Resting energy expenditure from DXA: A Cross-Sectional Study

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RESTING ENERGY EXPENDITURE FROM DXA: A CROSS-SECTIONAL STUDY

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Abstract

Background: The traditional methods used to estimate Resting Energy Expenditure (REE) is bases of the indirect calorimetry (IC) is a global approach, and does not consider the different metabolic activities of organs (heart, kidney and liver), bone tissue (BT), adipose tissue (AT) and skeletal muscle tissue (SMT). Then, our objective is to validate a 3C approach model of REE measured by dual-energy x-ray absorptiometry (DXA) based on IC. **Methods:** Participated in this cross-sectional study 155 college students, both sexes (18 to 30 years old). Anthropometric measures, REEs estimated via IC and whole-body DXA-scan (3C approach) were determined. The REE of each component was determined after transforming the DXA components at the molecular level to the organ tissue level. Bland-Altman and proportional bias analysis were used to verify agreement between methods (IC and DXA). **Results:** The results show significant ($p<0.05$) higher fat-free mass index (FFMI), cranial area and residual tissue (RT) in men. And they have smaller amounts of fat mass (FM) and AT in comparison to women. Also higher REEs (p<0.001) were found among men for all components in comparison to women, except for AT expenditure (p<0.001). **Conclusions:** This approach has important implications for the interpretation of multicomponent energy metabolism, considering interpersonal differences in terms of heat production. It is a strategy applicable in the health and sports contexts to prescribe exercises and diets because it shows the REE magnitude of each body component.

Keywords: Energy metabolism; Body composition; Indirect calorimetry; Young adult.

Background

Every living organism is in constant heat exchange with the environment. Through the cellular respiration process, amount of energy is lost and released as heat that is proportional to energy expenditure (EE). Thus, the EE can be quantified by direct calorimetry. The resting energy expenditure (REE) can be estimated using oxygen consumption (VO2) and carbon dioxide production (VCO2) during the breathing cycle using indirect calorimetry (IC) (1). REE estimation is a common practice because it allows comparison of individuals with different body dimensions. In the absence of measured REE, height, age, body weight and sexy are used as predictors of REE (2, 3). Such equations, however, do take into account inter-individual differences accruing from body composition (BC) (4).

Body mass (BM) includes organs and tissues with different metabolic activities. These differences should be considered because REE does not depend only on quantity but also on the specific metabolic activity of each body component. For instance, even though organs such as the liver, kidneys, heart and brain together represent from 5% to 6% of total BM, they account for 60% of total REE (5). Such metabolic rates are from 15 to 40 times higher than that of the skeletal muscle tissue (SMT) (6), which corresponds to 40% of an adult's BM; however, it expresses a low resting metabolic rate (≅10 to 15 kcal/kg/day) (5).

Therefore, models to estimate REE, in addition to fat, muscle and bones, including organs of the trunk, brain and residual tissue (RT), present advantages over traditional ones (7). Additionally, tissue predictive modeling could decrease biases in REE estimates for different body tissues (8) and better determine interpersonal differences (9). Imaging methods provide a good estimation of REE at the tissue level (10), among which the dual-energy x-ray absorptiometry (DXA) imposes minimal radiation exposure (11), has greater precision in the simultaneous definition of different tissues, requires minimal participation of voluntaries, and observers have greater independency, fast, painless (12), in addition to important for estimating energy expenditure from body composition (13). Considering the advantages of using DXA, the REE metabolic map was developed by totaling five components: fat mass (FM); appendicular lean soft tissue (ALST); cranial area; bone mineral content (BMC); and residual mass, combined with the specific metabolic rate of each component (8). Later, another model, based on DXA, was also validated to predict expenditure of organs such as: the heart, liver, kidney and spleen (14), as they account for significant proportions of the total metabolic rate. The components measured by DXA belong to level 2 of the reference five-level model (15). Therefore, they need to be transformed to the tissue level (4), since only at this level is REE determined (6).

Even though REE at the tissue level is frequently used (8, 14, 16, 17), the proposed models have not yet been validated with the IC as the reference. Additionally, each proposal considers different components of BC, though this approach promises to explain variations of REE among individuals (14). Therefore, we initially sought to determine REE using DXA, having IC as reference. After which, we tested the validation of the adapted REE_{DXA} predictive model (8, 14) among Brazilian young college students of both sexes.

Material and Methods

Study population

In this study, the sample was selected for convenience and we adopted a cross-sectional design. This manuscript followed the guidelines from The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) conference list, and the completed checklist is attached.

155 individuals were assessed: 76 men and 79 women aged between 18 and 30 years old. The participants were college students (from a State University), who were personally or were through social media invited during the second semester of 2016. Inclusion criteria were: reporting no medications or supplements with direct or indirect action on the sympathetic nervous system or drugs that stimulate the central nervous system or that alter a person's metabolism; oxidized carbohydrate substrate analysis; reporting being healthy, condition that was verified through a questionnaire addressing general health status; not presenting diseases that alter BC; having no amputated limbs; not exceeding 10 hours of exercise per week; and not having hypothyroidism or hyperthyroidism. Six ethnicities were considered by self-reported: mixed race, Afro-descendants, Asian descendants, indigenous, Caucasian, and Hispanic according to the IBGE classification (18).

A similar population study (19) was chosen to be a reference for the sample calculation, at variance to determine REE for both sexes at an organ-tissue level. The combined differences (men and women) between measured and predicted REE (kJ/day) reached by those authors were used as a reference for maximum desired error (5%) and the population's standard deviation (525.0 kcal/day). Hence, the minimum sample size (n=153) should minimize estimation errors and ensure the expected confidence level (95%).

