Fat-free mass in overweight and obese older women: analysis of concurrent validity of bioelectrical impedance equations

Massa livre de gordura em idosas com sobrepeso e obesidade: análise da validade concorrente de equações de impedância bioelétrica

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Abstract – Older adults, especially women, show a higher level of functional dependence and disability because of muscle and bone mass loss and of a progressive increase in body fat mass. These changes in body composition components have been observed by different techniques. The aim of this study was to analyze the concurrent validity of bioelectrical impedance equations obtained with the Valhalla device 7 and those proposed by Gray et al. 8 for the estimation of fat-free mass (FFM) in Brazilian elderly women. The sample (n=34; 60-71 years old, height of 140-162 cm) was divided into two groups (n=17) according to relative body fat (%BF) obtained by DXA: %BF ≤41 and %BF >41. DXA was used as the gold standard. All correlation coefficients were satisfactory (r>0.79). FFM Valhalla (%BF ≤41: 36.1±3.4 kg; %BF >41: 39.3±3.2 kg) did not differ (p>0.01) from FFM DXA (38.7±3.7 kg) in either group. However, the standard error of the estimate (SEE) was slightly higher (2.114 kg) than the recommended one in the %BF >41 group. FFM Gray differed (p<0.01) from FFM DXA in the two groups, although the SEE was satisfactory (<1.8 kg) in the %BF ≤41 group. The residual scores indicated the absence of agreement between FFM Gray and FFM DXA, reaching 7.08 kg. Only 9% of the subjects had FFM estimated within an acceptable error when the equation of Gray et al. 8 was used, while this percentage was 82% when the Valhalla equation was used. The latter equation showed concurrent validity for overweight and obese older women.

Key words: Body composition; Electrical impedance; Older adult; Test validity Validation studies.

Resumo – Os idosos têm apresentado maior dependência funcional e incapacidade, principalmente as mulheres, em decorrência da redução da massa muscular e óssea e do aumento progressivo da gordura corporal. Estas alterações nos componentes da composição corporal têm sido observadas por meio de diferentes técnicas. Nesse contexto, o objetivo deste estudo foi analisar a validade concorrente das equações de impedância bioelétrica para estimar a massa livre de gordura (MLG), do fabricante Valhalla 7 e de Gray et al. 8, em idosas brasileiras. A amostra (n= 34), com idade de 60-71 anos e estatura de 140-162 cm, foi dividida em dois grupos (n= 17) por gordura relativa (G%) via DEXA: G% ≤41%, G% >41%. A DEXA foi usada como padrão ouro. Todos os coeficientes de correlação foram (r >0,79) satisfatórios. Nos dois grupos, a MLG Valhalla (G% ≤41: 36,1±3,4kg; G% >41: 39,3±3,2kg) não diferiu (p >0,01) da MLG DXA (38,7±3,7kg), no entanto, o EPE (2,114 kg) foi um pouco acima do recomendado no grupo G% >41. A MLG Gray diferiu (p <0,01) da MLG DXA nos dois grupos, ainda que o EPE tenha sido satisfatório (<1,8 kg) no grupo com G% ≤41. Os escores residuais mostraram a falta de concordância da MLG Gray com a MLG DXA, chegando até 7,08kg. Pela equação de Gray et al. 8, somente 9% teve a MLG estimada dentro de um erro aceitável, enquanto que, pela equação Valhalla, 82%. Esta equação apresentou validade concorrente para as idosas com sobrepeso e obesidade.

Palavras-chave: Composição corporal; Estudos de validação; Idoso; Impedância elétrica; Validade dos testes.
INTRODUCTION

Following a worldwide trend, two processes have occurred in Brazil since the 1980s, which have produced important changes in the profile of diseases in the population. One process, called “demographic transition”, is characterized by a significant reduction in fertility and birth rates and a progressive increase in life expectancy. As a result, there is a progressive increase in the proportion of older adults compared to the other age groups, a trend that is expected to grow in the coming decades. The other process, characterized by important changes in the morbidity and mortality profile, is called “epidemiological transition”, in which the occurrence of infectious diseases is reduced and morbidity and mortality due to chronic noncommunicable diseases are increased. This transition is the result of different factors such as urbanization, access to health services, and significant lifestyle changes.

