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原著

Validity of predictive equations for resting energy expenditure in sarcopenic older adults in long-term care

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key words Bioimpedance analysis, long-term care, nutritional assessment, resting energy expenditure, sarcopenia

abstract

Objectives：It is essential to estimate daily energy needs for those population at higher risk of malnutrition and with decreased muscle mass, i.e., sarcopenia. The aim of the study was to compare predicted Resting Energy Expenditure (pREE) using reported predictive equations to determine measured REE (mREE) via bioimpedance analysis in hospitalized elderly in long-term care (LTC) wards.

Methods：Consecutive older patients aged 65 and older hospitalized in LTC wards were recruited. bioelectrical impedance analysis (BIA) was used to measure body composition and calculate mREE. We compared the mREE with 24 predictive equations (pREE) available in the literature that combined four basic and anthropometric variables：age, sex, body weight, and height.

Results：The mean mREE was 917.9±63.4 kcal for females and 1,086.9±97.7 kcal for males. The strength of the relationship between pREE and mREE ranged from very weak to moderate (Pearson r=0.128 to 0.779). Overall, up to only 56.5% of subjects had pREEs within the range of±10% of their mREEs.

Conclusions：Commonly used predictive equations are inadequate for estimating REE in LTC patients with sarcopenia.

Clinical implications：Older LTC patients' nutritional assessment should be individualized and based on the skills and experience of multidisciplinary experts in clinical nutrition.

Introduction

There is a physiological decline in older ages[1]. This condition is termed, "anorexia of ageing" and may be associated with declines in skeletal muscle mass, energy expenditure, and physical activity that occur over the lifespan[2, 3]. Decreased skeletal muscle mass has been related to malnutrition, length of stay in a care facility, morbidity, and mortality[4, 5], and malnutrition becomes more frequent in populations with higher morbidity and care burden. It has been reported that about 8% of

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older people needing help from domiciliary care services have malnutrition[6], and that up to 25% of functionally dependent older adults experience unintentional weight loss[7]. Furthermore, only one third of long-term care (LTC) residents have been found to be well nourished[8]. A mismatch between prescribed energy intake and energy expenditure can promote unintentional weight change and further complicate nutritional status, particularly in LTC elderly unable to modulate their own dietary intake. Therefore, it is essential to estimate daily energy needs for LTC elderly at higher risk of malnutrition and with decreased muscle mass, i.e., sarcopenia.

Resting energy expenditure (REE) contributes to about 70% of total energy expenditure (TEE), depending on physical activity and metabolic stress[9]. Assessment of REE is a primary step for weight management and determining adequate nutritional strategies. REE can be measured by using indirect calorimetry and predicted based on body composition or estimative equations. However, the cost of indirect calorimetry instruments, the training necessary to acquire reliable data, and the difficulty performing this test on older people limits the usage of indirect calorimetry in daily clinical practice[10]. The assessment of REE by measuring body composition through bioelectrical impedance analysis (BIA), commonly using skeletal muscle mass, is a more practical and reliable method for attaining this measurement in clinical settings[11, 12]; however, to date, BIA usage is not wide spread in LTC settings. Therefore, predictive equations based on demographic characteristics (age, sex, etc.) and anthropometric variables (height, weight, etc.) have been developed to allow simple, rapid, and easy calculation of REE.

Systematic review of the literature has allowed identification of some predictive equations commonly used in LTC settings for nutritional assessment, including "Harris-Benedict 1919"[13], "Mifflin"[14], and "Owen"[15]. While using these equations may be efficient, they are based on demographic variables that may not account for the variety in REE. Further, these formulas are likely to result in significant systematic error because of the limited sample sizes and different population samples used to derive them. Actually, these equations are typically derived from healthy adults who may be only moderately elderly.

There is little evidence of the accuracy and precision of predictive equations, as compared to measured REE in the elderly, especially those in LTC settings. Therefore, the present study aimed to compare predicted REE (pREE) using reported predictive equations to determine measured REE (mREE) via BIA in older patients hospitalized in LTC wards.