All participants volunteered for the study, received clarification about the study's objectives and signed the written consent in agreement with the Declaration of Helsinki. The study project was approved by an ethics committee of the University of São Paulo. The study was conducted for scientific purposes only, and thus, there's no conflict of interest to be declared.

Study protocol

One morning was sufficient to perform the procedures with each participant at the *Hospital das Clínicas* at the Medical School of University of São Paulo at Ribeirão Preto (HCFMRP/USP). A questionnaire was initially applied to identify the volunteers' general health status and establish that they were in healthy condition. The questions addressed diagnosed problems and/or treated conditions, symptoms, health-related behavior, and self-perceived health. Next, body mass was measured (Kg) using a Filizola® electronic scale (Personal model) and height was measured in cm using a wall-mounted stadiometer in accordance with procedures recommended by (20) . IC was then used to calculate REE and DXA was used to calculate BC, as detailed below.

Measurement of resting energy expenditure by indirect calorimetry

The IC method was employed using a Quark RMR® calorimeter (Cosmed, Roma, Italy). A Cosmed® ethanol kit was used to perform the ethanol combustion test to ensure the quality of measurements and precision of the equipment and gas analyzers.

The exam was performed with volunteers after a 12-hour fast, four hours without using nicotine or caffeine, and 24 hours without performing exercises (21). Before initiating the test, the participants rested 30 minutes, lying down in a supine position in a silent room at 23ºC (22). During the test, the participants kept their heads elevated at 30 degrees, with lower limbs extended and upper limbs resting on the side of their bodies. They were instructed not to sleep, maintain a regular breathing pattern, remain silent, and avoid coughing, yawning, talking, or sighing (21, 23). The exam lasted 30 minutes and records were taken every five minutes, while the first five minutes were discarded. Energy production was determined using Weir's formula (24), denominated in this study of REE_{IC}, based on the VO_2 and VCO_2 from the 5^{th} to the 30^{th} minutes (24). The reliability test-retest of eight individuals resulted in a coefficient of variation (CV) of 2.95% for the REE_{IC}, which is within acceptable parameters (21).

Body Composition Analysis and REE by DXA

BC was estimated using whole-body and local DXA-scan, EE Medical Systems Lunar - Prodigy Advance (encore software version 13.60), using a linear x-ray fan-beam. The equipment was calibrated every morning before measurements, in accordance with the manufacturer's instructions, always by the same technician; Differences of absorption performed by attenuation of x-rays, in a single scan, determined whole-body and local body components in grams (g): total body mass; fat mass; lean soft tissue; bone mineral content and scanning area (cm^2). The reliability test-retest of 11 individuals resulted in a coefficient of variation for lean soft tissue, fat mass and bone mineral content of 0.8%; 1.6% and 1.6%, respectively.

The participants were asked to remove metallic objects (e.g., ear rings, rings) and wear a hospital gown when necessary and were positioned in a supine position, centered on the scanner table, with their lower limbs joined by Velcro strips. The participants' hands remained open, with palms resting on the examination table, and arms extended along the body (within the sweep lines of the table) as by the manufacturer's instructions. The image alignment adjustments were made, following the anatomical points of the body regions, to quantify each component.

The adapted REE_{DXA} resulted from the combination of two models proposed in the literature (8, 14), is summarized in Table 1. The transformation of body components, estimated by DXA (molecular level), to tissue level (15) were performed according to well-established procedures (8, 14, 25-27). Following this, the energetic expenditure of each component was estimated considering their specific metabolic rates (5, 8, 14) and the REE_{DXA} was estimated by totaling the REE of all the components (Table 1).

Table 1. Transformation of components from molecular to tissue level and resting energy expenditure of each component.

Tissue	Molecular level (kg)	Energy expenditure (kcal/d)
AT	1.18 x FM	EE_{TA} = 4.5 x AT
BT	1.85 x BMC[1] x 1.0436[2]	EE_{TO} = 2.3 x BT
SMT	(1.13 x ALST) – (0.02 x age) + (0.61 x sex) + 0.97)	EE_{TME} = 13 x SMT
Brain	0.005 x Cranial $area_{DXA}$ + 0.2 x sex* + 0.24	EE_{Brain} = 240 x Brain
Heart	$(0.012*LBM_{trunk})^{1.0499}$	EE_{Heart}= 441.68 x Heart
Kidney	$(0.0165*LBM_{trunk})^{0.9306}$	$EE_{Kidneys}$= 441.68 x Kidneys
Liver	$(0.0778*LBM_{trunk})^{0.9277}$	EE_{Liver}= 200.76 x Liver
RT_1	Body Mass - (AT + BT + SMT + Brain)	EE_{RT1} = 43 x RT_1
RT_2	Heart + Kidney + Liver	EE_{RT2} = 7.17 x RT_2
RT_{DXA}	$RT_1 – RT_2$	$EE_{RTDXA} = EE_{RT1} – EE_{RT2}$
REE_{DXA}	**$EE_{AT} + EE_{BT} + EE_{SMT} + EE_{Brain} + EE_{Heart} + EE_{kidneys} + EE_{Liver} + REE_{TDXA}$**	

Abbreviations: AT: adipose tissue; BT: bone tissue; SMT: skeletal muscle tissue; LBM_{trunk}: lean body mass; RT: residual tissue (8); RT_2: organ residual tissue (14); RT_{DXA}: residual tissue adapted model; FM: fat mass; BMC: bone mineral content; ALST: appendicular lean soft tissue; DXA: dual x ray absorptiometry; EE: energy expenditure; REE_{DXA}: resting energy expenditure derived from DXA measurements.
*Sex = 0 female sex, 1 male sex.

