Nutr Res Pract. 2022;16(Suppl 1):S11-20
https://doi.org/10.4162/nrp.2022.16.S1.S11
pISSN 1976-1457·eISSN 2005-6168

Nutrition Research and Practice

Review

A narrative review on the application of doubly labeled water method for estimating energy requirement for Koreans

Oh Yoen Kim [1,2], **Jonghoon Park** [3], **and Eun-Kyung Kim** [4§]

[1]Department of Food Science and Nutrition, Dong-A University, Busan 49315, Korea
[2]Department of Health Science, Graduate School of Dong-A University, Busan 49315, Korea
[3]Department of Physical Education, Korea University, Seoul 02841, Korea
[4]Department of Food and Nutrition, Gangneung-Wonju National University, Gangneung 25457, Korea

Received: Nov 4, 2021
Revised: Jan 7, 2022
Accepted: Jan 24, 2022
Published online: Feb 25, 2022

§Corresponding Author:
Eun-Kyung Kim
Department of Food and Nutrition, Gangneung-Wonju National University, 7 Jukheon-gil, Gangneung 25457, Korea.
Tel. +82-33-640-2336
Fax. +82-33-640-2330
Email. ekkim@gwnu.ac.kr

ORCID iDs
Oh Yoen Kim
https://orcid.org/0000-0001-9262-3309
Jonghoon Park
https://orcid.org/0000-0002-5994-399X
Eun-Kyung Kim
https://orcid.org/0000-0003-1292-7586

Funding
This research was supported by the Policy Research Program for Project No. 20180415A13-00, 25193068200, 25203084501 from the Ministry of Health and Welfare in 2018–2020.

ABSTRACT

Research articles were reviewed to validate the estimated energy requirements (EERs) equations developed by the Institute of Medicine of the National Academies (IOM). These equations are based on total energy expenditure (TEE) measured by the doubly labeled water (DLW) method. We subsequently aimed to provide the basis for the suitability to apply the IOM equations as EER equations for Koreans, and develop relevant equations for EER in the Dietary Reference Intake for Koreans (KDRI). Additionally, besides the EER(IOM) equations, other equations were examined for EER estimation. Research papers demonstrating the validation of the EER(IOM) equations based on TEE(DLW) were searched through PubMed (up to September 2019). Of the 637 potentially relevant articles identified, duplicates and unsuitable titles and abstracts were excluded. Furthermore, papers with irrelevant subject and inappropriate study design were also excluded. Finally, 11 papers were included in the review. Among the reviewed papers, 8 papers validated the application of the EER(IOM) equations for EER based on TEE(DLW). These included 3 studies for children (USA 1, Korea 2), 1 for adolescents (Portugal), 2 for adults (Korean), and 2 for the elderly (Korea, USA). EER(IOM) equations were found to be generally acceptable for determining EER by using the DLW method, except for Korean boys at 9–11 yrs (overestimated) and female athletes at 19–24 yrs (underestimated). Additionally, 5 papers include the validation of other EER equations, beside EER(IOM) for EER based on TEE(DLW). In Japanese dietary reference intake and recommended dietary allowance, EER equations are acceptable for determining EER based on TEE(DLW). The EER(IOM) equations is generally acceptable for determining EER using the DLW method in Koreans as well as several populations, although certain defined groups were found to be unfit for the estimation. Additionally, the concept of healthy body mass index of Koreans and physical activity levels need to be considered, thereby providing the basis for developing relevant equations of EER in KDRI.

Keywords: Estimated energy requirement; doubly labeled water method; Korean dietary reference intake; validation

Conflict of Interest
The authors declare no potential conflicts of interests.

Author Contributions
Conceptualization: Kim OY, Kim EK; Data curation: Kim OY, Park J, Kim EK; Writing - original draft: Kim OY, Kim EK; Writing - review & editing: Kim OY, Kim EK

INTRODUCTION

The balance between energy intake and energy expenditure is important for maintaining a stable body weight and healthy life [1,2]. Thus, in regular life, the exact estimation of total energy expenditure (TEE) is essential to suggest adequate energy intake for an individual energy requirement [1,2].

Estimated energy requirements (EERs) have been calculated through equations developed by the Institute of Medicine of the National Academies (IOM), the World Health Organization (WHO), Food and Agriculture Organization of the United Nations (FAO), the National Institute of Health and Nutrition (NIHN), the Japanese Dietary Reference Intake (J-DRI), the Japanese Recommended Dietary Allowance for Japanese (J-RDA), and the Recommended Nutrition Intake (RNI). It is also calculated by a method that applies energy balance, factorial approach, and physical record [3-13].

Among the EER predictive equations, the EER(IOM) equations are widely used globally, and was developed based on the TEE measured by the doubly labeled water (DLW) method (TEE[DLW]) [2]. The DLW method is considered the gold standard for measuring energy expenditure, and energy intake is supposed to be equal to energy expenditure with respect to energy balance [14-19]. This was developed by considering the energy expenditure of populations in several countries (i.e., the USA, Canada and Japan, etc.) [2].

