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ARTICLE

Estimation of underreporting of energy intake using different methods in a subsample of the ELSA-Brasil study

Estimativa da subnotificação de ingestão energética através de diferentes métodos em uma subamostra do estudo ELSA-Brasil

Estimación de la infradeclaración de la ingesta de energía utilizando diferentes métodos en una submuestra del estudio del ELSA-Brasil

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Abstract

Existing methods for assessing food consumption are subject to measurement errors, especially the underreporting of energy intake, characterized by reporting energy intake below the minimum necessary to maintain body weight. This study aimed to compare the identification of energy intake underreporters using different predictive equations and instruments to collect dietary data. The study was conducted with 101 selected participants in the third wave of the Longitudinal Study of Adult Health *(ELSA-Brasil) at the University Hospital of the University of São Paulo. For the dietary assessment, we applied a food frequency questionnaire (FFQ), two 24-hour diet recall (24hR) using the GloboDiet software, and two 24hR using the Brasil-Nutri software. The energy intake underreport obtained from the FFQ was 13%, 16%, and 1% using the equations proposed by Goldberg et al. (1991), Black (2000), and McCrory et al. (2002), respectively. With these same equations, the 24hR described an underreport of 9.9%, 14.9%, and 0.9% respectively with the GloboDiet software and 14.7%, 15.8%, and 1.1% respectively with the Brasil-Nutri software. We verified a low prevalence of underreported energy intake among the three self-report-based dietary data collection methods (FFQ, 24hR with GloboDiet, and Brasil-Nutri). Though no statistically significant differences were found among three methods, the equations for each method differed among them. The agreement of energy intake between the methods was very similar, but the best was between GloboDiet and Brasil-Nutri.*

Diet Surveys; Energy Intake; Questionnaires and Surveys

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Introduction

The study of food consumption has important applications in the development, review, and monitoring of nutritional recommendations, public health policies, and nutritional epidemiological research [1,2]. In recent decades, nutritional epidemiological studies have significantly contributed to public health in diet-disease relationships, but the quality of evidence from observational studies has been questioned – partly because of methodological limitations, such as the measurement error of all self-reported assesments [3]. One of the most prevalent dietary measurement errors is underreporting energy intake [4]. The equation developed by Goldberg et al. [5], consisting of the relationship between energy intake (EI) and basal metabolic rate (BMR), is one of the most used methods to detect underreporting. However, this equation has limitations regarding physical activity level, being later reviewed by Black [6]. McCrory et al. [7] developed the most recent equation used to calculate underreporting, which is the ratio of reported EI (EIr) to predicted total energy expenditure (TEEp) considering sex, age, and height at the individual level.

The development of new technologies for dietary assessment is a field of research which can address long-existing challenges of traditional methods. Using computers, software, and applications can reduce the costs and time required to collect, to encode, and to analyze data and to improve data quality [8,9,10,11,12,13,14].

The *Longitudinal Study of Adult Health* (ELSA-Brasil) is a multicenter cohort survey with 15,105 participants of both sexes, active and retired workers from six Brazilian states, which aims to investigate the incidence of noncommunicable chronic diseases and their risk factors [15]. The primary method of collecting dietary data is the food frequency questionnaire (FFQ) [16]. However, in the third wave of the survey, held from 2017 to 2019, dietary data collection was introduced by the 24-hour diet recall (24hR) in a subsample using the Brazilian version of the GloboDiet software [17]. In parallel, a validation study of the Brasil-Nutri, GloboDiet, and FFQ instruments was conducted in a subsample of the ELSA-Brasil.

This study aimed to compare the identification of EI underreports using different predictive equations and instruments to collect dietary data.

Materials and methods

Study design

This study used data from a validation study of the Brazilian version of the GloboDiet software. The sample included 101 participants from the third wave ELSA-Brasil of the São Paulo Research Center. Eligible participants were adult and older-adult females and males, non-smokers, without comorbidities, with stable body weight in the last six months, with no intention of losing body weight or changing their diet, and not under medications that affect appetite/food intake or body water balance. Disease information was obtained from the medical records and from the questionnaire applied specifically for the validation study. Individuals diagnosed with diabetes, cardiovascular disease, hypertension, and obesity (body mass index [BMI] > 30kg/m^2) were excluded.