Data Analysis

Exploratory analysis was used to investigate potential outliers. Descriptive analysis was used to characterize the sample with central tendency measures, standard deviation (SD), and confidence interval (IC 95%). The test of differences (independent samples t-test) and analysis of variance (One-way ANOVA) were used to establish groups according to sex and age, respectively. The Paired-Samples T Test, Bland-Altman analysis and proportional bias were used to determine the accordance between REE_{IC} and REE_{DXA} (8, 14). Parametric statistics were used considering the central limit theorem

[1] Proposed by Snyder et al. (1975), based on human reference values.

[2] Proposed by Ballor (1996), in which bone mineral content represents the gray portion where bone adjustment is performed.

(28). Analyses were performed using the SPSS v. 20.0 (Chicago, IL), with the level of significance established at α=0.05.

Results

The characteristics and comparisons between groups are presented in Table 2, with descriptive values, confidence interval (95%) and test of differences (t-test) performed between sexes. In addition to the BC transformed to a tissue level, table 2 also presents the REE (Kcal/d) of each component and for organs (14).

No differences were found between ages ($F_{(2\ 153)} = 0.947$, $p = 0.597$), but there were differences between sexes ($T_{(2,\ 153)} = -12.964$, $p \leq 0.001$), confirming the need to make a distinction in the analysis between male (n=76) and female groups (n=79). The ethnic frequency was 14.5% and 7.6% for mixed race, 1.3% and 2.5% for Afro-descendants, 3.9% and 3.8% for Asian descendants, 0% and 1.3% for Indigenous, 67.1% and 63.3% for Caucasian and 13.2% and 21.5% for Hispanics for men and women, respectively. A previous analysis (ANOVA) of ethnicity did not present differences (data not shown).

Table 2. Descriptive values of body components at the tissue level, energy expenditure and test of differences.

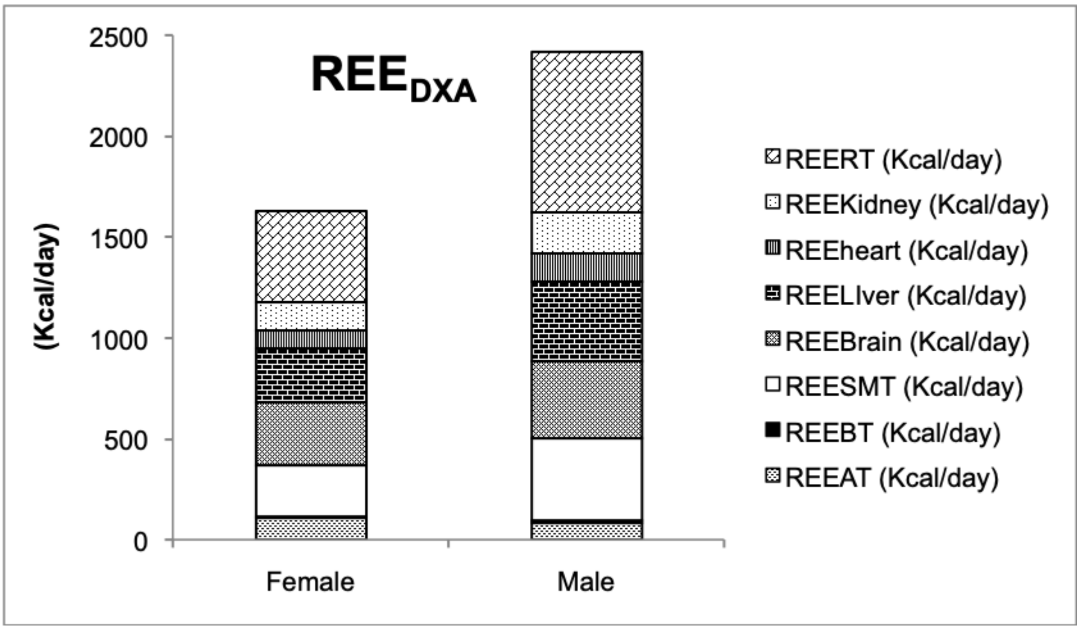
	Men (n=76)		Women (n=79)		t-test	
	Mean (SD)	**CI 95%**	**Mean (SD)**	**CI95%**	**Value**	***p***
Age (years)	23.8 (3.8)	23.0 to 24.7	24.0 (3.5)	23.1 to 24.6	0.053	0.958
Height (cm)	178.1 (7.5)	176.4 to 179.8	166.1 (5.6)	164.8 to 167.3	-11.333	≤0.001
Body weight (kg)	75.9 (11.9)	73.2 to 78.6	59.8 (8.6)	57.8 to 61. 7	-9.728	≤0.001
REE_{IC} (kcal/day)	2105.9 (285.3)	2040.7 to 2171.1	1615.6 (174.3)	1576.6 to 1654.7	-12.964	≤0.001
REE_{DXA} (kcal/ day)	2417.1 (235.7)	2363.2 to 2470.9	1623.6 (155.1)	1588.9 to 1658.3	-24.846	≤0.001
Body Composition (DXA) – Tissue Level						
AT (kg)	17.9 (9.9)	15.7 to 20.2	23.6 (7.8)	21.9 to 25.4	3.987	≤0.001
BT (kg)	6.2 (0.9)	6.0 to 6.4	4.8 (0.7)	4.6 to 4.9	-11.024	≤0.001
SMT (kg)	31.3 (3.9)	30.4 to 32.2	19.3 (2.4)	18.7 to 19.8	- 22.982	≤0.001
Brain (kg)	1.6 (0.1)	1.6 to 1.6	1.3 (0.1)	1.3 to 1.3	-26.217	≤0.001
Heart (kg)	0.306 (0.038)	0.297 to 0.314	0.195 (0.023)	0.190 to 0.201	-21.851	≤0.001
Kidneys (kg)	0.470 (0.051)	0.458 to 0.482	0.316 (0.033)	0.309 to 0.323	-22.104	≤0.001
Liver (kg)	1.985 (0.218)	1.935 to 2.035	1.337 (0.139)	1.306 to 1.368	-22.110	≤0.001
RT_{DXA} (kg)	16.2 (2.6)	15.6 to 16.8	8.9 (2.2)	8.4 to 9.4	-19.588	≤0.001
REE_{DXA} Estimates						
EE_{AT} (Kcal/day)	80.7 (44.7)	70.5 to 90.9	106.4 (35.2)	98.5 to 114.3	3.987	≤0.001
EE_{BT} (Kcal/day)	14.3 (2.1)	13.8 to 14.8	10.9 (1.6)	10.7 to 11.3	-11.024	≤0.001
EE_{SMT} (Kcal/day)	406.4 (51.0)	394.7 to 418.0	250.7 (31.4)	243.7 to 257.7	-22.982	≤0.001
EE_{Brain} (Kcal/day)	383.9 (17.5)	379.9 to 387.9	315.4 (15.1)	312.1 to 318.8	-26.217	≤0.001
EE_{Heart} (Kcal/day)	134.9 (16.8)	131.1 to 138.8	86.3 (10.2)	84.1 to 88.6	-21.851	≤0.001
$EE_{Kidneys}$ (Kcal/day)	207.5 (22.9)	202.2 to 212.7	139.6 (14.6)	136.3 to 142.9	-22.104	≤0.001
EE_{Liver} (Kcal/day)	397.1 (43.7)	387.1 to 407.1	267.4 (27.9)	261.2 to 273.7	-22.110	≤0.001
REE_{TDXA} (Kcal/day)	793.7 (121.7)	766.0 to 821.5	449.0 (97.1)	427.1 to 470.9	-19.472	≤0.001