Since 2003, several researches in Korea have performed the validation of the EER equations by TEE(DLW) [3,5,6,13,20,21]. However, data to develop the EER equations by considering the age group has been insufficient. Thus, although of differing characteristics such as ethnicity and environmental conditions [22], the EER(IOM) equations developed for the US population [2] has been applied since 2005 for establishing the EER in the Dietary Reference Intakes (DRI) for Koreans, by considering the height, weight and age of Koreans in the equations [23-26].

The current study reviews the research articles that have validated the EER(IOM) equations based on TEE(DLW), thereby providing a basis for the appropriateness of the use of IOM equations as EER equations for Koreans, and the subsequent development of relevant equations of EER in DRI for Koreans. In addition, besides the EER(IOM) equations, we examine other equations for EER.

IMPORTANCE OF EER IN THE DRI

In the estimation of the 4 concepts of DRI (estimated average requirement [EAR], recommended nutrient intake, adequate intake, and tolerable upper intake level), EER reflects the EAR and is indicative of the amount required to maintain energy balance in healthy adults [2,26].

The establishment of EER is important, since energy is the basis for determining the intake amount and proportion of other nutrients in DRI. For example, the proportion of energy intake derived from the energy-supplying macronutrients (carbohydrate, fat, and protein) is reported to be related to the health status [2,26]. Accordingly, DRI for Koreans (KDRI) has set the appropriate proportion of energy intake derived from these macronutrients, to maintain optimal health status [26]. In addition, to determine the adequate intake of dietary fiber, the median daily energy intake by each gender and age group is considered. Moreover, micronutrients involved in energy metabolism (e.g., thiamine, riboflavin, and niacin) are dependent on the amount of energy expenditure [26]. However, adequate intake of the above micronutrients established in KDRI are based on the values suggested in the US DRI [2,26]. Therefore, future studies are required to apply EER for calculating the reference intake of energy-dependent micronutrients in the DRI for the Korean population.

THE DLW METHOD FOR MEASURING TEE

The DLW method measures energy expenditure using ^2H (deuterium) and ^{18}O (stable isotope) with an isotope ratio mass spectrometer [14]. This method is based on the principle that the elimination rate of ^{18}O is greater than that of ^2H; it calculates the rate of carbon dioxide (rCO_2) eliminated from the body by measuring the difference between ^2H and ^{18}O excreted in the urine for 1–2 weeks after consumption of DLW ($^2H_2{}^{18}O$), which is administered proportional to the unit body weight of the individual [14]. Along with the food quotient estimated from the food consumption survey, rCO_2 calculated by the DLW method is applied to the Weir equation for calculating TEE [15]. However, the DLW method is expensive and requires special equipment [18]; moreover, it determines only TEE, and is unable to evaluate the physical activity level (PAL), and frequencies and duration of physical activity [2]. Nevertheless, the DLW method is the gold standard for measuring TEE, and since it is measured under free-living conditions, it can be widely applied lifelong to all individuals [14].

EXPLORING FOR ARTICLES THAT VALIDATE THE EER(IOM) EQUATIONS BASED ON TEE(DLW)

PubMed (up to September 2019) was examined to search for research papers that demonstrated validation of the EER(IOM) equations based on TEE(DLW). The search keywords were a combination of words. For example, words used for energy exposure: 'energy' for nutrients, 'Dietary Reference Intake (DRI) equations', 'doubly labeled water (DLW)', 'body weight', 'body mass index (BMI)', 'physical activity (PA)', and for outcomes of interest: 'estimated energy requirement (EER)', 'total energy expenditure (TEE)', 'resting energy expenditure (REE)', 'basic metabolic rate (BMR)', 'physical activity level (PAL)', 'validation', and 'accuracy'. We obtained 637 potentially relevant articles from PubMed. After removing duplicates (n = 231) and unsuitable titles and abstracts (n = 321), 85 papers were selected for full text screening. Of these, 74 papers were excluded due to irrelevant subject or inappropriate study design. Finally, 11 papers were included in the narrative review. All these studies comprised of a case-control (n = 1) and cross-sectional (n = 10) design, and included healthy people in the USA (n = 2), Korea (n = 4), Japan (n = 3), China (n = 1), and Portugal (n = 1).

Validation parameters included 'mean % difference' and 'prediction % (accurate, underestimation, and overestimation)'. The mean % difference was calculated by the equations [EER(IOM) − TEE(DLW)]/TEE(DLW) × 100; 'accurate prediction' indicates the percentage of subjects predicted by the EER(IOM) equations within 90 and 110% TEE(DLW), 'over-prediction %' represents the percentage of subjects predicted by the EER(IOM) equations > 110% of TEE(DLW), and 'under-prediction %' explains the percentage of subjects predicted by the EER(IOM) equations < 90% of TEE(DLW) [3,5,6,11].

https://doi.org/10.4162/nrp.2022.16.S1.S11

RESEARCHES VALIDATING THE EER(IOM) EQUATIONS FOR EER BASED ON TEE(DLW)

Table 1 summarizes the basic characteristics and main outcomes of the 8 out of 11 papers reviewed that validated the EER(IOM) equations for EER based on TEE(DLW) [3-13]; 3 studies were performed in children (USA 1, Korea 2), 1 in adolescents (Portugal), 2 in adults (Korean), and 2 in the elderly (Korea and USA).