Data for each participant were collected from August 2018 to December 2019 using anthropometric measurements, a general characterization questionnaire, FFQ, and 24hR on nonconsecutive days with two different software (GloboDiet and Brasil-Nutri). The first interviews were conducted in person and the second preferably by telephone call.

Data was collected by interviewers trained at the Laboratory for Assessment of Food Consumption, School of Public Health, University of São Paulo (FSP/USP). In the first in-person meeting, participants were instructed on the study protocol and signed an informed consent form. This study was approved by the Research Ethics Committee of the University Hospital/USP.

Dietary data collection

- **GloboDiet**

The GloboDiet software is a European computerized methodology for collecting 24hR. Previously named EPIC-Soft the program was developed by the International Agency for Research on Cancer (IARC)/World Health Organization (WHO) [13]. Brazil is one of the Latin American countries seeking to adapt international data collection methods. A Brazilian version of the GloboDiet software was thus developed to monitor the country's diet [14].

This instrument has five steps: basic information about the respondent and the day remembered; a quick list of consumed foods and recipes; description and quantification of foods and recipes; control of the amount of food and nutrients; and information about dietary supplements. Food and recipe lists were drawn based on data from the local food and dietary survey [14]. The description of foods and recipes allowed standardizing the level of detail to compare foods and recipes within and across countries. Several quantification methods are available in GloboDiet, including weight and volume, photos of portions, household measurements, shape (estimating the surface area and thickness), and standard units [13]. To help quantify the foods and beverages mentioned during the interviews, a printed photographic manual was provided to participants [18] for the in-person interview and a digital file was sent by email for the telephone interview.

- **Brasil-Nutri**

The Brasil-Nutri software is a computerized platform used to collect 24hR. It was developed by the Brazilian Ministry of Health in partnership with the Institute of Social Medicine, State Universty of Rio de Janeiro (IMS/UERJ) and used by the Brazilian Institute of Geography and Statistics (IBGE) in the *Brazilian Household Budget Survey* (POF) in 2008-2009. The software starts with questions about salt and added sugar/sweeteners, supplement use, and restrictive diet. Then, it inquires all food and drinks consumed the day before and the place and time of consumption. In this study, each food and drink is described by entering the preparation data, type of unit, and quantity in household measures or standard units [12].

- **Food frequency questionnaire**

The FFQ applied in the third wave of the ELSA-Brasil study was used to assess the usual food consumption of participants in the last 12 months. This questionnaire was applied by trained interviewers using an answer card with options of consumption frequency and household measurements to help participants decide [16].

Anthropometric assessment

Duplicate anthropometric measurements were performed while participants wore light clothing, no shoes and adornments, and had empty pockets. Weight was measured using a calibrated platform scale with a maximum capacity of 150kg and a precision of 100g (Tanita; https://www.tanita.com) on a flat, firm, smooth surface, away from the wall. Height was measured using a portable stadiometer of scale 0 to 220cm and precision of 0.1cm (Seca; https://www.seca.com) fixed to a smooth wall with no baseboard. The BMI was calculated from body weight and height. For adults (aged 43 to 59 years), BMI values between 18.5 and 24.9kg/m^2 were considered as normal weight; BMI > 18.5kg/m^2 as underweight; and from 25 to 29.9kg/m^2 as overweight [19]. In older adults (60 years or more), BMI values from 22 to 27kg/m^2 were considered as normal weight; BMI ≤ 22kg/m^2 as underweight; and BMI > 27kg/m^2 as overweight [20].

Waist circumference was measured with an inextensible measuring tape with 0.1cm precision. Females and males with waist circumference values ≥ 80cm and ≥ 94cm, respectively, were classified as having an increased risk of chronic noncommunicable diseases [21].

Other variables

The *International Questionnaire of Physical Activity* (IPAQ) was applied to classify the physical activity level (PAL) of the participants according to their time spent walking, doing moderate and vigorous activity, and sitting down during the days of the last week [22]. The criteria of the Brazilian Association of Research Companies [23] were used to classify the socioeconomic income of the participants with questions related to schooling level, number of certain electronic devices and automobiles, residence characteristics, and gross family income.

