Validity of the dietary reference intakes for determining energy requirements in older adults

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BACKGROUND/OBJECTIVES: The objectives of this study were to evaluate the accuracy of the Dietary Reference Intakes (DRI) for estimating the energy requirements of older adults, and to develop and validate new equations for predicting the energy requirements of this population group.
MATERIALS/METHODS: The study subjects were 25 men and 23 women with a mean age of 72.2 ± 3.9 years and 70.0 ± 3.3 years, and mean BMI of 24.0 ± 2.1 and 23.9 ± 2.7, respectively. The total energy expenditure (TEE) was measured by using the doubly labeled water (DLW) method, and used to validate the DRI predictive equations for estimated energy requirements (EER) and to develop new EER predictive equations. These developed equations were cross-validated by using the leave-one-out technique.
RESULTS: In men, the DRI equation had a -7.2% bias and accurately predicted the EER (meaning EER values within ±10% of the measured TEE) for 64% of the subjects, whereas our developed equation had a bias of -0.1% and an accuracy rate of 84%. In women, the bias was -6.6% for the DRI equation and 0.2% for our developed equation, and the accuracy rate was 74% and 83%, respectively. The predicted EER was strongly correlated with the measured TEE, for both the DRI equations and our developed equations (Pearson's r = 0.915 and 0.908, respectively).
CONCLUSIONS: The DRI equations provided an acceptable prediction of EER in older adults and these study results therefore support the use of these equations in this population group. Our developed equations had a better predictive accuracy than the DRI equations, but more studies need to be performed to assess the performance of these new equations when applied to an independent sample of older adults.

INTRODUCTION

Recently, the number of older adults has been increasing across the world [1] and this change has an impact on global and national public health systems [2]. Aging is among the risk factors for developing non-communicable chronic diseases (NCCDs) [3,4]. In older adults, regular physical activity is associated with a reduced mortality [5,6], a decreased risk for NCCDs such as type 2 diabetes, cardiovascular disease and cancer [7-9] and a decreased prevalence of cognitive impairment[10]. However, studies have shown that aging is accompanied by a decline in physical activity [11,12], contributing to reduced energy requirements in older adults [13]. In addition to this low level of physical activity, aging results in metabolic changes which influence the energy requirements of older adults. Compared to younger people, older adults have a lower resting energy expenditure (REE), which is related to the loss of fat-free mass

(FFM) accompanying the aging process [14,15].

This context raises the importance of accurate assessment of older adults' energy requirements. This can be achieved by measuring the total energy expenditure (TEE), which is equal to estimated energy requirements (EER) for adults who no longer have the need for tissue growth and maturation and who are in energy equilibrium [16]. The most accurate method for measuring TEE is the doubly labeled water (DLW) method, which is based on the use of hydrogen and oxygen stable isotopes [17]. The method is used as the gold standard in the development and validation of other methods of energy expenditure assessment. The limitation of the DLW method remains its high cost, which limits its use in studies and has reduced the number of subjects in most studies.

In its 2002 report, the Institute of Medicine of the National Academies published various equations for estimating the energy requirements for the different population groups, based

on the TEE results of different DLW studies conducted in Americans and Canadians in previous years [16]. During these predictive equations development, older adults were not considered separately as a group. However, various studies have indicated that aging is associated with changes in energy metabolism [18,19], which could affect the accuracy of these equations when applied to older adults. The objectives of this study were to evaluate the accuracy of the Dietary Reference Intakes (DRI) for estimating the energy requirements of older adults, and to develop new equations for predicting the energy requirements of this population group on a trial basis.

SUBJECTS AND METHODS

Subjects

The study subjects were forty-eight older adult subjects (25 men and 23 women), living in Gangneung city, Gangwon Province, South Korea. The inclusion criteria were: (1) Being aged 65 years or older, (2) having a normal body weight (18.5 ≤ BMI < 30), (3) not being on a diet plan for weight change, (4) not regularly engaging in hard activities such as athletes, (5) not having a disease or taking medicines that have an impact on energy or water metabolism, and (6) staying in the study province for at least two weeks before and during the study. The study was approved by the Institutional Review Board (IRB) of Gangneung-Wonju National University (approval number GWNUIRB-2016-26-1). In addition, informed consent was received from every subject before enrolling in the study.