According to the study by Bandini *et al.* [10], the EER(IOM) equations are acceptable for predicting EER based on TEE(DLW) in non-obese and premenarcheal US girls (8–12 yrs, n = 161). Specifically, when categorized by PAL, the accuracy of the prediction was 63% in subjects with sedentary or low active level (n = 90), and 78% in active and very active individuals [10]. Kim *et al.* [6] also reported that the EER(IOM) equations are acceptable for predicting the EER based on TEE(DLW) in Korean girls (9–11 yrs, n = 11), but is over-predictable in Korean boys (9–11 yrs, n = 14). A validation study performed in Japanese children (10–12 yrs: boys, n = 33; girls, n = 23) demonstrated that the EER(IOM) equations are highly accurate for determining the energy requirement based on TEE(DLW) (accurate prediction: 93.9% in boys and 100.0% in girls) [9].

In addition, Silva *et al.* [12] reported that the EER(IOM) equations are valid for determining the EER based on TEE(DLW) in Portuguese adolescent basketball players (16–18 yrs; accurate prediction: 98.0%).

According to the Korean studies [3,5], the EER(IOM) equations are valid for determining EER based on TEE(DLW) in young adults (20–49 yrs: men, n = 35; women, n = 36), and non-athletic females (19–24 yrs, n = 7), but is underestimated in athletic females (19–24 yrs, n = 8). Moreover, the EER(IOM) equations were reportedly valid for determining the energy requirement by TEE(DLW) among the Korean elderly (≥ 65 yrs: men, n = 25; women, n = 23) [11]. Cooper *et al.* [8] similarly reported that the EER(IOM) equations are acceptable for predicting the energy requirement by TEE(DLW) in both elderly men (82.2 ± 3.2 yrs, n = 47) and women (82.0 ± 3.1 yrs, n = 40).

Although most results are statistically meaningful, discrepancy in the studies validating EER(IOM) by TEE(DLW) may be due to various factors such as population characteristics (i.e., race, body frame size, and PAL) and number of subjects included in the study. Thus, to validate the EER(IOM) equations based on TEE(DLW), further studies which include a greater number of subjects throughout the life cycle are required.

RESEARCHES VALIDATING OTHER EER EQUATIONS FOR EER BASED ON TEE(DLW)

Table 2 summarizes the basic characteristics and the main outcomes of 5 of the 11 papers reviewed, that validate other EER equations [3-13]. Totally, 1 study included children (Japan), 3 studies comprised Japanese young adult swimmers and college wrestlers (18–23 yrs), and Chinese adults (20–26 yrs), and 1 study in the US included the elderly.

The validation study performed in Japanese children (10–12 yrs: boys, n = 33; girls, n = 23) demonstrated that besides the EER(IOM) equations, the EER(J-DRI) equation is also

Table 1. Descriptive information of the selected studies for validating the EER(IOM) equation by TEE(DLW)