Statistical analysis

Data on socioeconomic, anthropometric, and lifestyle characteristics of the sample were described by means and standard deviation (SD) or medians and interquartile range. Meanwhile, Student's t-test or Mann-Whitney U test were used to check the differences between sexes. The latest version of the Brazilian Food Composition Table was used to convert food consumption data into nutrients, emphasizing energy information [24]. For the analyses, the predictive equations of underreporting were proposed by Goldberg et al. [5], Black [6], and McCrory et al. [7]. The proportion of underreporters obtained by each method of food consumption assessment was compared using Fisher's exact test. The divergence of EI between self-report-based dietary data collection methods was examined according to the methodology proposed by Bland & Altman [25]. Stata software, version 14.0 (https://www.stata.com) was used for the statistical treatment of data.

- **Predictive equations**

Goldberg's method identifies inaccurate reporting of EI by the EI:BMR ratio. The BMR was calculated using the Schofield equation. The cut-off was calculated as ±2SD of the EI:BMR ratio with a fixed PAL value of 1.55 for both sexes with population-level interpretation and considering variations in EI (23% within-person variation), TEEp estimate (15% within-person variation), and the total energy expenditure (TEE) when calculated by the gold standard method of doubly labeled water (8.5% variation) [5]. The method therefore uses the following equation:

$$\frac{\mathrm{EI}}{\mathrm{BMR}} < \mathrm{PAL} * \exp[+2\mathrm{max} * (\frac{\frac{\mathrm{S}}{100}}{\sqrt{\mathrm{n}}})]$$

(over)

$$\frac{\mathrm{EI}}{\mathrm{BMR}} > \mathrm{PAL} * \exp[-2\mathrm{mín} * (\frac{\frac{\mathrm{S}}{100}}{\sqrt{\mathrm{n}}})]$$

(low)

Where *PAL* is the level of physical activity, *S* is the factor that considers the variation in EI, and *n* is the number of food surveys applied.

$$\mathrm{S} = \sqrt{[(\frac{\mathrm{CVwEI}^2}{\mathrm{d}}) + \mathrm{CV}^2\mathrm{wB} + \mathrm{CV}^2\mathrm{tP}]}$$

Where *CVwEI* is the intrapersonal coefficient of variation in EI, *d* is the number of days of diet assessment, *CVwB* is the coefficient of variation of repeated BMR measurements or the accuracy of the estimate compared to the measured BMR. *CVtP* is the coefficient of variation derived from the mean and standard deviation of a study, including the true variation between subjects, an element of within-person variation, and methodological errors.

The Goldberg method, revised by Black, adopts the same equation and the same ±2SD cut-off for the EI:BMR ratio. However, PAL is specific at the individual level according to the intensity of physical activity and the gender of participants based on the recommendations of the Food and Agriculture Organization (FAO) [26], being: light (1.55 for men and 1.56 for women); moderate (1.78 and 1.64); and intense (2.10 and 1.82 for men and women, respectively).

For the McCrory method, the cut-off was calculated as ±2SD of the EI:TEEp ratio. The TEEp was estimated using the equation of Vinken et al. [27]. The estimated SD considered the variations in EI (23% within-person variation), TEEp (17.7% within-person variation), and TEE when calculated using the gold standard method of doubly labeled water (8.2% variation) [7]. This method uses the following equation:

$$\pm 2 = \sqrt{(\mathrm{CV}^2\,\mathrm{wEI/d} + \mathrm{CV}^2\mathrm{wTEEp} + \mathrm{Cv}^2\mathrm{tmTEE})}$$

Where *CV²wEI* is the within-person variation coefficient of EI, *d* is the number of food surveys applied, *CV²wTEEp* is the within-person variation coefficient of TEEp, *Cv²tmTEE* is the TEE variation coefficient calculated by the doubly labeled water method.

Results

Out of the 101 study participants, 55 were females and 46 were males; about 47.5% had over 8 years of schooling (higher education and/or postgraduate education) and 53.5% belonged to a high social class. In total, 62.4% of the individuals were overweight and 63.4% had a high waist circumference. Regarding physical activity, most (52.5%) were classified as light (Table 1).