Materials and methods

This was a retrospective, single-institution, cross-sectional study conducted at a 172-bed hospital that provides chronic geriatric care in Fukuoka City, Japan, which has a population of 1.53 million, 21% of whom are >65 years old. Because the study was retrospective, an opt-out procedure for recruitment was instituted; therefore, patients could withdraw from the study at any time. The study was approved by the Institutional Review Board of Saku Hospital and adhered to the tenets of the Declaration of Helsinki.

1) Subjects

Consecutive patients, who were hospitalized in LTC wards in April 2015, were recruited. All

patients aged 65 years or older with more than 30 days of hospital stay were included. The following patients were excluded : 1) patients for whom BIA was not applicable because of restlessness, implanted metallic devices, or other medical equipment use ; 2) those with acute diseases or chronic high-grade inflammatory diseases, and 3) those who were medically unstable. Body weight and height were measured under standard conditions by the same operators, in the morning, before breakfast. Body mass index (BMI) was calculated as body weight divided by squared height. Physical and cognitive functional levels were measured using the Functional Independence Measure (FIM) [16] by trained rehabilitation therapists. Hand-grip strength (HG) was assessed via the hand-grip test by using a Smedley dynamometer (TTM, Tokyo, Japan) in the non-dominant hand with the patient in a standing or seated position, depending on their mobility. HG were measured according to the directions of trained rehabilitation therapist's instructions. The minimum detectable value of the instrument was 5 kg.

2) Study procedures

REE was calculated via BIA, which was conducted under standardized conditions by using the following protocol. The assessment was made eight hours after the last meal and after a patient had rested in bed for one hour, when there was no current status of fever, tremor, or poor physical condition. The instrument we used (InBody S10 ; InBody, Tokyo, Japan) is the latest version of a validated, multi-frequency BIA instrument, and its measurement is considered to be minimally affected by fluid overload when estimating fat-free mass (FFM) or skeletal muscle mass [17]. Moreover, multi-frequency BIA has been validated for estimating FFM in older adults [18], and BIA-derived body composition can be used to more accurately predict REE than can reported predictive equations [19]. Thus, we used the basal metabolic rate, as calculated by BIA, which was deemed to be the mREE, as a control of the predictive equations' accuracy.

The predictive equations utilized in the current study are provided in Table 1. We selected the 24 predictive equations available in the literature that combined four basic and anthropometric variables : age, sex, body weight, and height.

3) Data analysis

Descriptive data were summarized either by means and standardized deviations or counts and frequencies. pREE was compared with mREE via BIA. The mean percentage difference (bias) between pREE and mREE was calculated as (mREE-pREE/mREE) ×100%. The accuracy rate was determined as the percentage of predicted values within ±10% of the measured value [20, 21], which is a clinically acceptable error rate. pREE lower than 90% of mREE was considered to be under predicted and pREE higher than 110% of mREE was considered over predicted. Pearson correlation was performed to assess the association between predicted and measured REEs. Data were analyzed using SPSS 21.0 (IBM ; Armonk, NY USA) for Windows. $P<0.05$ was considered statistically significant.

Results

The descriptive characteristics of the study patients are shown in Table 2. We included in

Table 1. Predictive equations for resting energy expenditure.