Study	Year	Race	Life span (age range)	Group (No.)	Age (yrs)	BMI (kg/m²)	DRI predictive equation for EER(IOM) (kcal/day)	PAL	kcal/day		Mean % difference	Prediction (%)			Evaluation
												Accurate	Over	Under	
Bandini *et al.* [10]	2013	White (USA MIT)	Children (8–12 yrs)	Total girls (161)	10.0 ± 1.0	42.2 ± 23.4[1)]	For girls < 9 yrs = 135.3 − [30.8 × age (yrs)] + PA × [10.0 × weight (kg)] + [934 × height (m)] + 20	56% of subjects: 1.00–1.59[2)], 44% of subjects: 1.60–2.49[2)]	· TEE(DLW)	1,959 ± 260	−6.2	70.0	2.5	28	Acceptable
									· EER(IOM)	1,838 ± 229					
				Sedentary/low active (90)			For girls ≥ 9 yrs = 135.3 − [30.8 × age (yrs)] + PA × [10.0 × weight (kg)] + [934 × height (m)] + 25		· TEE(DLW)	1,851 ± 213	−8.8	63.0	-	-	Acceptable
									· EER(IOM)	1,689 ± 150					
				Active/very active (71)					· TEE(DLW)	2,097 ± 249	−3.3	78.0	-	-	
									· EER(IOM)	2,028 ± 161					
Kim *et al.* [6]	2018	Korean	Children (9–11 yrs)	Boys (14)	10.1 ± 0.8	18.2 ± 2.1	88.5 − [61.9 × age (yrs) + PA] × [26.7 × weight (kg) + 903 × height (m)] + 25	1.58 ± 0.20	· TEE(DLW)	1,925 ± 381	12.6	28.6	64.3	7.1	Overestimated
									· EER(IOM)	2,168 ± 511					
				Girls (11)	10.7 ± 0.4	18.3 ± 1.4	135.3 − [30.8 × age (yrs)] + PA × [10.0 × weight (kg) + 934 × height (m)] + 25	1.55 ± 0.13	· TEE(DLW)	1,930 ± 279	−1.6	63.6	9.1	27.9	Acceptable
									· EER(IOM)	1,899 ± 242					
Komura *et al.* [9]	2017	Japanese	Children (10–12 yrs)	Boys (33)	8.9 ± 1.8	18.6 ± 2.8	For boys (9–18 yrs): 88.5 − 61.9 × age (yrs) + PA × [26.7 × body weight (kg) + 903 × height (m)]	1.60 ± 0.16	· TEE(DLW)	2,107 ± 273	-	-	-	-	Acceptable
									· EER(IOM)	2,153 ± 321	2.1	93.9	6.1	0.0	
				Girls (23)	8.9 ± 1.8	17.2 ± 1.9	For girls (9–18 yrs): 135.3 − 30.8 × age (yrs) + PA × [10.0 × body weight (kg) + 934 × height (m)]	1.56 ± 0.19	· TEE(DLW)	1,847 ± 269	-	-	-	-	Acceptable
									· EER(IOM)	1,882 ± 271	1.9	100.0	0.0	0.0	
Silva *et al.* [12]	2013	Portuguese	Adolescent (junior basketball players) (16–18 yrs)	Men (12)	17.0 ± 0.7	21.8 ± 1.8	88.5 − [61.9 × age (yrs) + PA] × [26.7 × weight (kg) + 903 × height (m)] + 25	2.90 ± 0.50	· TEE(DLW)	4,626 ± 682	-	98.0	-	-	Acceptable
									· EER(IOM)	4,599 ± 355					
				Women (7)	16.9 ± 0.7	21.4 ± 2.2	135.3 − [30.8 × age (yrs)] + PA × [10.0 × weight (kg) + 934 × height (m)] + 25	2.60 ± 0.30	· TEE(DLW)	3,497 ± 242					
									· EER(IOM)	3,160 ± 88					
Ndahimana *et al.* [3]	2017	Korean (case-control)	Adults (female) (19–24 yrs)	Athletes (8)	20.4 ± 1.2	21.7 ± 2.1	354 − [6.91 × age (yrs)] + PA × [9.36 × weight (kg) + 726 × height (m)]	1.97 ± 0.17	· TEE(DLW)	2,780 ± 430	−2.7	37.5	25.0	37.5	Underestimated
									· EER(IOM)	2,706 ± 430					
				Non-athletes (7)	21.7 ± 1.1	21.4 ± 3.3		1.60 ± 0.15	· TEE(DLW)	2,012 ± 161	1.4	85.7	14.3	0.0	Acceptable
									· EER(IOM)	2,041 ± 67					
Kim *et al.* [5]	2017	Korean	Adults (20–49 yrs)	Men (35)	33.5 ± 8.8	23.2 ± 2.1	662 − [9.53 × age (yrs)] + PA × [15.91 × weight (kg) + 539.6 × height (m)]	1.55 ± 0.19	· TEE(DLW)	2,707 ± 419	−1.4	77.1	11.4	11.4	Acceptable
									· EER(IOM)	2,670 ± 272					
				Women (36)	33.3 ± 8.5	22.2 ± 3.2	354 − [6.91 × age (yrs)] + PA × [9.36 × weight (kg) + 726 × height (m)]	1.46 ± 0.16	· TEE(DLW)	2,106 ± 329	−5.7	62.9	8.6	28.6	
									· EER(IOM)	1,987 ± 219					
Ndahimana *et al.* [11]	2019	Korean	Elderly adults (≥ 65 yrs)	Men (25)	72.2 ± 3.9	24.0 ± 2.1	662 − [9.53 × age (yrs)] + PA × [15.91 × weight (kg) + 539.6 × height (m)]	1.83 ± 0.28	· TEE(DLW)	2,673 ± 297	−7.2	64	0.0	36	Acceptable
									· EER(IOM)	2,480 ± 329					
				Women (23)	70.0 ± 3.3	23.9 ± 2.7	354 − [6.91 × age (yrs)] + PA × [9.36 × weight (kg) + 726 × height (m)]	1.65 ± 0.19	· TEE(DLW)	2,024 ± 254	−6.6	−74	0.0	26	
									· EER(IOM)	1,889 ± 204					
Cooper *et al.* [8]	2013	Black (USA)	Elderly (≥ 80 yrs)	Men (47)	82.2 ± 3.3	27.1 ± 4.8	662 − [9.53 × age (yrs)] + PA × [15.91 × weight (kg) + 539.6 × height (m)]	1.68 ± 0.21	· TEE(DLW)	2,208 ± 56	4.2	-	-	-	Acceptable
									· EER(IOM)	2,305 ± 35					
				Women (40)	82.0 ± 2.8	28.0 ± 4.3	354 − [6.91 × age (yrs)] + PA × [9.36 × weight (kg) + 726 × height (m)]	1.67 ± 0.31	· TEE(DLW)	1,814 ± 42	−1.9	-	-	-	
									· EER(IOM)	1,781 ± 20					

Data are shown as mean ± SD, or %.