Abbreviations: DXA: Dual x ray absorptiometry; REE_{IC}: Resting energy expenditure via indirect calorimetry; REE_{DXA}: adapted resting energy expenditure (8, 14); FM: Fat mass; BMC: Bone mineral content; BT: Bone tissue; AT: Adipose tissue; SMT: Skeletal muscle tissue; RT_{DXA}: Adapted residual tissue (8, 14); EE: energy expenditure; EE_{AT}: Energy expenditure of adipose tissue; EE_{BT}: Energy expenditure of bone tissue; EE_{SMT}: Energy expenditure of skeletal muscle tissue; EE_{RTDXA}: Energy expenditure of adapted residual tissue (8, 14).

The body composition of men was significantly higher in values and heavier than that of women. Men presented greater values ($p<0.001$) of FFMI (BMC, lean mass tissue of upper and lower limbs and trunk), cranial area and RT and smaller amounts of FM and AT ($p<0.001$) than women. In the comparisons of REE specific for each component, men also presented greater expenditure (p<0.001) in all components, except for the AT metabolic rate (p<0.001) (Table 2).

The estimated REE_{DXA} and for each component derived from DXA according to sex is presented in Figure 1.

Figure 1. Estimated resting energy expenditure REE_{DXA} of men and women at the tissue level.