Equations	Factors used for calculation	REE predictive equations	
Harris JA et al, *Proc Natl Acad Sci USA*, 1918.	Sex, WT(kg), HT(cm), age(y)	Male	WT×13.7516+HT×5.0033−age×6.755+66.473
		Female	WT×9.5634+HT×1.8496−age×4.6756+655.0955
Roza AM et al, *Am J Clin Nutr*, 1984.	Sex, WT(kg), HT(cm), age(y)	Male	WT×13.397+HT×4.799−age×5.677+88.362
		Female	WT×9.247+HT×3.098−age×4.33+477.593
Japanese Society for Parental and Enteral Nutrition (JSPEN), *JSPEN Guideline for parental and enteral nutrition, 3rd edition. (in Japanese)*, 2013.	Sex, WT(kg), HT(cm), age(y)	Male	66+13.7×WT+5.0×HT−6.8×age
		Female	665+9.6×WT+1.7×HT−7.0×age
Mifflin MD et al, *Am J Clin Nutr*, 1990.	Sex (M : 1 ; F : 0), WT (kg), HT (cm)		9.99×WT+6.2×HT−4.92×age+166×sex−161
Owen OE et al, *Am J Clin Nutr*, 1987.	Sex, WT (kg)	Male	WT×10.2+879
		Female	WT×7.18+795
Black AE et al, *Eur J Clin Nutr*, 1996.	Sex, WT (kg), HT (m), age (y)	Male	$1.083\times WT0.48\times HT0.50\times age^{-0.13}$
		Female	$0.963\times WT0.48\times HT0.50\times age^{-0.13}$
Miller MD et al, *Br J Nutr*, 2005.	Sex (M : 1 ; F : 0), WT (kg), age (y)		0.047×WT+1.009×sex+0.01452×age+3.21
Miller MD et al, *Br J Nutr*, 2005.	Sex (M : 1 ; F : 0), WT (kg), HT (cm), age (y)		BMI≦18.5 : 0.07122×WT+0.02149×age+0.82×sex+0.731
			BMI of >18.5 to 25 : 0.02219×WT+0.02118×HT+0.884×sex+0.01191×age+1.233
			BMI of >25 to 30 : 0.04507×WT+1.006×sex+0.01553×age+3.407
Livingston EH et al, *Obes Rex*, 2005.	Sex, WT (kg), age (y)	Male	$293\times WT^{0.4330}-5.92\times age$
		Female	$248\times WT^{0.4356}-5.09\times age$
Henry CJ, *Public Health Nutr*, 2005.	Sex, WT (kg), age (y)	Male	age 30-60y : 0.0592×WT+2.48, age≧60y : 0.0563×WT+2.15
		Female	age 30-60y : 0.0407×WT+2.9, age≧60y : 0.0424×WT+2.38
Henry CJ, *Public Health Nutr*, 2005.	Sex, WT (kg), HT (m), age (y)	Male	age 30-60y : 0.0476×WT+2.26×HT−0.574, age≧60y : 0.0478×WT+2.26×HT−1.07
		Female	age 30-60y : 0.0342×WT+2.1×HT−0.0486, age≧60y : 0.0356×WT+1.76×HT+0.0448
A Joint, *FAO/WHO/UNU Expert Consultation, World Health Organ Tech Rep Ser, 1985. Henry CJ, Public Health Nutr*, 2005.	Sex, WT (kg), age (y)	Male	age 30-60y : 11.6×WT+879, age≧60y : 13.5×WT+487
		Female	age 30-60y : 8.7×WT+829, age≧60y : 10.5×WT+596
A Joint, *FAO/WHO/UNU Expert Consultation, World Health Organ Tech Rep Ser, 1985. Henry CJ, Public Health Nutr*, 2005.	Sex, WT (kg), HT (m), age (y)	Male	age 30-60y : 11.3×WT−16×HT+901, age≧60y : 8.8×WT+1128×HT−1071
			age 30-60y : 8.7×WT−25×HT+865, age≧60y : 9.2×WT+637×HT−302