Anthropometry and body composition measurements

The subjects' body weight and height were measured by using a stadiometer, with the subjects wearing the lightest clothes possible and without shoes. The BMI was calculated as the subject's weight (kg) divided by the height squared (m^2). Body composition was assessed through the bioelectrical impedance analysis (BIA), using Inbody 720 Body Composition Analyzer (Biospace, Korea).

REE

In the majority of the subjects (37 out of 48), the REE was measured by using indirect calorimetry (TrueOne2400, Parvo Medics, USA). The subjects were instructed to fast for at least 8 hours before the measurement and after arriving in the laboratory, they rested for at least 10 minutes before covering their heads with a facial mask while they were lying in a supine position. The facial mask was connected to the calorimeter, and the subjects were instructed to relax and stay awake during the measurement which lasted for 15 minutes. The respiratory data collected included the volume of oxygen consumed (VO_2), the volume of CO_2 produced (VCO_2) and the respiratory quotient (RQ), which were averaged over 1-minute interval for data analysis. The first 5 minutes of collected data were discarded, and the remaining 10 minutes was used to calculate REE, by using the Weir equation [20]. In the case of the remaining 11 subjects (8 men and 3 women) for whom we could not conduct indirect calorimetry due to technical problems with the machines, we used the predictive equations to estimate the REE. The most accurate equations were selected

based on the results of indirect calorimetry from the measured group. In the case of men, the Huang equation [21] was used. In comparison to indirect calorimetry, this equation had a mean bias of 0.7% and an accuracy rate of 76%. For women, the equation of Lazzer [22,23] was applied. Compared to the measured REE, the Lazzer equation had a mean bias 1.4% and the accuracy rate was 90%.

Dietary intake assessment

The subjects' dietary intake was assessed by the 24-hour diet recall method. The dietary data were collected during the two weeks of DLW measurements. For every individual subject, three days data were collected, including two weeks days and one weekend day. The collected data were analyzed with the computer-aided nutritional analysis program (CAN pro) software (web version 5.0, Korean Nutrition Society, Seoul, Korea).

Total energy expenditure (TEE) measurement

TEE was measured over a period of 14 days, by using the DLW method. At the beginning, each subject provided a 20 mL urine sample, which was then followed by the ingestion of the DLW oral dose of 1.1 g/kg of body weight. This dose was made of 1.03 g of $H_2^{18}O$ (10% enriched; Taiyo Nippon Sanso, Japan) and 0.07 g of 99.9% enriched ^2H_2O (Sigma-Aldrich, USA) per kilogram of body weight. To ensure the accuracy of measurement, the used dose container was rinsed with 100 mL tap water which was then ingested by the subject. Post-dose urine samples were collected at day 1 (a day after dose ingestion), day 2, day 13 and day 14. To reduce the risk of bias, the subjects were instructed to collect urine samples at a similar time of the day and the collection times were recorded. The collected samples were brought to the laboratory where they were kept at -20℃ before they were analyzed.

Urine analysis was done by using the isotope ratio mass spectrometry (IRMS), using a Sercon 20-20 spectrometer (Sercon Ltd., Crewe, UK).To calculate the CO_2 production rate (rCO_2), the following formula was used [17]:

$$rCO_2 \ (mol/day) = 0.4554 \times TBW \ (1.007 \ k_o \text{-} 1.041 \ k_h),$$

Where TBW: total body water, k_o: rate of ^{18}O elimination and k_h: rate of ^2H elimination. TEE was calculated based on a multiple-point approach, using the modified Weir's formula as follows [24]:

$$TEE \ (kcal/day) = 22.4 \ [3.9 \ (rCO_2/FQ) + 1.1 \ rCO_2].$$

The food quotient (FQ) was obtained by dietary intake records, by applying the equation of Black *et al.* [25]. The subjects' mean FQ was applied in the formula. Physical activity level (PAL) was determined as TEE/REE.