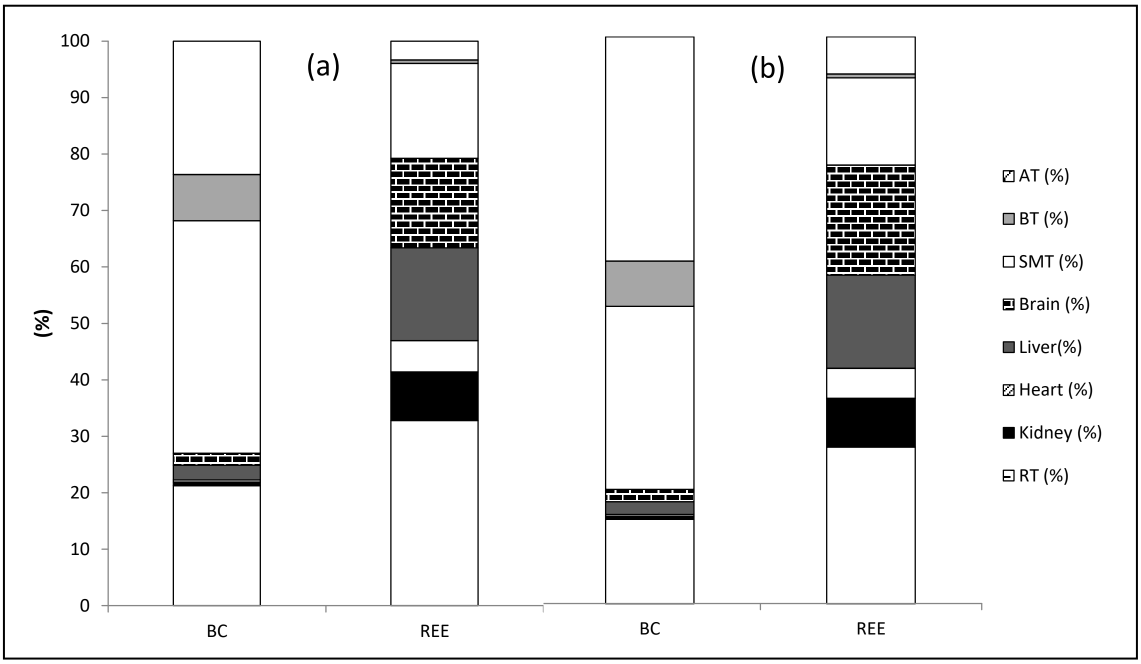


Abbreviations: REE: resting energy expenditure; REE_{AT}: resting energy expenditure of adipose tissue; REE_{BT}: resting energy expenditure of bone tissue; REE_{SMT}: resting energy expenditure of skeletal muscle tissue; REE_{Brain}: resting energy expenditure of brain; REE_{Liver}: resting energy expenditure of liver; REE_{Heart}: resting energy expenditure of heart; $REE_{Kidneys}$: resting energy expenditure of kidneys; REE_{RT}: resting energy expenditure residual tissue.

The total REE (Figure 1) is mainly composed of REE_{RT} (32.8%; 27.6%), followed by REE_{Brain} (15.9%; 19.4%), REE_{Liver} (16.4%; 16.4%), REE_{TME} (16.8%; 15.4%), $REE_{Kidneys}$ (8.6% and 8.6%), REE_{Heart} (5.6%; 5.3%), do REE_{AT} (3.3%; 6.5%) and REE_{BT} (0.6%; 0.7%) for men and women, respectively. Women presented a greater amount of REE_{AT} (organ with a low metabolic rate) and smaller amounts of REE_{SMT}, REE_{Liver}, $REE_{Kidneys}$, REE_{Heart}, REE_{RT} and REE_{Brain} in comparison to men.

Values referring to the mass of each body component and REE were very distinct. Figure 2 shows relative values (%) estimated via DXA and the respective REE for each sex. Note that participation relative to each component in the BC was very different from their proportion in the REE.

Figure 2. Proportion of body components and resting energy expenditure estimated by DXA, for men and women.



Abbreviations: AT: adipose tissue; BT: bone tissue; SMT: skeletal muscle tissue; RT: residual tissue.
Letter a = men; letter b = women.

REE represents whole-body metabolic rate, considering that the measurement via IC does not permit fractioning the REE of organs and tissues. Hence, the approach adopted in this study allows for a more refined assessment, taking into account the different metabolic activities of each body component. The results presented in Figure 2 show that the brain, liver, heart and kidneys represented from 5% to 6% of total body weight, while accounting for 46.5% and 49.7% of the REE of men and women, respectively. On the other hand, BT represented 8.2 and 8.0 % of body weight (of men and women, respectively), but accounted for less than 1% of REE. Likewise, AT, which composed 23.6% and 39.6% of body mass (Figure 2a and 2b), accounted for only 3.3% and 6.5% of men's and women's REE, respectively.

Validation of the adapted REE_{DXA} model to estimate the REE

The estimated measures were compared with the reference method (REE_{IC}) in order to validate the adapted REE_{DXA} model. The indicators used to verify agreement between the two methods (Paired-Samples T Test, Plots de Bland-Altman and Proportional bias.) are reported in Table 3 and Figure 3.

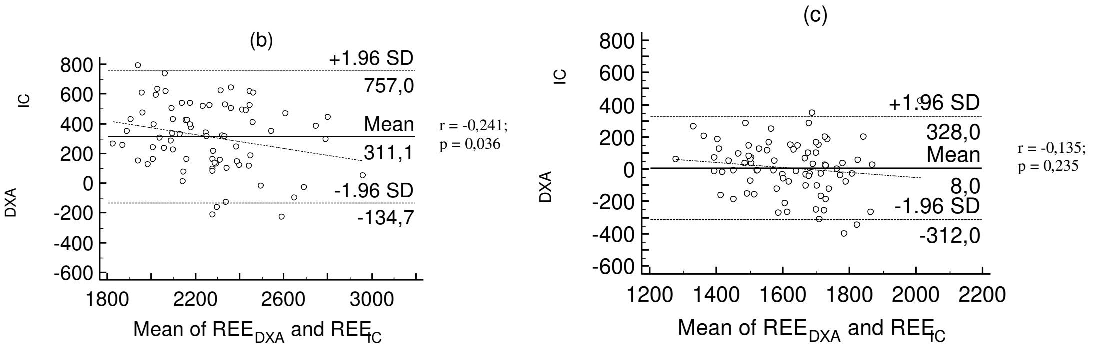
Table 3. Validation of the REE_{DXA} using the REE_{IC} as reference.

Grouping	**REE_{IC} Mean (SD)**	**REE_{DXA} Mean (SD)**	**t**	***p***
Men (n=76)	2105.9 (285.3)	2417.1 (235.7)	11,925	≤ 0.001
Women (n=79)	1615.6 (174.3)	1623.6 (155.1)	0,434	0.667

Abbreviations: REE_{IC}: Resting energy expenditure measured by indirect calorimetry (kcal/day); REE_{DXA}: Adapted resting energy expenditure (8, 14) (kcal/day);

REE differences were found for the men ($p \leq 0.001$) but not for female (p = 0.677). Bland-Altman plots were also used to identify the degree of agreement between the two methods (Figure 3). The results depict biases in the mean of the differences between the measured and the predicted, overestimating the REE for the men (311.1 kcal). For women, the plots confirmed the validity of the model, with low differences between the measured and predicted REE.

Figure 3 - Plots of Bland-Altman and degree of agreement between resting energy expenditure measured and estimated.