EER(IOM), estimated energy expenditure calculated with predictive equation developed by the Institute of Medicine; TEE(DLW), total energy expenditure measured by double labeled water method; BMI, body mass index; DRI, dietary reference intake; PAL, physical activity level calculated with total energy expenditure measured by double labeled water method divided by resting energy expenditure; Mean % difference, [EER(IOM) − TEE(DLW)]/TEE(DLW) × 100; Accurate prediction %, the percentage of subjects predicted by the DRI predictive equations within 90 and 110% of TEE(DLW); Over-prediction %, the percentage of subjects predicted by the DRI predictive equations > 110% of TEE(DLW); Under-prediction %, the percentage of subjects predicted by the DRI predictive equations < 90% of TEE(DLW).

1)BMI percentile.

2)Indicates range of physical activity level.

https://doi.org/10.4162/nrp.2022.16.S1.S11

Table 2. Descriptive information of the selected studies for validating the EER equations other than EER(IOM) by TEE(DLW)

Study	Year	Race	Life span (age range)	Group (No.)	Age (yrs)	BMI (kg/m^2)	Other predictive equation for EER (kcal/day)	PAL	kcal/day		Mean % difference	Prediction (%)			Evaluation
												Accurate	Over	Under	
Komura *et al*. [9]	2017	Japanese	Children (10–12 yrs)	Boys (33)	8.9 ± 1.8	18.6 ± 2.8	EER(J-DRI): BMR standard* (kcal/kg/day) × body weight (kg) × PA(J-DRI)	1.60 ± 0.16	· TEE(DLW)	2,107 ± 273	-	-	-	-	
							EER(FAO):		· EER(J-DRI)	2,264 ± 470	6.9	63.6	33.3	3.0	Acceptable
							For boys (1–18 yrs): 310.2 + 63.3 × body weight (kg) − 0.263 × body weight (kg)^2		· EER(FAO)	2,320 ± 279	9.2	57.6	42.2	0.0	Overestimated
				Girls (23)	8.9 ± 1.8	17.2 ± 1.9	For girls (1–18 yrs): 263.4 + 65.3 × body weight (kg) − 0.454 × body weight (kg)^2	1.56 ± 0.19	· TEE(DLW)	1,847 ± 269	-	-	-	-	
									· EER(J-DRI)	2,007 ± 401	8.0	69.6	26.1	4.2	Acceptable
									· EER(FAO)	2,031 ± 183	9.1	34.8	60.9	4.3	Overestimated
Ebine *et al*. [4]	2000	Japanese	Senior, Junior (synchronized swimmers) (18–23 yrs)	Women (9)	19.8 ± 2.8	20.7 ± 0.7	EER(J-RDA) = BMR + (BMR × X) + 1/10 A	2.18 ± 0.42	· TEE(DLW)	2,738 ± 672	-	-	-	-	Acceptable
							*BMR = C (kcal × m^{-2} × h^{-1}) × (Weight$^{0.444}$ × Height$^{0.663}$ × 88.83/1,000) (m^2) × 24 (h) × 1.04 -X: activity level (1.0; level 4) -C: 36.9 for 16 yrs, 36.0 for 17 yrs, 35.6 for 18 yrs, 35.1 for 19 yrs, 34.3 for 20–29 yrs		· EER(J-RDA)	2,897 ± 139	5.8				
Sagayama *et al*. [7]	2017	Japanese	Adult (college wrestlers)	Men (10)	20.4 ± 0.5	25.7 ± 1.7	EER(NIHN) = estimated BMR (kcal/day) × PA	2.58 ± 0.34	· TEE(DLW)	4,283 ± 590	-	-	-	-	Underestimated
							*Estimate BMR = [0.1238 + (0.0481 × body weight (kg) + (0.0234 × height (cm)) − (0.0138 × (age (yrs) − 0.5473] × 1.000/4.186		· EER(NIHN)	3,548 ± 253	−20.7				
Zhuo *et al*. [13]	2013	Chinese	Adults (20–26 yrs)	Men (16)	23 ± 1	23 ± 1	EER(EB) (MJ/day) = energy intake (MJ/day) + decrease or increase of body weight (kg) × 29 ÷ experimental period (days)	1.59 ± 0.22	· TEE(DLW)	2,258 ± 180	-	-	-	-	Overestimated
							EER(PA) = pBEE × PAL		· EER(EB)	2,373 ± 315	4.8				
							*pBEE: (15.3 × weight + 679) × 95% (kcal)		· EER(PA)	2,463 ± 104	8.3				
							EER(PR): sum of metabolic equivalents (METs)/min × activity's duration (min) × unit of the MET (0.0175 kcal·kg^{-1}·min^{-1}) × body weight (kg)		· EER(PR)	2,582 ± 136	12.5				
Cooper *et al*. [8]	2013	Black (USA)	Elderly (≥ 65 yrs)	Men (47)	82.2 ± 3.3	27.1 ± 4.8	EER(WHO): BMR (kcal/day) × PA	1.68 ± 0.21	· TEE(DLW)	2,208 ± 56	24.3	-	-	-	Overestimated
									· EER(WHO)	2,915 ± 31					
				Women (40)	82.0 ± 2.8	28.0 ± 4.3		1.67 ± 0.31	· TEE(DLW)	1,814 ± 42	21.6	-	-	-	
									· EER(WHO)	2,315 ± 21					