The FFQ reported an EI underreport of 13%, 16%, and 1% using the equations proposed by Goldberg et al., Black, and McCrory et al., respectively. Using the same equations, the 24hR showed an underreport of 9.9%, 14.9%, and 0.9%, respectively, with the GloboDiet software and of 14.7%, 15.8%, and 1.1%, respectively, with the Brasil-Nutri software. No statistically significant differences were found between the three methods using Fisher's exact test, but equations for each method differed among each other (Table 2).

Table 1

Characteristics of participants in the validation study of the Brazilian version of the GloboDiet software (n = 101). São Paulo, Brazil, 2020.

Characteristics	n	Mean	SD	Median	IQR
Male					
Height (cm)	46	171.1	5.1	170.4	167.3-175.0
Weight (kg)	46	77.2	8.2	76.6	71.8-82.4
WC (cm)	46	92.3	7.1	94.4	87.6-96.5
Age (years)	46	54.4	5.5	54.0	50.0-57.0
BMI (kg/m²)	46	26.4	2.4	26.7	24.9-28.3
BMR	46	1,723.5	123.7	1,724.2	1,660.7-1,802.1
TEE	46	2,525.9	189.7	2,521.7	2,391.1-2,623.2
Female					
Height (cm)	55	157.8 *	7.1	157.2	153.9-162.7
Weight (kg)	55	64.5 *	8.7	63.9	57.6-70.6
WC (cm)	55	83.9 *	8.0	84.4	77.9-88.8
Age (years)	55	54.5	6.2	54.0	51.0-58.0
BMI (kg/m²)	55	25.9	2.9	25.9	24.1-28.6
BMR	55	1,350.8 *	88.4	1,353.2	1,298.9-1,393.1
TEE	55	1,911.2 *	240.4	1,908.1	1,735.3-2,053.7

BMI: body mass index; BMR: basal metabolic rate (using Schofield equation); IQR: interquartile range; TEE: total energy expenditure (using Vinken equation); SD: standard deviation; WC: waist circumference.

* $p < 0.05$ (there are differences between the groups). Student's T test was used to verify differences between groups regarding the variables height, weight, and waist circumference The Mann-Whitney U test was used for the variables age, BMI, BMR, and TEE.

Table 2

Description of the underreporting of food surveys used in the validation study of the Brazilian version of the GloboDiet software. São Paulo, Brazil, 2020.

Equations	Food surveys						p-value *
	FFQ (n = 100)		GloboDiet (n = 101)		Brasil-Nutri (n = 95)		
	n	%	n	%	n	%	
Goldberg et al.	13	13.0	10	9.9	14	14.7	0.582
Black	16	16.0	15	14.9	19	20.0	0.604
McCrory	1	1.0	1	0.9	1	1.1	1.000
p-value **	< 0.001 *		0.001 *		< 0.001 *		

FFQ: food frequency questionnaire.

* There are significant differences between the predictive equations for each dietary method;

** p < 0,05 (there are differences between groups) by Fisher's exact test.

The Bland-Altman graphs showed very similar means and limits of agreement for EI between the methods, but the best agreement was between GloboDiet and Brasil-Nutri (Figure 1). All comparisons showed wide dispersion and a few outliers were detected.

Discussion

This study aimed to compare the identification of EI underreporters using different predictive equations and instruments for dietary data collection: FFQ and 24hR collected by the softwares GloboDiet and Brasil-Nutri. We found no statistical difference between the methods in the estimated proportion of underreporting, only according to the equation used.

Brasil-Nutri and the FFQ had no statistical differences between each other. GloboDiet, however, showed the lowest proportion of underreporting in the equations, possibly because it is more complex and has several more precise measures to obtain information about the foods consumed [14].

A European study [28] assessed the underreporting among the European Prospective Investigation into Cancer and Nutrition (EPIC) Research Centers using the EPIC-Soft program (currently GloboDiet), developed for the collection of 24hR and the relationship between EI and BMR proposed by Goldberg et al. and Black. In the study, percentage of underreporting among the participating countries was 10.3% for males and 13.8% for females. Similarly, we found an underreporting proportion of 9.9% for GloboDiet with the equation proposed by Goldberg et al. and 14.9% with the equation revised by Black.