REE_{IC}: resting energy expenditure measured by indirect calorimetry (kcal/day); REE_{DXA}: resting energy expenditure estimated by DXA (kcal/day); Men - letter b; Women - letra c.

Therefore the results of differences (t) tests and agreement between methods from the Bland-Altman plots did not confirm the validity of REE_{DXA} for the men, but for women.

In addition, the correlation between the mean of the differences of REE_{IC} and REE_{DXA} showed heteroscedasticity of the data for the men (p = 0.036), not indicating the tendency to error for women (p = 0.235).

Discussion

Differences between men and women may influence body composition (29) and, for this reason, the distinction between sexes confirmed the need to be analyzed separately in this study. The adapted REE_{DXA} model did not present statistically significant differences between women. The Bland-Altman plot indicated agreement between the methods and the correlation between the mean oh the differences of REE_{IC} and REE_{DXA} not indicated the trend for error for women (p = 0.235). However, for men differences were found, moreover, the Bland-Altman plots did not confirm the validity of REE_{DXA} and the correlation between the mean of the differences of REE_{IC} and REE_{DXA}

showed heteroscedasticity of the data (p = 0.036) . Thus, REE_{DXA} demonstrated validity only for women.

The data results show that the REE_{IC} was 24% greater among men (2,105.9 kcal/day) than among women (1615.6 kcal/day), confirming what is expected for young populations (30). A lower REE among women may be partly explained by a larger amount of AT, with low consumption of O_2 (≅4.5 kcal/kg/day) (31) and for smaller amounts of SMT (30). Figure 2 shows that AT in women (39.6%) is significantly greater than men (23.6%), but it represented an expenditure of only 6.5% of the total REE. Additionally, a decline in REE begins earlier in women (31.9 years old) than in men (36.8 years old); decreasing 112 and 74 kcal/decade in women and men, respectively (32). Age, therefore, is an important factor to be considered in this type of analysis. For this reason, only individuals belonging to the same age group were selected for this study. Initially, we considered three age groups (< 20 to 25 > years old), but no differences were found. This study sample was composed of college students within a 12.7 years range.

Another difference of REE between sexes involves differences in brain weight, which on average is 14% heavier in men than women (33). In this study, the difference was 17.87%. Even though the brain represents approximately 2% of BM (34, 35), its contribution to the metabolic rate reaches a fifth of the total REE (36, 37). Variations in brain mass, therefore, may be small but are clinically significant to explaining individual differences of energy demand between sexes (38, 39). In this study the women addressed here presented less brain mass (1.3 kg), as well as lower energy expenditure (315.5 kcal/d) compared to men (1.6 kg; 383.9 kcal/d), as shown in Table 2. The REE_{Brain} corresponded to 15.9% and 19.4% of total REE_{DXA} for men and women, respectively (Figure 2). The brain's high energy demand may explain heterogeneity in the metabolic FFM rate (40).

One of the limitations of the study is that DXA to estimate the REE of organs and tissues (after transformation) from predictive regression models, with their respective errors. Even though these equations are well-established and the models present good reliability requires caution. Another limitation involves the sample's ethnic differences, which limited generalizations our results. For this, further studies of these models accuracy are recommended. Finally, this study addressed individuals from a single origin, while inter-population studies are more suitable to confirm the model, although our intention was not to generalize, but demonstrate its potential. Our results prove that in fact the metabolic rates of BM are not homogeneous, given the differences in the metabolic activity of organs and tissues [43]. Therefore, not considering component-specific expenditures leads to inaccurate REE estimates. DXA, considered a 3-C model, is a potential resource for estimating multicomponent REE based on total BC [11], with good accuracy and low patient risk. Thus, this approach provides an opportunity to examine energy metabolism considering individual differences of young populations.

This approach has important implications for the evaluation and interpretation of energy metabolism considering the differences in heat production between individuals, since body weight is not always determinant for REE. In a study conducted with adolescents, Venturini, Abdalla (41) found greater total body REE and residual tissue REE in individuals with low weight in comparison to obese individuals. These findings are relevant and have important implications for the assessment and interpretation of heat production between individuals of different ages and sexes (40). Thus, an estimated REE that considers the expenditure of the main organs and tissues using DXA favors the applicability of this approach in young adults. Additionally, DXA provides a reading of various body components, including organs, the brain and heart from a single scanning.

Conclusions

This approach has important implications for the assessment and interpretation of energy metabolism, considering metabolic differences among individuals, broadening understanding of differences in regard to the mass of metabolically active tissue. The adapted model presents advantages for clinical practice, as it more precisely portrays the magnitude of heat production of body components.

Declarations

Acknowledgements

Not applicable.

Abbreviations

REE: Resting energy expenditure; IC: Indirect calorimetry; BT: Bone tissue; AT: Adipose tissue; SMT: Skeletal muscle tissue; DXA: Dual x ray absorptiometry; FFMI: Fat-free mass index; RT: Residual tissue; FM: Fat mass; BC: Body composition; BM: Body mass; ALST: Appendicular lean soft tissue; BMC: Bone mineral content; REE_{DXA}: adapted resting energy expenditure; REE_{IC}: Resting energy expenditure via indirect calorimetry; LBM_{Trunk}: Lean body mass trunk; RT_{DXA}: Adapted residual tissue; EE: energy expenditure; EE_{AT}: Energy expenditure of adipose tissue; EE_{BT}: Energy expenditure of bone tissue; EE_{SMT}: Energy expenditure of skeletal muscle tissue; EE_{RTDXA}: Energy expenditure of adapted residual tissue.