DRI equations for predicting EER

To predict the EER, we applied the DRI equation published by the Institute of Medicine of the National Academies [16]. The physical activity coefficient (PA) which was applied in the equations, was deduced from every subject's PAL. Below are the assessed DRI equations for predicting the EER.

EER for men aged 19 years and older:

EER (kcal/day) = 662 - [9.53 × age (yrs)] + PA ×

[15.91 × weight (kg) + 539.6 × height (m)],

Where PA is the physical activity coefficient:

PA = 1.00 if it is estimated that $1.0 \le PAL < 1.4$ (sedentary)

PA = 1.11 if it is estimated that $1.4 \le PAL < 1.6$ (low active)

PA = 1.25 if it is estimated that $1.6 \le PAL < 1.9$ (active)

PA = 1.48 if it is estimated that $1.9 \le PAL < 2.5$ (very active)

EER for women aged 19 years and older:

EER (kcal/day) = 354 - [6.91 × age (yrs)] + PA ×

[9.36 × weight (kg) + 726 × height (m)],

Where PA is the physical activity coefficient:

PA = 1.00 if it is estimated that $1.0 \le PAL < 1.4$ (sedentary)

PA = 1.12 if it is estimated that $1.4 \le PAL < 1.6$ (low active)

PA = 1.27 if it is estimated that $1.6 \le PAL < 1.9$ (active)

PA = 1.45 if it is estimated that $1.9 \le PAL < 2.5$ (very active)

Development of new equations for predicting EER

Based on the DLW results, the subjects' anthropometric variables were used to develop new predictive equations for EER. This was done by performing a nonlinear regression, using the iterative technique. The new equations were cross-validated and then their performance was compared with that of the DRI equations. Cross-validation was done by using the leave-one-out procedure [26], given the small size of our study sample. The technique consisted of removing one case from the sample and developing a regression equation based on the remaining cases. The obtained equation was then applied to the left-out case to predict the EER, and the error was computed by comparing the result with the measured TEE. This process was repeated on each case of the sample, with the regression equation obtained each time. The accuracy of our developed equations when applied on the corresponding left-out cases, represented the cross-validity of the regression equation based on all cases [26].

Statistical analysis

Data analyses were conducted with SPSS version 23 (IBM, USA). The results of descriptive statistics are presented as means ± standard deviation (SD). To compare the results of men and women, independent t-test was used for normally distributed variables, and the Mann-Whitney U test was used for the variables that were not normally distributed. The paired t-test was used to compare the measured TEE and predicted EER.

The accuracy of the EER predictive equations at the group level was evaluated by calculating the bias, which was expressed as the mean percentage error between the predicted EER and the measured TEE. At an individual level, an accurate prediction was defined as an EER prediction between 90% and 110% of the measured TEE, under-prediction as an EER prediction which was < 90% of the measured TEE, and over-prediction as an EER prediction which was > 110% of the measured TEE [27,28]. The accuracy rate was calculated as the percentage of subjects who had their EER predicted within ± 10% of the measured TEE [29]. The root mean squared errors (RMSEs) were also used to assess the equations' accuracy. The RMSE was calculated as follows:

$$RMSE = \sqrt{[\sum(EER_{predicted} - TEE_{measured})^2/N]}$$

Where $EER_{predicted}$ is the EER predicted by the DRI equations or by our developed equations, and $TEE_{measured}$ is the TEE measured by the DLW method. The agreement between measured TEE and predicted EER was evaluated with the Bland-Altman method. Statistical significance was declared at $P < 0.05$.