Data are shown as mean ± SD, or %.

EER, estimated energy requirement; EER(IOM), EER calculated with predictive equation developed by the Institute of Medicine; TEE(DLW), total energy expenditure measured by double labeled water method; BMI, body mass index; PAL, physical activity level calculated with total energy expenditure measured by double labeled water method divided by resting energy expenditure; EER(J-DRI), equation of dietary reference intake for Japanese; EER(FAO), estimated energy expenditure by the equation of food and agriculture organization of the United Nations; EER(J-RDA), estimated energy expenditure calculated by equation of the Recommended Dietary Allowance; EER(NIHN), estimated energy expenditure calculated by equation of the National Institute of Health and Nutrition; EER(EB), estimated energy expenditure by energy balance method; EER(PA), estimated energy expenditure by physical activity; EER(PR), estimated energy expenditure by physical record; EER(WHO), EER by the World Health Organization equation; Mean % difference, [EER(IOM) − TEE(DLW)]/TEE(DLW) × 100; Accurate prediction %, the percentage of subjects predicted by the DRI predictive equations within 90 and 110% of TEE(DLW); Over-prediction %, the percentage of subjects predicted by the DRI predictive equations > 110% of TEE(DLW); Under-prediction %, the percentage of subjects predicted by the DRI predictive equations < 90% of TEE(DLW).

https://doi.org/10.4162/nrp.2022.16.S1.S11

acceptable for determining the EER based on TEE(DLW). However, the EER(FAO) equations overestimated EER based on TEE(DLW) (overestimation: 42.2% in boys; 60.9% in girls) [9]. Two other studies performed in Japanese sportsmen reported that EER(J-RDA) was fairly similar to the EER based on TEE(DLW) in synchronized female swimmers (18–23 yrs, n = 9), whereas the EER(NIHN) equation underestimated the EER based on TEE(DLW) in college male wrestlers (20.4 ± 0.5 yrs, n = 10) [4,7].

In addition, the EER calculated by the 3 EER equations applied in Chinese young men (23 ± 1 yrs, n = 16) were 10% higher than values obtained in TEE(DLW) [13]. Cooper *et al.* [8] also reported that the EER(WHO) equation over-predicted EER based on TEE(DLW) in both elderly men (82.2 ± 3.2 yrs, n = 47) and women (82.0 ± 3.1 yrs, n = 40).

PERSPECTIVES IN THE DEVELOPMENT OF EER EQUATIONS FOR KOREANS USING THE DLW METHODS

Data presented in **Table 1** indicates that EER(IOM) equations are generally acceptable for determining the EER of a population by applying the DLW method, except in some cases such as Korean boys (9–11 yrs, overestimated) and Korean female athletes (19–24 yrs, underestimated). As mentioned above, the EER(IOM) equation used in the KDRI since 2005 was developed for the US and Canadian populations using the DLW method [2]. Therefore, the necessity arose for validating the EER(IOM) equations for application to Koreans. As shown in **Table 1**, several studies for determining the validity of the EER(IOM) equations based on TEE(DLW) have been recently performed in Koreans (including children, university students, adults and the elderly) [3,5,6,13]. It is, indeed, a big step to set up the EER equations in the DRI dedicated to Koreans.

However, larger data measuring the TEE by the DLW method throughout the life cycle, and including infants and elderly subjects over 75 yrs, needs to be accumulated to accomplish the development of the EER equations in the DRI for Koreans. Furthermore, besides subjects within the normal range of BMI, studies for determining the EER equations in the DRI needs to be performed by including underweight, overweight and obese individuals.

Another concerning factor is the physical condition, such as height, weight, BMI, and PAL, which need to be considered while formulating the EER predictive equations. According to the US DRI [2], the ideal physical condition (i.e., weight, height, and PAL) maintaining energy balance for good health in each age group by gender, is applied to the process establishing the EER for the US population.

