI and BFMI ranges that correspond to BMI categories. Table 2 shows the amount of FFMI or BFMI that would be expected for a given BMI range and would represent low, normal or high amounts. The ranges were developed from polynomial regression equations and are based on 5629 healthy white adults (age 18–98 years). These ranges are independent of changes in body composition with increasing rates of obesity.

In a practical application of these FFMI and BFMI ranges, Kyle *et al.* (unpublished data) found that physically active individuals were significantly less likely to have a low or high FFMI (logistic regression, $P<0.001$) and a high or very high BFMI ($P<0.001$), and were more likely to have a low BFMI ($P<0.001$) compared with sedentary adults.

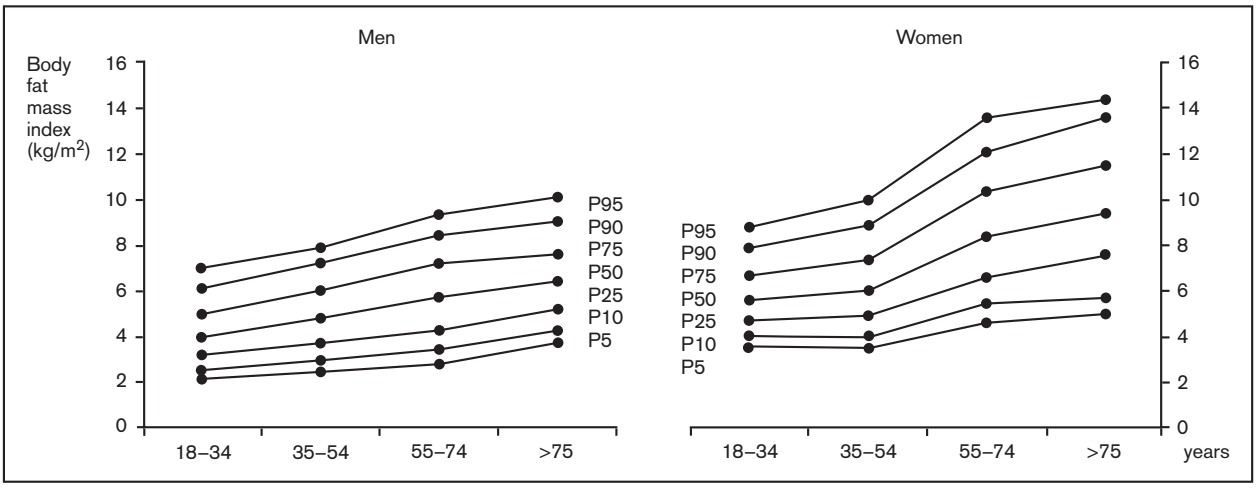
Multiple logistic regressions also showed a significant association ($P<0.001$) between the length of hospital stay and low FFMI and very high BFMI of 1762 patients evaluated at hospital admission in Geneva and Berlin, compared with volunteers. Low FFMI and very high BFMI thus appear to be indicators for longer lengths of stay [3•].

Figure 1. Percentile of fat-free mass index in Caucasian men (left) and women (right) from 15 to 98 years



Adapted from Schutz *et al.* [14••].

Figure 2. Percentile of body fat mass index in Caucasian men (left) and women (right) from 15 to 98 years



Adapted from Schutz *et al.* [14••].

Bioelectrical impedance vector analysis

The ultimate attractiveness of BIA lies in its potential as a stand-alone procedure free from equations and models, based on patterns of body composition derived from direct measurements of the impedance vectors. The vector BIA approach followed by Piccoli and colleagues [17,18,19••] only needs to take care of two unavoidable errors, i.e. the impedance measurement error and the biological variability of individuals. In vector BIA, resistance (*R*) and reactance (*Xc*), standardized for height, are plotted as point vectors in the *R*–*Xc* plane. An individual vector can then be compared with the reference 50, 75, and 95% tolerance ellipses calculated in the healthy population of the same sex and race (*RXc* graph method) (Figure 3).