RESULTS

Characteristics of the subjects

The subjects' characteristics are presented in Table 1. The mean age was 72.2 ± 3.9 years for men and 70.0 ± 3.3 years for women. The weight, height and FFM were significantly higher in men than in women ($P < 0.001$). On the contrary, women

Table 1. Characteristics of the subjects

	Total (n = 48)	Men (n = 25)	Women (n = 23)	P-value[2]
Age (yrs)	71.1 ± 3.8[1]	72.2 ± 3.9	70.0 ± 3.3	0.05[a]
Weight (kg)	60.6 ± 8.5	64.8 ± 6.6	56.0 ± 8.0	< 0.001[a]
Height (cm)	159.1 ± 7.8	164.8 ± 4.5	153.0 ± 5.9	< 0.001[a]
BMI (kg/m²)	23.9 ± 2.4	24.0 ± 2.1	23.9 ± 2.7	0.887[a]
Fat mass (kg)	17.6 ± 4.9	16.3 ± 4.4	19.0 ± 5.2	0.053[a]
Fat-free mass (kg)	43.0 ± 7.0	48.5 ± 4.2	37.0 ± 3.5	< 0.001[b]
% body fat	29.0 ± 6.7	25.0 ± 5.4	33.4 ± 4.9	< 0.001[a]

[1] Mean ± SD
[2] P-value obtained by using [a] independent t-test or [b] Mann-Whitney U test

Table 2. Energy expenditure and physical activity level of the subjects

	Total	Men	Women	P-value[2]
REE (kcal/day)	1,359.5 ± 191.6[1]	1,475.2 ± 167.7	1,233.7 ± 126.4	< 0.00[a]
REE/BW	22.5 ± 2.1	22.9 ± 2.4	22.2 ± 1.8	0.304[a]
TEE$_{DLW}$ (kcal/day)	2,361.9 ± 422.7	2,673.3 ± 297.4	2,023.5 ± 234.9	< 0.001[a]
TEE/BW (kcal/kg/day)	39.1 ± 5.5	41.5 ± 4.9	36.6 ± 4.9	0.001[a]
PAL	1.74 ± 0.26	1.83 ± 0.28	1.65 ± 0.19	0.062[b]
EER$_{DRI}$ (kcal/day)	2,200.0 ± 406.9	2,485.3 ± 329.2	1,889.3 ± 204.1	< 0.001[a]
EER$_{This\ study}$ (kcal/day)	2,363.1 ± 395.7	2,671.4 ± 251.7	2,027.5 ± 198.0	< 0.001[a]

[1] Mean ± SD
[2] P-value obtained by using [a] independent t-test or [b] Mann-Whitney U test
REE, Resting energy expenditure; REE/BW, REE adjusted for body weight; TEE$_{DLW}$, total energy expenditure measured by the DLW method; TEE/BW, total energy expenditure adjusted for body weight; PAL, physical activity level; EER$_{DRI}$, Estimated energy requirements predicted by the DRI equation.

had higher body fat percentage than men ($P < 0.001$). The BMI did not differ significantly between the two groups.

Energy expenditure and physical activity level of the subjects

The mean REE was significantly higher in men than in women (Table 2), but not after adjusting for the subjects' body weight ($P > 0.05$). The TEE was also significantly higher in men than in women ($P < 0.001$), and this difference persisted even after adjusting for body weight. The PAL did not differ significantly between men and women ($P = 0.062$).

Developed equations for predicting EER in older adults

We developed two equations (one for men and one for women), by using non-linear regression analysis with the iterative technique. These equations were then cross-validated for accuracy, by the leave-one-out technique [26]. The developed equations are presented below:

Men:
 EER (kcal/day) = 2,377.07 - [18.53 × age (yrs)] + PA × [14.52 × weight (kg) + 186.64 × height (m)]
Women:
 EER (kcal/day) = 334.15 - [2.02 × age (yrs)] + PA × [13.3 × weight (kg) + 482.94 × height (m)]

Where PA is the physical activity coefficient which depends

Table 3. Accuracy of the EER predictive equations based on bias, root-mean-squared prediction error (RMSE), and percentage of accurate predictions