Equations	Factors used for calculation	REE predictive equations	
Simple Formula for Japanese Japanese Society for Parental and Enteral Nutrition, *JSPEN Guideline for parental and enteral nutrition, 3rd edition*, 2013.	Sex, WT (kg)	Male	14.1×WT+620
		Female	10.8×WT+620
Ganpule AA et al. *Eur J Clin Nutr*, 2007.	Sex, WT (kg), HT (cm), age (y)	Male	0.1238+ (0.0481×WT) + (0.0234×HT) − (0.0138×age) −0.5473×1)) ×1000/4.186
		Female	0.1238+ (0.0481×WT) + (0.0234×HT) − (0.0138×age) −0.5473×2)) ×1000/4.186
Miller MD et al. *Br J Nutr*, 2005.	Sex, WT (kg), age (y)	Male	age30-60y : 11.6×BW+879
		Female	age30-60y : 8.7×BW+829
Kreymann G et al. *Ger Med Sci*, 2009.	WT (kg), age (y)		age 30-70y : 22.5×WT, age>70y : 20×WT
Bernstein RS et al, *Am J Clin Nutr*, 1983.	Sex, WT (kg), HT (cm), age (y)	Male	11.02×WT+10.23×HT−5.8×age−1032
		Female	7.48×WT-0.42×HT−3×age+844
Schofield WN, *Hum Nutr Clin Nutr*, 1985.	Sex, WT (kg), age (y)	Male	age 30-60y : 0.048×WT+3.653, age≧60y : 0.049×WT+2.459
		Female	age 30-60y : 0.034×WT+3.538, age≧60y : 0.038×WT+2.755
Schofield WN, *Hum Nutr Clin Nutr*, 1985.	Sex, WT (kg), HT (m), age (y)	Male	age 30-60y : 0.048×WT−0.011×HT+3.67, age≧60y : 0.038×WT+4.068×HT−3.491
		Female	age 30-60y : 0.034×WT+0.006×HT+3.53, age≧60y : 0.033×WT+1.917×HT+0.074
Korth O et al. *Eur J Clin Nutr*, 2007.	Sex (M : 1 ; F : 0), WT (kg), HT (cm), age (y)		41.5×WT+35.0×HT+1107.4×sex−19.1×age−1731.2
De Lorenzo A et al, *Eur J Clin Nutr*, 2001.	Sex, WT (kg), HT (cm), age (y)	Male	53.284×WT+20.957×HT−23.859×age+487
		Female	46.322×WT+15.744×HT−16.66×age+944
Lazzer S et al, *J Endocrinol Invest*, 2007.	Sex, WT (kg), HT (m), age (y)	Male	0.048×WT+4.655×HT−0.020×age−3.605
		Female	0.042×WT+3.619×HT−2.678

BMI, body mass index ; HT, height ; WT, weight

our analysis a total of 75 patients (32 men and 43 women), aged 79.3±11.2 years, with lengths of hospital stay of 1,395±862 days and BMIs of 19.6±3.0 kg/m^2. All LTC patients in the current study were considered to be sarcopenic according to their decreased skeletal muscle mass indices (SMIs) as compared to the cut-off values set by the Asian Working Group for Sarcopenia (AWGS)[22] : SMI<7.0 kg/m^2 for men and SMI<5.7 kg/m^2 for women. All subjects measured the grip strength according to the researcher's instruction, and the result was 0 kg. The mean mREE was 917.9±63.4 kcal for females and 1,086.9±97.7 kcal for males. The mean pREEs are presented in Table 3, and range from 877.8±229.6 kcal (Harris-Benedict for Japanese) to 1,334.1±147.7 (World Schofield). As the pREE uses common anthropometric variables, the strength of the relationship between pREE and mREE was found to range from very weak to moderate (Pearson r=0.128 to 0.779).

As shown in Figures 1 and 2, the predictive equations of "Harris-Benedict 1984"[23] and

Table 2. Patient demographics.