From clinical validation studies in adults (renal patients with altered hydration or undergoing chronic haemodialysis, critical care patients and obese individuals) [17,18,19••], vectors falling outside the 75% tolerance ellipse indicated an abnormal tissue impedance, which is interpreted and ranked by following two directions: (1) vector displacements parallel to the major axis of tolerance ellipses indicate progressive changes in tissue

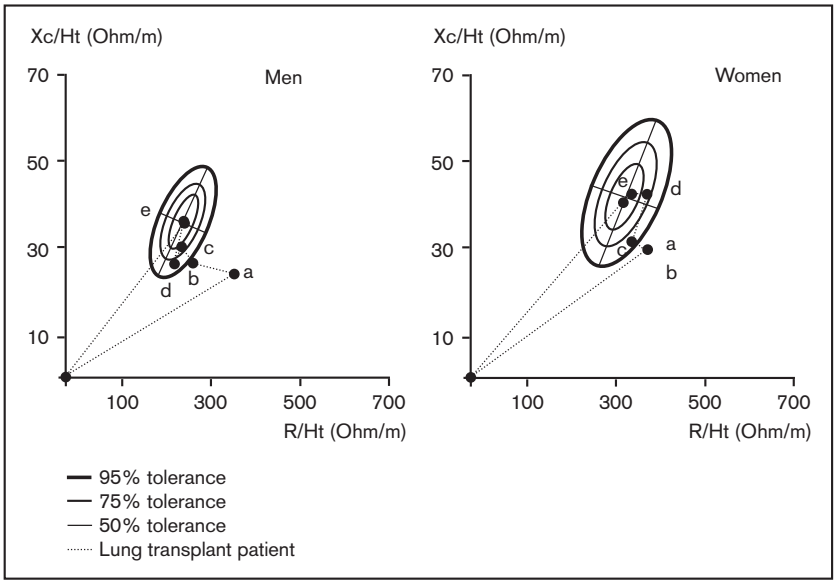
Table 2. Low, normal, high and very high fat-free mass index and body fat mass index values for corresponding body mass index categories in adults[a]

	Underweight	Normal weight	Overweight	Obesity
BMI category[a]				
Men and women (kg/m^2)	$\leqslant$18.5	18.5–24.9	25–29.9	$\geqslant$ 30
	Low	Normal	High	Very high
FFMI category[b]				
Men (kg/m^2)	$\leqslant$16.6	16.7–19.7	19.8–21.6	$\geqslant$21.7
Women (kg/m^2)	$\leqslant$14.5	14.6–16.7	16.8–18.1	$\geqslant$18.2
BFMI category[b]				
Men (kg/m^2)	$\leqslant$1.7	1.8–5.1	5.2–8.2	$\geqslant$8.3
Women (kg/m^2)	$\leqslant$3.8	3.9–8.1	8.2–11.7	$\geqslant$11.8

[a]World Health Organization categories, sex independent. [b]Adapted from Kyle *et al.* [16].

Figure 3. Vector bioelectrical impedance analysis with the *RXc* path graph of two patients after lung transplantation

The sex-specific, bivariate tolerance intervals for the impedance vector are depicted as 50, 75, and 95% tolerance ellipses calculated in our healthy Swiss reference population (age 18–59 years, 3102 men and 2643 women; *R*, resistance; *Xc*, reactance; and *Ht*, height). Repeated impedance measurements were obtained after lung transplantation: (a) 1 month; (b) 6 months; (c) 12 months; (d) 24 months; (e) 36 months. The initial vector position (a in man, a–b in woman) indicates soft tissue mass decrease (vector bioelectrical impedance analysis pattern of cachexia), more severe in man. The subsequent vector migration parallel to the minor axis of ellipses toward the target ellipse (a–d in man, b–c in woman) indicates an improvement in nutritional status with increasing hydrated soft tissue mass (i.e. decreasing *R* with increasing *Xc*). The final vector migration from the lower pole (vector bioelectrical impedance analysis pattern of tissue hyperhydration) to the centre of the 75% tolerance ellipse, following a trajectory parallel to the major axis (i.e. proportional increase in both *R* and *Xc*), indicates a loss of excess fluid leading to the complete restoration of tissue impedance, which was reached after 36 months in man (e) and 24 months in woman (d–e). Body weight increased from 52.5 to 74.1 kg in man (169 cm, 45 years), and from 42.5 to 52 kg in woman (161 cm, 39 years).