Predictive equation	TEE	Bias[1]	Maximum negative error[2]	Maximum positive error[3]	RMSE[4]	Accurate predictions[5]	Under predictions[6]	Over predictions[7]
	kcal/day	%	%	%	kcal/day	%	%	%
Men								
Measured TEE (TEE$_{DLW}$)[8]	2,673.3	-	-	-	-	-	-	-
EER$_{DRI}$[9]	2,479.6	-7.2	-19.6	5.7	274.0	64	36	0
EER$_{This\ study}$[10]	2,671.4	-0.1	-15.4	19.7	191.9	84	8	8
Women								
Measured TEE (TEE$_{DLW}$)[8]	2,023.5	-	-	-	-	-	-	-
EER$_{DRI}$[9]	1,889.3	-6.6	-18.8	4.7	189.7	74	26	0
EER$_{This\ study}$[10]	2,027.5	0.2	-15.2	14.6	155.0	83	4	13
All subjects								
Measured TEE (TEE$_{DLW}$)[8]	2,361.9	-	-	-	-	-	-	-
EER$_{DRI}$[9]	2,200.0	-6.9	-19.6	5.7	243.6	69	31	0
EER$_{This\ study}$[10]	2,363.1	0.1	-15.4	19.7	175.2	83	6	11

[1] Mean percentage error between predicted and measured TEE, or between EER and measured TEE.
[2] The largest under-prediction that was found with this predictive equation as a percentage of the measured value.
[3] The largest over-prediction that was found with this predictive equation as a percentage of the measured value.
[4] RMSE: root mean squared prediction error.
[5] The percentage of subjects predicted by the DRI predictive equation within 10% of TEE$_{DLW}$.
[6] The percentage of subjects predicted by the DRI predictive equation ⟨ 10% below TEE$_{DLW}$.
[7] The percentage of subjects predicted by the DRI predictive equation ⟩ 10% above TEE$_{DLW}$.
[8] TEE$_{DLW}$: total energy expenditure measured with the DLW method.
[9] EER$_{DRI}$: Estimated energy requirements predicted by the DRI equation.
[10] EER$_{This\ study}$: Estimated energy requirements predicted by our developed equation.
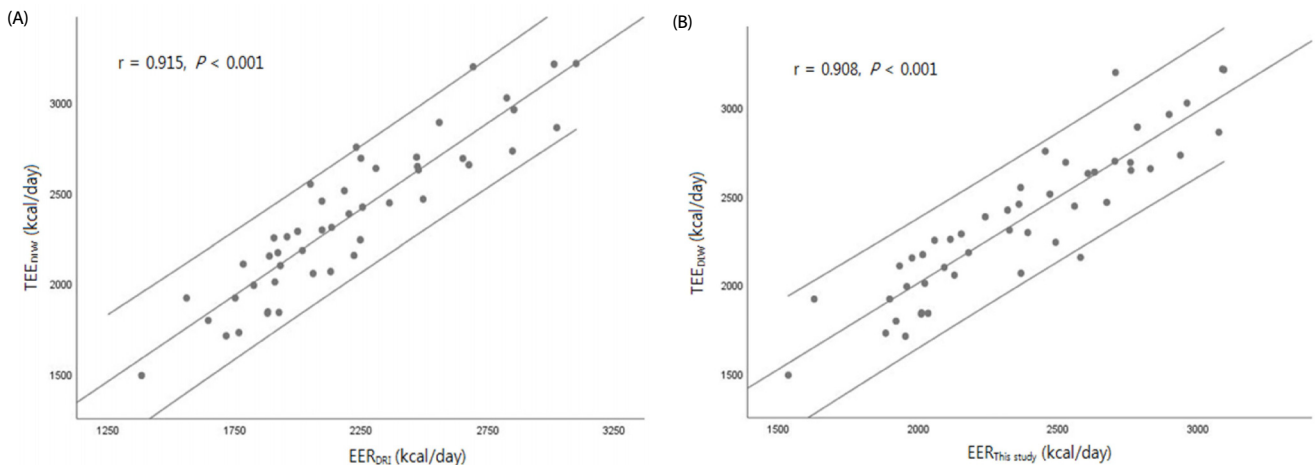