	Total (n=75)	Male (n=32)	Female (n=43)
Age (years)	79.3±11.2	73.6±11.9	83.6±8.4
Length of stay (day)	1395±862	1402±808	1389±902
Oral intake (n [%])	11 (14.7)	7 (21.9)	4 (9.3)
Motor-FIM	15±8	17±10	14±5
Cognitive-FIM	8±6	9±8	7±4
Handgrip strength (kg)	0.0	0.0	0.0
Albumin (mg/dl)	3.2±0.5	3.1±0.5	3.2±0.5
CRP (mg/dl)	1.8±2.9	2.3±3.5	1.4±2.3
Body composition			
Height (cm)	153.1±11.4	162.8±7.4	145.9±79
Weight (kg)	46.0±8.4	51.4±8.4	41.9±5.8
Body mass index (kg/m^2)	19.6±3.0	19.4±2.8	19.8±3.1
Muscle mass (kg)	25.1±7.7	30.2±7.9	21.0±7.6
Skeletal muscle mass (kg)	9.4±2.6	12.3±3.7	7.5±2.1
Skeletal muscle mass index (kg/m^2)	4.0±1.1	4.7±0.9	3.5±1.0
Fat mass (kg)	19.9±7.5	18.5±7.7	21.1±6.9
Body fat (%)	36.5±8.2	34.7±7.3	38.5±9.5
Basal metabolic rate (kcal)	993.8±85.0	1086.9±97.7	917.8±63.4
Diagnostic category (n [%])			
Stroke	34 (45.3)	20 (58.8)	14 (31.1)
Malignancy	4 (5.3)	2 (5.9)	2 (4.4)
Neurodegenerative disease	14 (18.7)	5 (14.7)	9 (20.0)
Chronic heart failure	21 (28.0)	5 (14.7)	16 (35.6)
Chronic obstructive pulmonary disease	6 (8.0)	2 (5.9)	4 (8.9)

FIM : Functional Independence Measure

"Black" yielded the most accurate predictions (56.5% of subjects), with biases of −4.9 and −8.5, respectively. In contrast, the "Müller" predictive equation yielded a 0% accurate prediction, with a bias of -68.9. Overall, up to only 56.5% of subjects had pREEs within the range of ± 10% of their mREEs. The predictive equations with accurate predictions of 50% or over included "Harris-Benedict 1984", "Black", "Livingston" (55.1%, bias of 1.0), "Henry (Age)" (50.7%, bias of -10.5), and "Henry (WT. HT. age)" (50.7%, bias of -9.9).

Discussion

Energy estimation is a critical part of nutritional assessment, which determines the nutritional intervention, outcome evaluation, and monitoring of the clinical course. To date there has been little data reported regarding the precision and accuracy of commonly used predictive equations for REE in older LTC patients, especially those who present with sarcopenia. The key finding in the current study is that many reported predictive equations are unsuitable for predicting REE in the population studied. The best accuracy between pREE and mREE was observed with the "Harris-Benedict 1984" and "Black" equations, which indicated that only 56.6% of subjects' pREEs were within ± 10% of their mREEs. Furthermore, while the lowest bias between pREE and mREE was observed by

Table 3. Comparison of predicted REE with measured REE.

	REE (kcal/day) mean±SD	Under Prediction, n (%)	Over Prediction, n (%)	Pearson r
Measured REE	993.8±85.0	—	—	—
Harris-Benedict 1919	1000.2±157.4	18 (26.1)	17 (24.6)	0.602*
Harris-Benedict 1984	1034.0±159.9	6 (8.7)	24 (34.8)	0.656*
Harris-Benedict for Japanese	877.8±229.6	42 (60.9)	10 (14.5)	0.723*
Simple Formula for Japanese	1188.6±162.8	0 (0)	58 (84.1)	0.695*
Ganpule	946.2±220.0	23 (33.3)	14 (20.3)	0.764*
Miller	1313.7±158.4	0 (0)	67 (97.1)	0.709*
Owen	1230.1±166.5	0 (0)	63 (91.3)	0.697*
Mifflin	927.8±243.3	30 (43.5)	13 (18.8)	0.768*
Kreymann	945.0±196.9	27 (39.1)	15 (21.7)	0.551*
Bernstein	814.5±130.4	41 (59.4)	1 (1.4)	0.128
Black.	1071.5±186.5	6 (8.7)	24 (34.8)	0.747*
Livingston	978.1±210.8	16 (23.2)	15 (21.7)	0.696*
World Schofield	1334.1±147.7	0 (0)	53 (76.8)	0.360*
Schofield	1111.6±154.7	1 (1.4)	43 (62.3)	0.755*
FAO (Age)	1113.1±145.3	1 (1.4)	40 (58.0)	0.606*
FAO (WT. HT. age)	1112.4±168.4	1 (1.4)	44 (63.8)	0.760*
Henry (Age)	1087.5±142.4	2 (2.9)	32 (46.4)	0.681*
Henry (WT. HT. age)	1084.7±156.8	1 (1.4)	33 (47.8)	0.755*
Müller	1661.0±171.7	0 (0)	69 (100)	0.679*
Müller (BMI)	1085.5±300.5	27 (39.1)	26 (37.7)	0.224
Korth	1072.3±304.5	19 (27.5)	34 (49.3)	0.779*
De Lorenzo	937.6±286.4	22 (31.9)	16 (23.2)	0.689*
Lazzer.	1103.9±157.5	1 (1.4)	40 (58.0)	0.660*