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Ethics approval and consent to participate

The study protocol was in accordance with the Declaration of Helsinki and was approved by an ethics committee of the University of São Paulo, Ribeirão Preto, Brazil (CAAE: 57511516.5.0000.5659). Participants gave informed consent before any intervention related to the study and they received no monetary incentive.

Consent for publication

Not applicable.

Availability of data and materials

The datasets analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that have no competing interests.

Author's contributions

ACRV, PPA, APS, FGB, TCA, VAAAS, NMCA, DRLM designed and collected the data, analyzed the data and wrote the manuscript. AMS, EF, EBC participated in the study design and coordination and helped to draft the manuscript. DRLM supervised the research and reviewed the manuscript throught the study. All authors read and approved the final manuscript.

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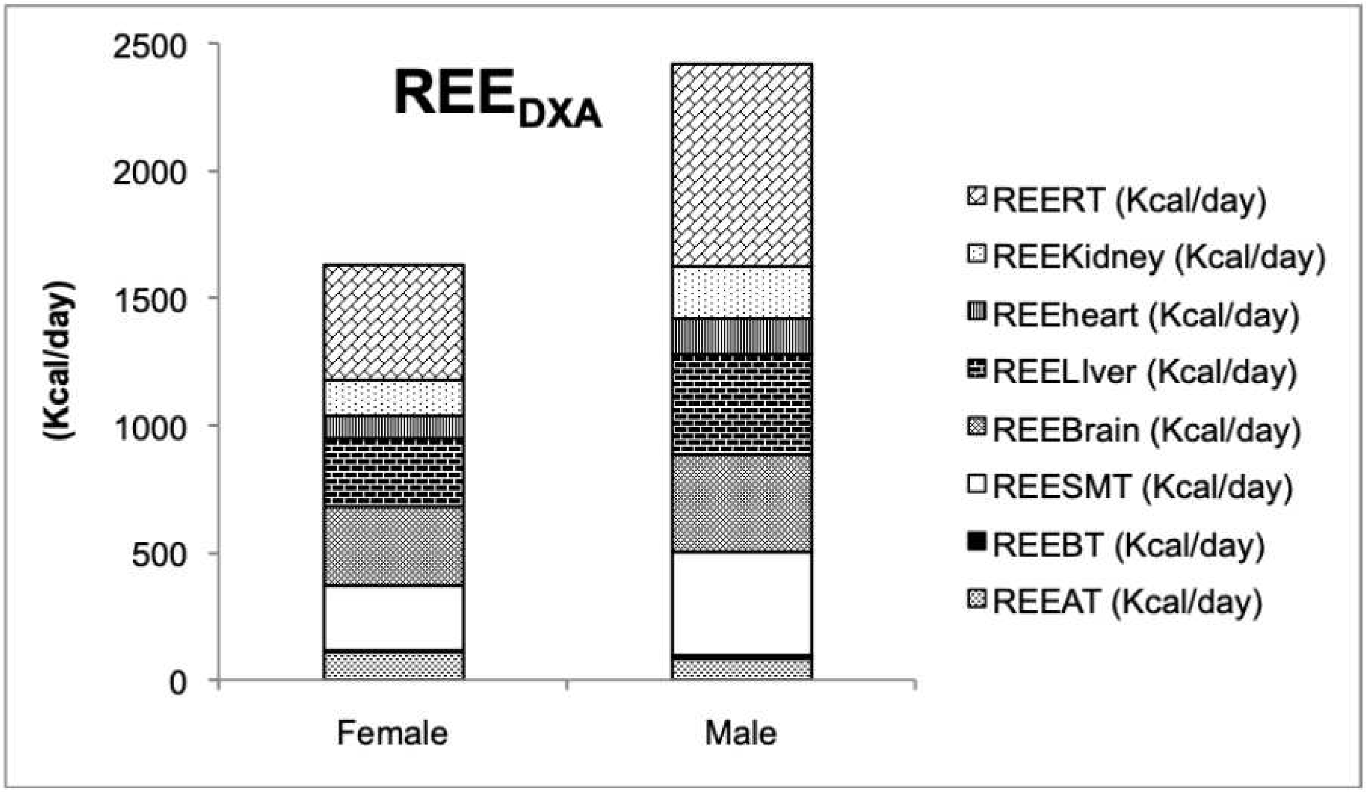
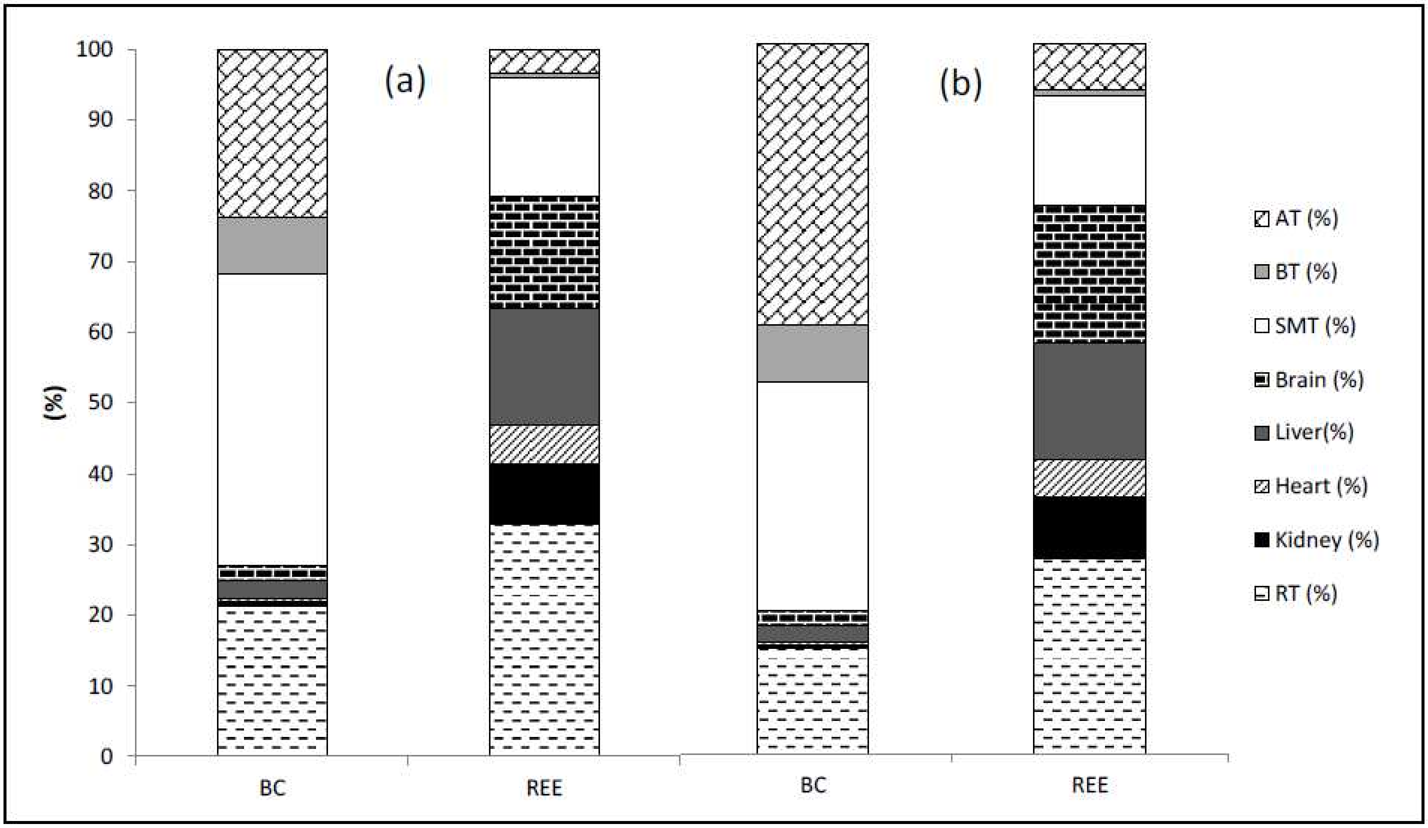
Figures