Fig. 1. Correlation between the EER predicted by the equations and the TEE measured by the DLW method. (A) DRI equations for EER prediction, (B) our newly developed equations for EER prediction. TEE$_{DLW}$, total energy expenditure measured by the doubly labeled water method; EER$_{DRI}$, estimated energy requirement predicted by the DRI equation; EER$_{This\ study}$, estimated energy expenditure predicted by our developed equation.
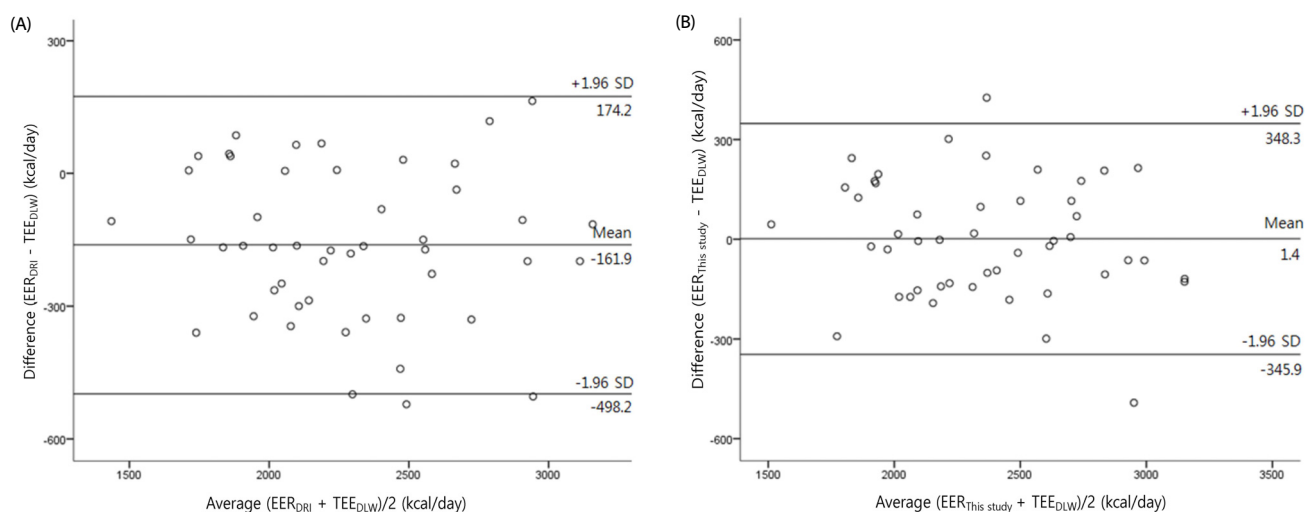
Fig. 2. Bland-Altman plots showing the agreement between the EER predicted by the equations and the TEE measured by the DLW method. (A) DRI equation for EER prediction, and (B) our newly developed equation for EER prediction. TEE_{DLW}, total energy expenditure measured by the doubly labeled water method; EER_{DRI}, estimated energy requirement predicted by the DRI equation; $EER_{This\ study}$, estimated energy expenditure predicted by our developed equation.

on the subject's PAL. We adopted the same values as those used in the DRI equations [16]:

Accuracy of the EER prediction equations

The DRI equations had a prediction bias of -7.2% in men and -6.6% in women, and the accuracy rate was 64% and 74%, respectively (Table 3). Regarding our newly developed equations, the bias was -0.1% in men and 0.2% in women, and the accuracy rate was 84% and 83%, respectively. Among all subjects, the DRI equation had a bias of -6.9% and an accuracy rate of 69%, compared to 0.1% and 83% for the new equations, respectively. There was a very high correlation between measured TEE and predicted EER among all subjects (Fig. 1), both for the DRI equations (Pearson's r = 0.915, *P* < 0.001) and for our newly developed equations (Pearson's r = 0.908, *P* < 0.001). As presented in Fig. 2, the Bland-Altman analysis resulted in limits of agreement of -498.2 to 174.2 kcal/day for the DRI equations and -345.9 to 348.3 kcal/day for our developed equations.

DISCUSSION

The TEE in older adults was measured by using the DLW method and the results were used as a reference to assess the validity of the DRIs for determining energy requirements in older adults. In addition, we developed two new predictive equations based on the subjects' TEE measured by the DLW method (TEE_{DLW}) and their anthropometric variables, namely, age, body weight and height. The accuracies of both DRI and our newly developed equations were assessed by comparing the predicted EER with the measured TEE.