Within this context, in older adults, especially women, show a higher level of functional dependence and disability because of the loss of muscle and bone mass and of the progressive increase in body fat. These conditions increase the risk of falls, fractures, recurrent hospitalization, and mortality.

The alterations in body composition components have been observed by different techniques. Dual-energy X-ray absorptiometry (DXA) has been used to estimate different body components. Evidence indicates its validity to estimate fat-free mass (FFM) in older adults. In view of its high cost, time spent, radiation, and need for a well-trained technician, DXA is not an option for large-scale application. In contrast, the practicality and low cost of bioelectrical impedance analysis (BIA) facilitate its application to large samples and its use in field studies. Furthermore, equations containing predictors obtained by anthropometric measurements and BIA have been developed to estimate FFM more accurately as a function of certain physical, age, sexual and ethnic characteristics.

Among the existing equations developed for older adults, two recommended in classical studies did not have their concurrent validity tested in Brazilian elderly women, i.e., the equations of Valhalla and Gray et al. Therefore, the objective of the present study was to analyze the concurrent validity of these equations to estimate FFM in Brazilian elderly women.

METHODOLOGICAL PROCEDURES

Sample
The sample consisted of 34 women aged 60 to 71 years who lived in different satellite towns of Brasilia, DF, Brazil. All women of the study had migrated from different regions in the northeast and mid-west of Brazil to Brasilia and volunteered to participate in the study. The participants were informed about the objective and procedures adopted during data collection. All women read and signed the free informed consent form after all doubts about the procedure involved had been resolved. The study was
approved by the Research Ethics Committee of Universidade Católica de Brasília, DF (04/2005).

According to Pedhauzer\(^9\), in cross-validation studies the necessary number of subjects should correspond to 20\% or more of the sample size that gave origin to the equation. Hence, the minimum number of subjects in the present study was 13 for the equation of Gray \(et\ al.\)^8 and 15 for the Valhalla equation\(^7\).

**Data collection**

The volunteers were asked to adhere to the following protocol prior to the measurements: fasting for 4 h; no ingestion of coffee of alcoholic beverages 24 h before measurement; no strenuous physical activity; no use of diuretics, and to empty the bladder and bowels before measurement. During data collection, the participant was asked if she had followed the guidelines and if one or more had been ignored, data were collected on another day.

A single person made all measurements on the same day. First, body weight and height were measured, followed by DXA and BIA (Biodynamics 310). The room temperature during collection ranged from 20 to 26\°C. All participants were normally hydrated. Height was measured with a Filizola to the nearest 0.5 cm and body weight was measured with a scale to the nearest 100 g according to the procedures described by Gordon \(et\ al.\)^10.

The Hologic QDR-1500, software v.5.67 was used for the measurement of fat-free mass and relative fat by DXA. The algorithms of the software, which are used to obtain the values of body composition components, are unknown. The procedures described in the manual of the device were followed. Whole-body scans were obtained with the volunteer lying still with the elbows and knees extended. To guarantee the quality of the measurements, the device was calibrated weekly and daily. A phantom scan was performed for weekly calibration and quality control testing for daily calibration. The calibrations were carried out according to the procedures described in the manual of the equipment.

Resistance was estimated by BIA (Biodynamics 310) according to the instructions of the manual. This device is equipped with a software that provides the values of the body composition components, but the algorithms used to estimate these components are unknown. Resistance (R), body weight (BW) and height (H) were used in the equation of Gray \(et\ al.\)^8 and in another equation reported by Lohman\(^\). However, this equation is given in the body of a table entitled “Bioelectrical impedance equations used in Valhalla bioimpedance analyzers”. Certainly, this is an equation of the manufacturer Valhalla and not of Lohman and will from now on be called “Valhalla equation”.