Abbreviations: REE: resting energy expenditure; REE_{AT}: resting energy expenditure of adipose tissue; REE_{BT}: resting energy expenditure of bone tissue; REE_{SMT}: resting energy expenditure of skeletal muscle tissue; REE_{Brain}: resting energy expenditure of brain; REE_{Liver}: resting energy expenditure of liver; REE_{Heart}: resting energy expenditure of heart; $REE_{Kidneys}$: resting energy expenditure of kidneys; REE_{RT}: resting energy expenditure residual tissue.

Figure 1

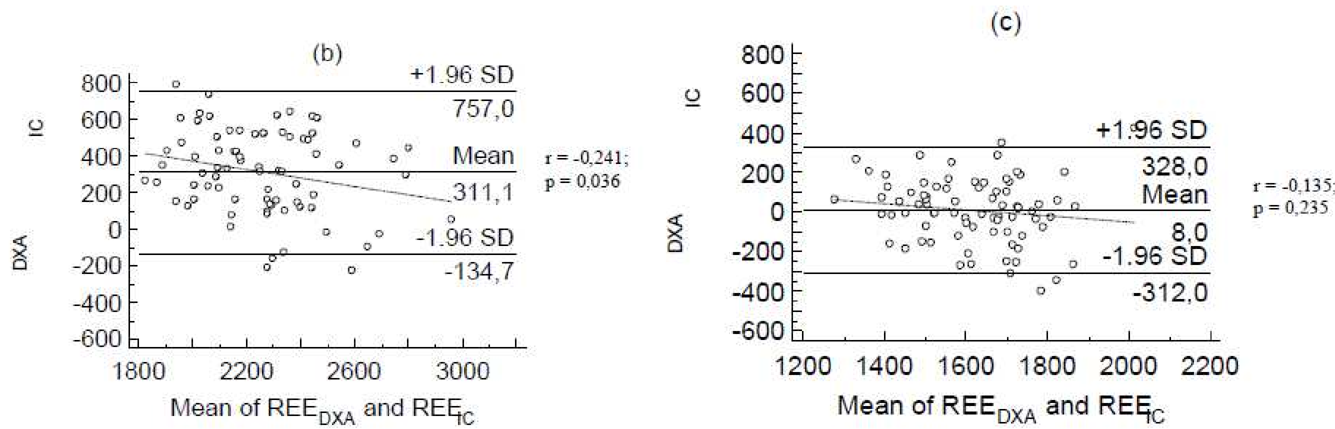
Estimated resting energy expenditure REEDXA of men and women at the tissue level.



Abbreviations: AT: adipose tissue; BT: bone tissue; SMT: skeletal muscle tissue; RT: residual tissue.
Letter a = men; letter b = women.

Figure 2

Proportion of body components and resting energy expenditure estimated by DXA, for men and women.



REE_{IC}: resting energy expenditure measured by indirect calorimetry (kcal/day); REE_{DXA}: resting energy expenditure estimated by DXA (kcal/day); Men - letter b; Women - letra c.

Figure 3

Plots of Bland-Altman and degree of agreement between resting energy expenditure measured and estimated.

Supplementary Files

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