BMI, body mass index ; HT, height ; REE, resting energy expenditure ; WT, weight. *$p<0.01$

using "Harris-Benedict 1919" (bias of -1.6), the equation was only clinically accurate for 34% of the subjects.

Energy requirements are affected by various factors, and, as a result, REE is highly variable among subjects due in part to differences in skeletal muscle mass and physical activity level, even when patients are medically stable. Consistent with the reported variability in REE[24], we found that about one half of the subjects' measurements were either overestimated or underestimated for the pREE as compared with those of the mREE. This result indicates that metabolism varied significantly among those subjects. If patients experience complications such as hip fractures, acute infection or inflammation, pressure ulcers, or spasticity, energy needs increase. On the other hand, as diseases progress, muscle wasting reduces the metabolic demand leading to a relatively lower metabolism. Overestimation of energy needs may lead to weight gain[25] ; moreover, obesity in LTC settings may increase physical dependency. In contrast, malnutrition and weight loss can decrease REE by up to 40%[25]. Energy needs might also be decreased due to decreased physical activity. Thus, older LTC patients with mismatched energy needs, certain diseases, and decreases in physical performance

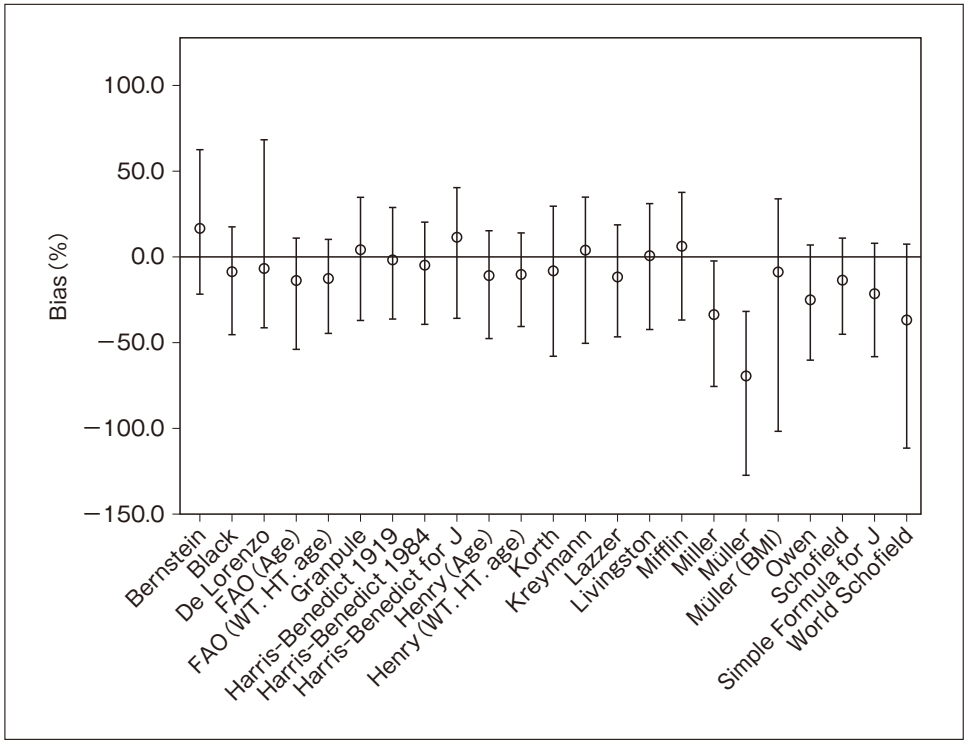

Figure 1. Percent bias of Resting Energy Expenditure (REE) prediction equations compared to measured REE.