Equation of Gray \(et\ al.\)^8:

\[
\text{FFM}_{kg} = 0.00151 \times (H^2) - 0.0344 \times (R_{\Omega}) + 0.14 \times (BW_{kg}) - 0.158 \times (Age_{\text{years}}) + 20.387.
\]

Valhalla equation:

\[
\text{FFM}_{kg} = 0.474 \times \left(\frac{H^2}{R_{\Omega}}\right) + 0.18 \times (BW_{kg}) + 7.3.
\]
Statistical analysis
First, the Kolmogorov-Smirnov test was applied to test the normality of the data, which showed a normal distribution. Descriptive statistics was used to characterize the sample and the independent \( t \)-test \((p \leq 0.05)\) to compare the two groups stratified according to the relative amount of body fat (%BF). The criteria suggested by Lohman\(^7\) were used to determine agreement between the Valhalla\(^7\) and Gray \textit{et al.}\(^8\) equations and DXA for estimating FFM in older women: Pearson’s linear correlation coefficient \((r) > 0.79\); paired \( t \)-test \((t)\), where \( t_{\text{calculated}} < t_{\text{tabulated}} \) \((p > 0.01)\), and standard error of the estimate \((\text{SEE} = s \sqrt{1 - R^2}) > 1.8 \text{ kg for the prediction of FFM.}\)

Finally, analysis of residual scores as proposed by Bland and Altman\(^12\) was performed. The data were analyzed using the licensed Statistical Package for the Social Sciences (SPSS)-IBM program, version 22.0.

RESULTS
We decided to divide the sample into two groups, one with %BF \( \leq 41\) and one with %BF >41 using the median of the sample itself. Gray \textit{et al.}\(^8\) showed that FFM estimated by BIA is overestimated compared to that obtained by hydrostatic weighing in more obese subjects and that this differences is smaller in subjects with %BF <41.1\%. The characteristics of these two groups are shown in Table 1. The groups were similar in age and height \((p > 0.05)\) and differed in terms of the other variables \((p \leq 0.05)\).

Table 1. Descriptive characteristics of older women stratified according to relative body fat.

<table>
<thead>
<tr>
<th>Variable</th>
<th>%BF ≤41 (n=17)</th>
<th>%BF &gt;41 (n=17)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimum</td>
<td>Maximum</td>
</tr>
<tr>
<td>Age (years)</td>
<td>64.3 ± 3.3(^a)</td>
<td>60</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>151.1 ± 5.1(^a)</td>
<td>141</td>
</tr>
<tr>
<td>Body weight (kg)</td>
<td>57.7 ± 6.1(^a)</td>
<td>48.2</td>
</tr>
<tr>
<td>BMI (kg/m(^2))</td>
<td>25.2 ± 2.2(^a)</td>
<td>22.8</td>
</tr>
<tr>
<td>%BF (DXA)</td>
<td>35.6 ± 3.4(^a)</td>
<td>30.2</td>
</tr>
</tbody>
</table>

%BF: relative body fat; BMI: body mass index; DXA: dual-energy X-ray absorptiometry. Means followed by the same superscript letter do not differ \((p > 0.05, \text{ independent } t\text{-test})\)

Table 2 shows the statistical results of the comparison of the BIA equations and DXA. All correlation coefficients were satisfactory \((r > 0.79)\). In the two groups, FFM obtained with the Valhalla equation (%BF ≤41: 36.1 ± 3.4 kg; %BF >41: 39.3 ± 3.2 kg) did not differ \((p > 0.01)\) from that obtained by DXA (38.7 ± 3.7 kg). However, the SEE (2.114 kg) was slightly higher than the recommended one\(^7\) in the group with higher %BF. Obviously, the criteria were met\(^7\) when the whole sample was considered \((n=34)\) \((\text{SEE} = 1.828 \text{ kg})\). FFM obtained with the equation of Gray \textit{et al.}\(^8\) differed significantly \((p < 0.01)\) from the FFM obtained by DXA in the two groups, although the SEE was only satisfactory in the group with %BF ≤41.
Table 2. Validation of equations to estimate fat-free mass in older women stratified according to relative body fat.