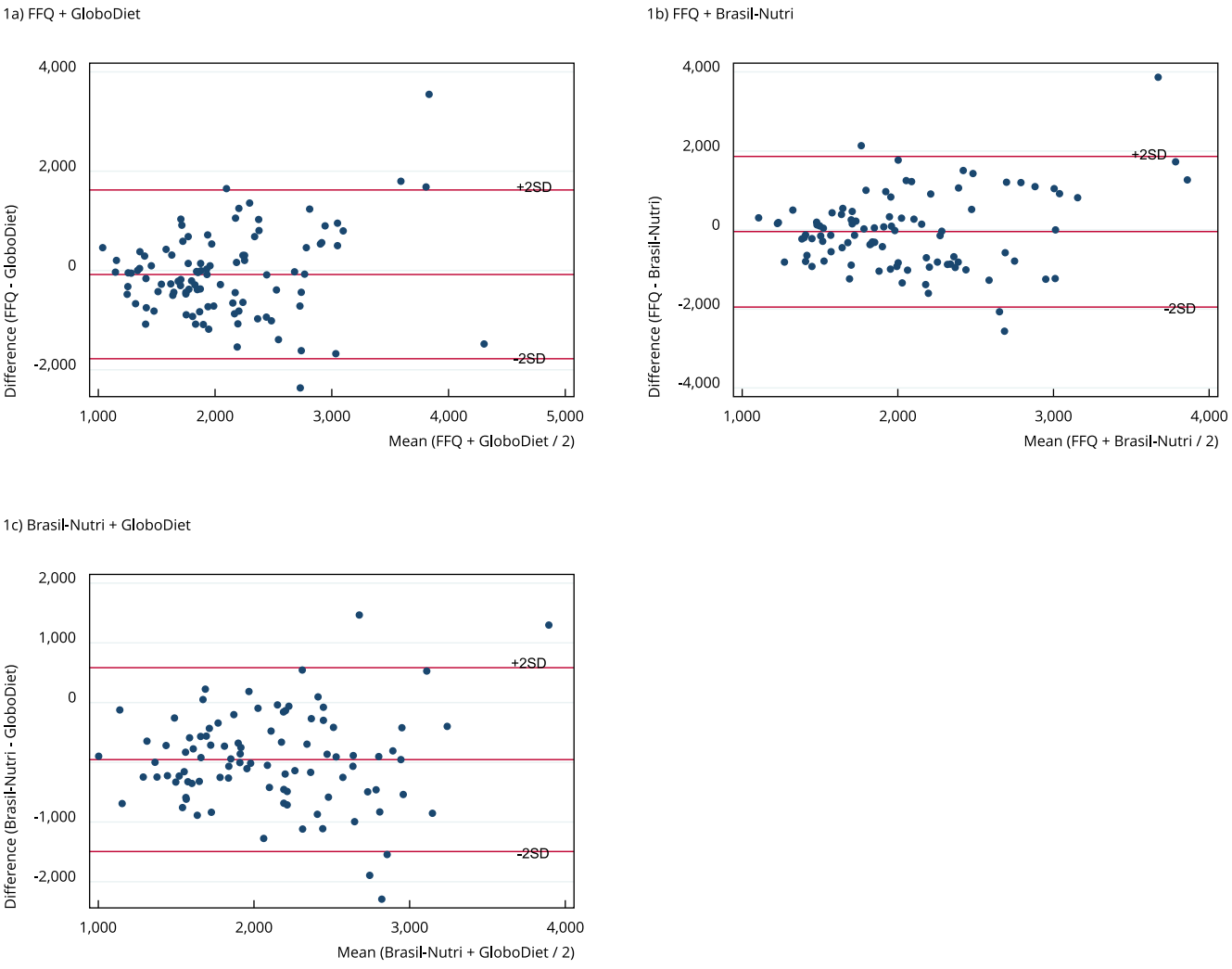
A study [29] conducted in Germany with 677 individuals aged 14-80 years from the *German National Nutrition Survey II* assessed the degree of agreement among three dietary assessment methods, including 24hR. The results (16% of under-reporters, using the equation of Müller et al. for BMR) were similar to those obtained with Brasil-Nutri, which found 14.7% under-reporters with the equation of Goldberg et al. and 20% using the equation of Black.