Contrary to Koreans, the Japanese recently did not apply the EER(IOM) equations developed for the US and Canadian populations. Instead, they used their own equations of EER by applying the reference weight and PAL of Japanese subjects [27]. Assuming that EER is the same as TEE, the EER was calculated by multiplying the REE with PAL. Since 2015, the Japanese have specifically focused on the importance of maintaining a healthy BMI for calculating the EER. Thus, the DRI for Japanese 2020 set the range of healthy BMI for good health by age group, based on the cohort data of East Asian and 2015 Japanese NHNS, followed by application of the reference weight indicating the healthy BMI for EER equations [28-30]. In addition, they provide EER for adults based on the TEE(DLW) measured in Japanese, and for children and adolescents based on the TEE(DLW) measured in Japan

https://doi.org/10.4162/nrp.2022.16.S1.S11

as well as in the USA [27]. However, the current prevailing problem is how to accurately and conveniently predict the PAL for calculating the EER. To overcome this problem, they conducted a validation study of the physical activity questionnaire for Japanese, indicating that total moderate physical activity and physical activity during work are related to PAL, whereas leisure time physical activity is not. They also suggested that an algorithm for heavy work should be added to improve the physical activity questionnaire [31]. Therefore, it is necessary to first verify the validity of applying the Japanese EER equations to Koreans using the DLW method. In addition, development of the equation that calculates Korean EER using Korean REE and PAL (similar to Japan) could be a challenging task for researchers in the future.

In the current narrative review, only PubMed was used as a search engine, and not the Cochrane library. We first attempted a search for articles through the Cochrane library using the combination of keywords proposed above. However, we were unable to find appropriate articles through this engine. This may be attributed to the characteristics of the topic (i.e., comparison between the EER formulas), and non-inclusion of clinical trials/intervention studies. Therefore, we determined that the Cochrane library was unsuitable for our search. Instead, for this narrative review, PubMed articles were examined step by step. If numerous intervention studies and clinical trials for validating the EER are accumulated in the future, Cochrane library would be the most useful and convenient tool for searching.

CONCLUSION

This narrative review indicates that the EER(IOM) equations are generally acceptable for determining the EER of a population by using the DLW method, in Korean as well as several other populations. However, some specific cases are unfit for the estimation (i.e., overestimated in Korean boys aged 9–11 yrs, and underestimated in Korean female athletes aged 19–24 yrs). In the future, we need to consider the concept of healthy BMI by defining a specific range suitable to the Korean population, and also conduct further study to predict PAL in using DLW method in different age groups.

REFERENCES

1. Hill JO, Wyatt HR, Peters JC. Energy balance and obesity. Circulation 2012;126:126-32.
PUBMED | CROSSREF
2. Institute of Medicine. Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids. Washington D.C.: The National Academies Press; 2005. p.107-264.
3. Ndahimana D, Lee SH, Kim YJ, Son HR, Ishikawa-Takata K, Park J, Kim EK. Accuracy of dietary reference intake predictive equation for estimated energy requirements in female tennis athletes and non-athlete college students: comparison with the doubly labeled water method. Nutr Res Pract 2017;11:51-6.
PUBMED | CROSSREF
4. Ebine N, Feng JY, Homma M, Saitoh S, Jones PJ. Total energy expenditure of elite synchronized swimmers measured by the doubly labeled water method. Eur J Appl Physiol 2000;83:1-6.
PUBMED | CROSSREF
5. Kim EK, Kim JH, Kim MH, Ndahimana D, Yean SE, Yoon JS, Kim JH, Park J, Ishikawa-Takata K. Validation of dietary reference intake equations for estimating energy requirements in Korean adults by using the doubly labeled water method. Nutr Res Pract 2017;11:300-6.
PUBMED | CROSSREF