<table>
<thead>
<tr>
<th>Variable</th>
<th>%BF ≤41 (n=17)</th>
<th>%BF &gt;41 (n=17)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(X)</td>
<td>(r^*)</td>
</tr>
<tr>
<td>FFM DXA (kg)</td>
<td>37.0 ± 3.3</td>
<td></td>
</tr>
<tr>
<td>FFM Valhalla(^7) (kg)</td>
<td>36.1 ± 3.4</td>
<td>0.916</td>
</tr>
<tr>
<td>FFM Gray et al.(^8) (kg)</td>
<td>32.3 ± 4.1</td>
<td>0.927</td>
</tr>
</tbody>
</table>

FFM: fat-free mass; %BF: relative body fat; SEE: standard error of the estimate; DXA: dual-energy X-ray absorptiometry. \(^*\): \(p<0.0005\); \(r\): Pearson’s correlation coefficient; \(t\): \(t\)-test; \(p\): \(p\) value (probability).

Residual analysis (Figure 1) supports the results shown in Table 2, demonstrating that only 9% of the subjects had FFM estimated within an acceptable error when the equation of Gray et al.\(^8\) was used, while 82% of the sample had their FFM estimated with excellent accuracy when the Valhalla equation was used.

**DISCUSSION**

The development of an accurate method that can be applied on a large scale is essential to monitor FFM in older women. In this respect, using the criteria proposed by Lohman\(^7\) as parameters, the present results indicate that the Valhalla equation shows concurrent validity to estimate FFM in both overweight (%BF ≤41) and obese (%BF >41) older women.

The equation of Gray et al.\(^8\) has been recommended in classical textbooks\(^7,13\). However, its concurrent validity could not be demonstrated for the present sample, since a difference (\(p\leq0.01\)) was observed between mean FFM estimated with this equation and that obtained by DXA. Residual analysis showed wide individual differences between the two procedures.
These findings agree with those reported by Stolarczyk et al.\textsuperscript{11} who used hydrostatic weighing as the gold standard.

The SEEs obtained with the Valhalla equation are lower than that of the original equation (2.8 kg). The correlations are of high magnitude and the coefficient of determination indicates that 70 and 84% of the FFM estimated in overweight and obese women, respectively, is explained by the BIA equation. This demonstrates the concurrent validity of this equation for women aged 50 to 71 years, with $\%BF_{\text{DXA}}$ of 30 to 51%. The standard deviations indicate that the sample is represented as a whole in terms of DXA. Furthermore, residual analysis (Figure 1) indicates that 82% of the women had their FFM estimated with excellent accuracy, with an SEE less than 1.8 kg, demonstrating the excellent concurrent validity of the Valhalla equation. The same does not apply to the equation of Gray et al.\textsuperscript{8} whose residuals indicate that most (91%) women had their FFM estimated with an SEE of 2 to 7.5 kg, an unacceptable fact.

The stability of the regression coefficient for each predictor variable in the model can contribute substantially to the determination of concurrent validity. The stability of this coefficient from one population to another mainly depends on the number of subjects used for the development of the original prediction equation. Very stable coefficients are obtained when the ratio of subjects for each predictor variable is at least 20:1\textsuperscript{9}. A proportion of 25:1 was used for the Valhalla equation in a sample of women aged 50 to 70 years, while Gray et al.\textsuperscript{8} used a proportion of 15:1. Therefore, the age homogeneity of the original sample and the high proportion of women for each predictor variable greatly favored the concurrent validity of the Valhalla equation for the sample of this study. In contrast, the age heterogeneity (22 to 74 years) of the original sample, wide variation in $\%BF$ (19.5 to 59%) and low proportion of subjects for each predictor variable (15:1) contributed to the fact that the equation of Gray et al.\textsuperscript{8} did not exhibit concurrent validity.