Tooze et al. [30] assessed the accuracy of the Goldberg et al. equation to characterize inaccurate reports of EI using the 24hR and FFQ methods. Using the Goldberg equation revised by Black, 10% of males and 13% of females were classified as underreporters in the 24hR and 52% of males and 51% of females were classified as underreporters in the FFQ. In our study, the FFQ found an underreporting proportion of 9.9% with the Goldberg's et al. equation and 16% with the Black's equation.

According to Black [6], Goldberg's et al. equation may underestimate the prevalence of underreporting by using the PAL fixed at 1.55 for all individuals, assuming a mild PAL. The author reported that when a cut-off point is assigned for a specific PAL for sex and activity intensity, the sensitivity for the estimation of underreported EI increases. In our study, the prevalence of underreporting by

Figure 1

Bland-Altman plots of energy intake among self-report-based dietary data collection methods.



FFQ: food frequency questionnaire; SD: standard deviation.

the Black's equation was higher than by Goldberg's et al. equation due to the personalized use of the physical activity factor (p = 0.001).

A review study [31] indicates that the FFQ is more likely to underreport than 24hR. This study found no statistically significant differences between the dietary methods. The underreporting estimate was similar in the FFQ and in both 24hRs. Accordingly, a study by Scagliusi et al. [32], conducted with 65 adult females in Brazil with the doubly labeled water technique, found that the 24hR (n = 16) had lower frequency of underreported EI than FFQ (n = 35).

A previous study by Yannakoulia et al. [33], which assessed underreporting in Greeks by semiquantitative FFQ, found 12.2% of underreporting for females and males, similarly to our results with the equation proposed by Goldberg et al. However, the authors classified individuals with the ratio EI/BMR < 1.14 as underreporters [33].

Estimates of underreported EI (1% in the FFQ, 0.9% in the GloboDiet software, and 1.1% in Brasil-Nutri) found in food surveys by McCrory et al. were very low compared to other studies [34,35] and other estimates, contrasting even with studies with doubly labeled water that indicate underestimations of around 10%. However, when adopting ±1SD instead of ±2SD, the proportion of underreporting rose to 25.7% in the FFQ, 22.8% in the GloboDiet software, and 21.1% in the Brasil-Nutri.

This is one of the first studies in Brazil to detect EI underreporting using different dietary data collection. However, this study has limitations. Underreporting was estimated only by predictive equations, which were not compared with gold standard measures or the doubly labeled water method to determine which equation is more sensitive and specific. Furthermore, the sample was a small group of public servants from teaching and research institutions with a high level of schooling and socioeconomic status, excluding individuals with obesity and chronic noncommunicable diseases, characteristics associated with underreporting [36,37,38,39,40]. If these instruments were applied to a more heterogeneous sample, underreporting prevalence would likely be higher. Nevertheless, our results showed no differences in EI underreporting between the methods, providing significant information to select and design epidemiological studies for dietary data collection.

Underreporting hinders food consumption assessment by influencing the results obtained in nutritional epidemiological studies. The literature shows that if measurement error is not considered, analyzes will be subject to biased estimation and incorrect inference [41]. Considering that the most underreported food items are still undefined, more studies should further analyze measurement errors to research factors associated with underreporting in heterogeneous samples and more accurate methods that can predict these types of errors.

Applying software to assess food consumption, such as the GloboDiet and Brasil-Nutri, which conduct the 24hR interview in a standardized and staged manner, can reduce time, costs, and errors caused during data collection by both the interviewer and interviewee, and data collection and encoding in real-time [42]. Using complementary tools, such as the photographic manual adapted for the Brazilian population [18] in the 24hR by GloboDiet software, can also help improve the accuracy of food consumption reports.

Conclusion

This study verified a low prevalence of underreported EI among the three self-report-based dietary data collection methods (FFQ, 24hR with GloboDiet and Brasil-Nutri). No statistically significant differences were found between the three methods but the equations for each method differed between each other. The agreement of EI between the methods was very similar, but the best was between GloboDiet and Brasil-Nutri.