In men and women, the mean TEE_{DLW} was 2,673.3 kcal/day and 2,023.5 kcal/day, and the REE was 1,475.2 kcal/day and 1,233.7 kcal/day, respectively. All these values were lower than those obtained by Tooze *et al.* in the OPEN study [30], where they used the DLW method to measure the TEE in 244 men

and 206 women. In their study, in men and women, the mean TEE_{DLW} was 2,899 kcal/day and 2,308 kcal/day and the REE was 1,716 kcal/day and 1,328 kcal/day, respectively. These differences in energy expenditure could be related to the subjects' age, given that the REE which makes the largest contribution to the TEE [31], declines as an individual ages [24,31]. In our study, the mean age of the subjects was 72.2 years for men and 70.0 years for women. In the OPEN study, the mean subjects' age was 54.0 years for men and 52.8 years for women. Another factor that could explain the difference in energy expenditure findings between the two studies is that the subjects in the open study had a higher FFM than those in our study (58.6 kg vs. 48.5 kg in men and 42.4 kg vs. 37.0 kg in women). An individual's amount of FFM has a positive impact on the REE [31,32].

Both the REE and TEE_{DLW} were higher in men than in women, as already reported in previous studies [33-35]. The difference in REE could be explained by the subjects' weight and body composition, given that men had a higher body weight and FFM than women. After adjusting the REE for body weight, the gender difference disappeared. The difference in TEE_{DLW} seems to be related to the fact that men had higher body weight and FFM than women, given that their PAL was not significantly different.

The accuracy of the equations was assessed based on the mean bias, the percentage of subjects in whom the EER was accurately predicted, and the correlation between measured TEE and predicted EER. The DRI equations underestimated the EER by 7.2% in men and by 6.6% in women, and were accurate in 64% of the men and 74% of women. There was also a very high correlation between measured and predicted results, with a Pearson's r of 0.915, *P* < 0.001.

Our study findings indicate that the DRI equations for predicting EER have an acceptable accuracy level when applied to older adults. These equations have been validated in previous studies, based on the results that were comparable to those

obtained in the present study. The DRI equation was reported to be accurate in adults in a study by Kim *et al.* [34], which included seventy-one participants (35 men and 36 women) aged between 20 and 49 years. According to their study results for men and women, the mean bias was -1.3% and -4.9%, the accuracy rate was77.1% and 62.9% and the Pearson's r was 0.783 ($P < 0.001$) and 0.810 ($P < 0.001$), respectively. Similarly, a study of Tooze *et al.* [30], which included 450 subjects (244 men and 206 women) aged 40-69 years, validated the use of the DRI equations for predicting EER. Their study found the DRI equations to have the mean bias of 5.9% for women and 7.5% for men. The rate of accurate predictions was 68% for men and 64% for women. They also found a strong correlation between the measured TEE and predicted EER, with a Pearson's r of 0.93.

In comparison to the DRI, our developed equations had a better performance with the mean bias between predicted EER and measured TEE of -0.1% and -0.2%, and the accuracy rate of 84% and 83% in men and women, respectively. The new equations also had a smaller RMSE than the DRI equation (191.9 kcal/day vs. 274.0 kcal/day in men and 155.0 kcal/day vs. 189.7 kcal/day in women). However, these equations need to be independently validated by using a separate sample of older adults.

The present study was limited by the small sample size, mainly due to the high cost of the DLW method. Nevertheless, to the best of our knowledge, this is the first to assess the validity of the DRI for determining energy requirements in older adults, and then to develop and validate new equations for this population group. Another limitation is that approximately a quarter of the subjects (11 out of 48), we were not able to perform indirect calorimetry for the measurement of REE due to technical problems with the machines.

In conclusion, the DRI equations provided an acceptable EER prediction in older adults and these study results therefore support the use of these equations in this population group. Our developed equations had a better predictive accuracy than the DRI equations, but more studies need to be performed to assess the performance of these new equations when applied to an independent sample of older adults.

CONFLICT OF INTEREST

The authors declare no potential conflicts of interests.

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