Another factor that could explain the concurrent validity of the Valhalla equation is the use of $H^2/R$, which is a better predictor than $H^2$ or $R$ alone. $H^2/R$ has shown a high predictive power for both FFM\textsuperscript{14-15} and skeletal muscle mass\textsuperscript{16}. BIA is based on the principle that the resistance offered to the passage of an electrical current is related to the square length of the conductor. In this respect, Hoffer et al.\textsuperscript{14} and Lukaski et al.\textsuperscript{15} showed that total body water volume is correlated with $H^2/R$ in humans. This was confirmed in the present study in which the Valhalla equation, which uses $H^2/R$ as the regression coefficient, exhibited validity, while the equation of Gray et al.\textsuperscript{8}, which uses $H^2$ and $R$ as separate predictors, did not. Furthermore, the level of hydration may have also played a role since it tends to decrease with increasing age\textsuperscript{17}, thus affecting the regression coefficient of resistance, given the characteristics of the original sample and the sample of the present study.

With respect to the effect of the amount of body fat on the estimation errors of FFM using the equations compared to DXA, the errors tended to be higher in women with $\%BF > 41$ (SEE = 2.114 kg) compared to those with
%BF ≤41 (SEE = 1.360 kg). These results agree with the study of Glaner\textsuperscript{18}, in which the concurrent validity of BIA equations were tested compared to DXA using a tetrapolar model, as well as with the results of comparison of bipolar BIA compared to DXA\textsuperscript{19}.

In general, few of the equations developed in other countries exhibit concurrent validity for Brazilian subjects. In a similar study\textsuperscript{18}, the only equation showing concurrent validity (compared to DXA) for adult men was a specific equation for individuals with elevated body fat (%BF ≥20%). On the one hand, this demonstrates that models for BIA should include the level of %BF of the subjects for more accurate prediction. This appears to be confirmed in the present study since the sample also had high %BF (30 to 51%). On the other hand, studies indicate that DXA tends to overestimate %BF compared to computed tomography\textsuperscript{20}, plethysmography\textsuperscript{21}, four-component model\textsuperscript{22,23}, hydrostatic weighing\textsuperscript{22,24}, anthropometry\textsuperscript{25}, and BIA\textsuperscript{26}. These two critical points leave gaps and indicate the need for more conclusive evidence, i.e., whether BIA models for the estimation of FFM should indeed be structured according to groups with relatively homogenous %BF, and whether DXA is only accurate to quantify bone mineral density.

One important limitation of this study and of any other study designed to elucidate the concurrent validity of these equations is the lack of an unquestionable gold standard. DXA has been indicated in the scientific literature as the gold standard for the quantification of %BF and FFM. However, the manufacturers of these devices themselves only recommend DXA for the quantification of bone density\textsuperscript{27}, a fact increasing the probability of error and reducing the validity of the results. Nonetheless, \textit{in vitro} experiments found no differences (p≥0.05) in the estimates of different body components\textsuperscript{28,29}, a fact justifying the use of this method in the present study.

**CONCLUSION**

The Valhalla\textsuperscript{7} equation exhibits concurrent validity to estimate FFM in overweight and obese Brazilian women with the same demographic characteristics as those of the present sample. Using this equation, FFM was estimated with an acceptable error (SEE <1.8 kg) in 82% of the sample. The results suggest that the Valhalla is a suitable alternative of relatively low cost to accurately estimate FFM and consequently %BF in Brazilian women. The equation of Gray \textit{et al.}\textsuperscript{8} did not exhibit concurrent validity.

**REFERENCES**


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