hydration (dehydration with long vectors, out of the upper pole, and hyperhydration with short vectors, out of the lower pole); and (2) vectors falling above (left) or below (right) the major axis of tolerance ellipses indicate more or less cell mass, respectively, contained in soft tissues. Different trajectories in the long-term monitoring of patients indicate combined changes in hydration and soft tissue mass. Figure 3 shows an example of vector BIA follow-up with the *RXc* path graph in a male (left) and female (right) patient after lung transplantation, using the 50th, 75th and 95th tolerance percentiles of our healthy Swiss reference population [11].

Limitations and precautions of bioelectrical impedance analysis

A number of limitations and precautions must be taken when BIA is used to determine body compartments, and a standardized measurement protocol must be followed to obtain valid results.

Elderly individuals

Genton *et al.* [20] found that previously validated BIA equations for use in the elderly under or overestimated FFM. The Geneva BIA formula, validated against dual-energy X-ray absorptiometry, showed small differences

and acceptable limits of agreement for FFM relative to FFM by dual-energy X-ray absorptiometry in elderly individuals with a BMI of 17–34.9 kg/m^2 [20]. External validation found that the Geneva equation gave an unbiased estimate of FFM in men, and underestimated FFM by 1.3 kg in women [21]. However, the use of 'general' prediction equations across different age groups without the previous testing of their validity should be avoided.

Ethnic groups

Deurenberg *et al.* [22•] found that the ethnic-specific bias of impedance-based prediction formulae for body composition is mainly caused by differences in body build among ethnic groups. This means that the use of 'general' prediction equations across different (ethnic) population groups without previous validation should be avoided. Total body impedance had a higher predictive value than segmental impedance.

Obesity

There is currently insufficient validation of BIA equations in obese individuals with BMIs above 34 kg/m^2. Bioimpedance spectroscopy (BIS) was slightly more accurate in obese individuals than linear regression, but was not sensitive enough for clinical use [23]. Changes in impedance did not satisfactorily predict the changes in anthropometric dimensions, despite the evidence of a substantial association between impedance and anthropometrics before and after a weight reduction program [24]. Cox-Reijven *et al.* [25••] found that BIS with the use of mixture equations overestimated fluid loss during weight loss in morbidly obese individuals. The error was associated with the amount of fat loss. Therefore, despite the enhancements in BIS technology, the differentiation of intra and extracellular water in obesity remains elusive [26]. More research is necessary to determine the validity of BIA in obesity.

Altered hydration state

Sonderberg *et al.* [27] found that although BIS corresponded well to weight changes at the group level, it correlated poorly in individual patients, which suggests that BIS is not suitable for monitoring fluid balance in patients with acute congestive heart failure undergoing diuretic treatment. The BIA also does not appear to be sufficiently accurate to determine intraperitoneal fluid changes, probably because the trunk contributes only 10% to whole body impedance. In our experience, repeated BIA measurements in patients at the end of haemodialysis treatment permit the longitudinal follow-up of changes in FFM and fat mass, but not an accurate estimation of acute changes in TBW. On the other hand, BIA equations, as currently available, are inadequate to determine the optimal dialysis volume and optimal dry body weight.

With vector BIA, the pre-postdialysis weight cycling of haemodialysis patients was represented with a cyclical, backward–forward displacement of the impedance vector along the major axis of tolerance ellipses [28].

Conclusion

An assessment of FFM and body fat provides valuable information about changes in body composition with weight gain or loss, physical activity, and during ageing. The use of percentiles and height-normalized FFM and body fat permit the refinement of the classification of patients as under or overnourished.

Acknowledgements

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