Contributors

P. S. Oliveira and J. Levy contributed to the study design and data analysis and interpretation. E. De Carli contributed to the data analysis. All the authors contributed to the writing and review, and approved the final version to be published.

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Additional informations

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Resumo

Os métodos existentes para avaliar consumo alimentar estão sujeitos a erros de medição, especialmente à subnotificação de ingestão calórica, que descreve a ingestão calórica abaixo do mínimo necessário para manter o peso corporal. Este estudo buscou comparar a identificação de subnotificações de ingestão calórica através de diferentes equações preditivas e instrumentos para coletar dados dietéticos. Este estudo foi realizado com 101 participantes selecionados na terceira onda do Estudo Longitudinal de Saúde do Adulto *(ELSA-Brasil) do Hospital Universitário da Universidade de São Paulo. A partir da avaliação dietética, aplicamos um questionário de frequência alimentar (QFA), dois recordatórios de 24 horas (24hR) pelo software GloboDiet e dois 24hR utilizando o software Brasil-Nutri. A subnotificação de ingestão calórica obtida pelo QFA foi de 13%, 16% e 1%, utilizando-se as equações propostas por Goldberg et al. (1991), Black (2000) e McCrory et al. (2002), respectivamente. Com essas mesmas equações, o 24hR achou uma subnotificação de 9,9%, 14,9% e 0,9%, respectivamente, com o software GloboDiet e de 14,7%, 15,8% e 1,1%, respectivamente, com o software Brasil-Nutri. Verificou-se baixa prevalência de ingestão calórica subnotificada entre os três métodos de captação de dados dietéticos por autorrelato (FFQ e 24hR com GloboDiet e Brasil-Nutri). As equações para cada método diferem entre si embora não tenhamos encontrado diferenças estatisticamente significativas entre os três métodos. A concordância de ingestão calórica entre os métodos foi muito semelhante, mas a melhor foi entre a GloboDiet e a Brasil-Nutri.*

Inquéritos sobre Dietas; Ingestão de Energia; Inquéritos e Questionários

Resumen

Los métodos existentes para evaluar el consumo de alimentos están sujetos a errores de medición, especialmente la infradeclaración de la ingesta de energía, caracterizada por la notificación de la ingesta de energía por debajo del mínimo necesario para mantener el peso corporal. El objetivo de este estudio era comparar la identificación de las infradeclaraciones de ingesta energética utilizando diferentes ecuaciones de predicción e instrumentos de recogida de datos dietéticos. El estudio se realizó con 101 participantes seleccionados en la tercera ola del Estudio Longitudinal de Salud del Adulto *(ELSA-Brasil) en el Hospital Universitario de la Universidad de São Paulo. Para la evaluación de la dieta, se aplicó un cuestionario de frecuencia de alimentos (QFA), dos recordatorios de dieta de 24 horas (24hR) utilizando el software GloboDiet, y dos 24hR utilizando el software Brasil-Nutri. La infradeclaración de la ingesta energética obtenida del QFA fue del 13%, el 16% y el 1,0% utilizando las ecuaciones propuestas por Goldberg et al. (1991), Black (2000) y McCrory et al. (2002), respectivamente. Con estas mismas ecuaciones, el 24hR describió una infradeclaración del 9,9%, el 14,9% y el 0,9% respectivamente con el software GloboDiet y del 14,7%, el 15,8% y el 1,1% respectivamente con el software Brasil-Nutri. Se verificó una baja prevalencia de ingesta de energía subdeclarada entre los tres métodos de recogida de datos dietéticos basados en el autoinforme (QFA, 24hR con GloboDiet y Brasil-Nutri). Aunque no se encontraron diferencias estadísticamente significativas entre los tres métodos, las ecuaciones de cada uno de ellos diferían entre sí. La concordancia de la ingesta de energía entre los métodos fue muy similar, pero la mejor fue entre GloboDiet y Brasil-Nutri.*

Encuestas sobre Dietas; Ingestión de Energía; Encuestas y Cuestionarios

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