6. Kim EK, Ndahimana D, Ishikawa-Takata K, Lee S, Kim H, Lim K, Lee IS, Tanaka S, Kim YJ, Choi YJ, et al. Validation of dietary reference intakes for predicting energy requirements in elementary school-age children. Nutr Res Pract 2018;12:336-41.
PUBMED | CROSSREF
7. Sagayama H, Hamaguchi G, Toguchi M, Ichikawa M, Yamada Y, Ebine N, Higaki Y, Tanaka H. Energy requirement assessment in Japanese table tennis players using the doubly labeled water method. Int J Sport Nutr Exerc Metab 2017;27:421-8.
PUBMED | CROSSREF
8. Cooper JA, Manini TM, Paton CM, Yamada Y, Everhart JE, Cummings S, Mackey DC, Newman AB, Glynn NW, Tylavsky F, et al. Longitudinal change in energy expenditure and effects on energy requirements of the elderly. Nutr J 2013;12:73.
PUBMED | CROSSREF
9. Komura K, Nakae S, Hirakawa K, Ebine N, Suzuki K, Ozawa H, Yamada Y, Kimura M, Ishii K. Total energy expenditure of 10- to 12-year-old Japanese children measured using the doubly labeled water method. Nutr Metab (Lond) 2017;14:70.
PUBMED | CROSSREF
10. Bandini LG, Lividini K, Phillips SM, Must A. Accuracy of dietary reference intakes for determining energy requirements in girls. Am J Clin Nutr 2013;98:700-4.
PUBMED | CROSSREF
11. Ndahimana D, Go NY, Ishikawa-Takata K, Park J, Kim EK. Validity of the dietary reference intakes for determining energy requirements in older adults. Nutr Res Pract 2019;13:256-62.
PUBMED | CROSSREF
12. Silva AM, Santos DA, Matias CN, Minderico CS, Schoeller DA, Sardinha LB. Total energy expenditure assessment in elite junior basketball players: a validation study using doubly labeled water. J Strength Cond Res 2013;27:1920-7.
PUBMED | CROSSREF
13. Zhuo Q, Sun R, Gou LY, Piao JH, Liu JM, Tian Y, Zhang YH, Yang XG. Total energy expenditure of 16 Chinese young men measured by the doubly labeled water method. Biomed Environ Sci 2013;26:413-20.
PUBMED | CROSSREF
14. Lifson N, Gordon GB, McCLINTOCK R. Measurement of total carbon dioxide production by means of D2O18. J Appl Physiol 1955;7:704-10.
PUBMED | CROSSREF
15. Weir JB. New methods for calculating metabolic rate with special reference to protein metabolism. J Physiol 1949;109:1-9.
PUBMED | CROSSREF
16. Speakman JR. The history and theory of the doubly labeled water technique. Am J Clin Nutr 1998;68:932S-938S.
PUBMED | CROSSREF
17. Westerterp KR. Doubly labelled water assessment of energy expenditure: principle, practice, and promise. Eur J Appl Physiol 2017;117:1277-85.
PUBMED | CROSSREF
18. Park J, Kazuko IT, Kim E, Kim J, Yoon J. Estimating free-living human energy expenditure: practical aspects of the doubly labeled water method and its applications. Nutr Res Pract 2014;8:241-8.
PUBMED | CROSSREF
19. Wong WW, Roberts SB, Racette SB, Das SK, Redman LM, Rochon J, Bhapkar MV, Clarke LL, Kraus WE. The doubly labeled water method produces highly reproducible longitudinal results in nutrition studies. J Nutr 2014;144:777-83.
PUBMED | CROSSREF
20. Lee SJ, Kim HR. Total energy expenditure of professional soccer players measured by the doubly labeled water method. Korean J Exerc Nutr 2003;7:241-6.
21. Yoon JS, Kim EK, Kim JH, Kim MH. Energy Expenditure Using the Doubly Labeled Water Method: Estimation of Resting Energy Expenditure and Physical Activity. 2nd Year Report. Cheongju: Korea Centers for Disease Control and Prevention; 2013.
22. Wang X, You T, Lenchik L, Nicklas BJ. Resting energy expenditure changes with weight loss: racial differences. Obesity (Silver Spring) 2010;18:86-91.
PUBMED | CROSSREF
23. Ministry of Health and Welfare (KR), The Korean Nutrition Society. Dietary Reference Intakes for Koreans 2005. Seoul: Ministry of Health and Welfare; 2005.

24. Ministry of Health and Welfare (KR), The Korean Nutrition Society. Dietary Reference Intakes for Koreans 2010. Seoul: Ministry of Health and Welfare; 2010.

25. Ministry of Health and Welfare (KR), The Korean Nutrition Society. Dietary Reference Intakes for Koreans 2015. Sejong: Ministry of Health and Welfare; 2016.

26. Ministry of Health and Welfare (KR), The Korean Nutrition Society. Dietary Reference Intakes for Koreans 2020. Sejong: Ministry of Health and Welfare; 2020.

27. Ministry of Health, Labour and Welfare. Report on the Dietary Reference Intake for Japanese. Tokyo: Ministry of Health, Labour and Welfare; 2019.

28. Sogabe N, Sawada SS, Lee IM, Kawakami R, Ishikawa-Takata K, Nakata Y, Mitomi M, Noguchi J, Tsukamoto K, Miyachi M, et al. Weight change after 20 years of age and the incidence of dyslipidemia: a cohort study of Japanese male workers. J Public Health (Oxf) 2016;38:e77-83.
PUBMED | CROSSREF

29. Ministry of Health, Labour and Welfare, National Institute of Health and Nutrition. Seminar on Dietary Reference Intake. Tokyo: Ministry of Health, Labour and Welfare; 2004. p.4-6.

30. Energy Committee. 2020 Dietary Reference Intake for Koreans (KDRI). Seminar on the Establishing Estimated Energy Requirement of 2020 KDRI. Seoul: Energy Committee; 2019.

31. Ishikawa-Takata K, Naito Y, Tanaka S, Ebine N, Tabata I. Use of doubly labeled water to validate a physical activity questionnaire developed for the Japanese population. J Epidemiol 2011;21:114-21.
PUBMED | CROSSREF