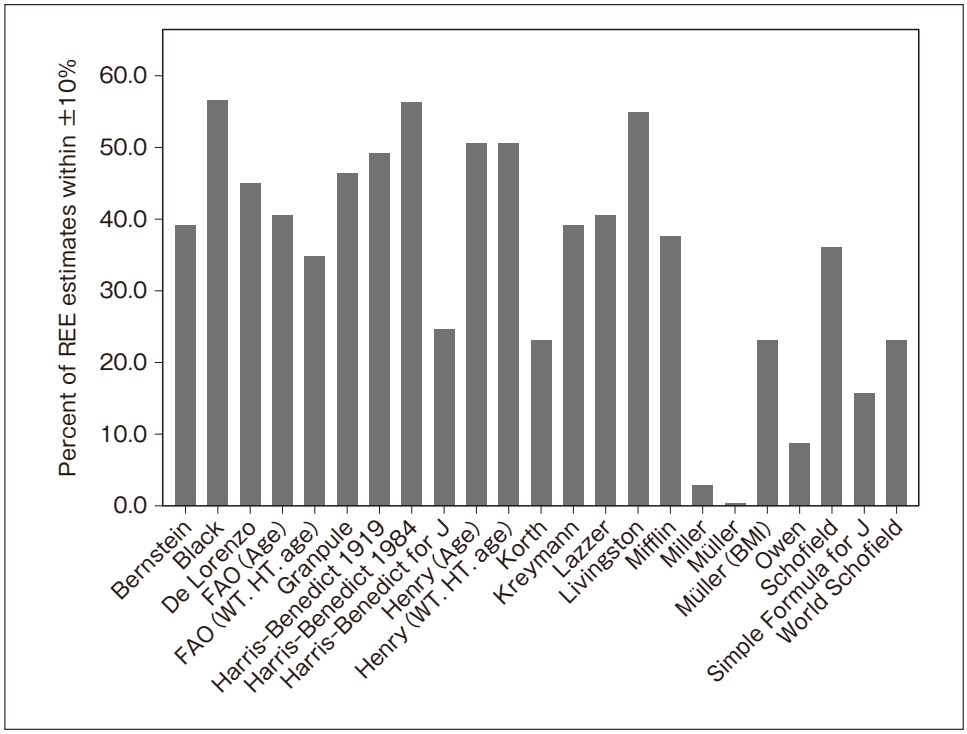

Figure 2. Percent of REE estimates with a Mean Relative Bias (%) within±10% of measured REE for each prediction equation.
REE, resting energy expenditure

may develop secondary sarcopenia[26]. To prevent either primary or secondary sarcopenia, adequate nutritional treatment based on appropriate nutritional assessment is the center of medicine in older adults[27-29].

The inadequacy of predictive equations is not entirely unexpected, as these formulas were derived from samples of subjects whose age and health status are dissimilar to those of LTC subjects[30]. "Harris-Benedict 1919" was based on women aged 31±14 years and men aged 27±9 years, "Mifflin" was derived from 498 adults of varying BMI and mean age of 44.5±14.1 years, and "Owen" was based on women aged 35±12 years and men aged 38±15.6 years. "FAO" included adults aged 19-82 years. A systematic review of the above four equations showed that "Mifflin" was the most likely to estimate within 10% of the mREE in healthy adults ; however, the expert panel recommended that dieticians use clinical judgment due to the potential for systematic error, especially in older adults[19]. Although indirect calorimetry remains the gold standard, it also remains impractical for common use in LTC settings.

The present study had some limitations. Although the study participants were homogeneous in age, medical condition, and muscle mass, the sample size was small. BIA, not indirect calorimetry, was used to measure REE and the results compared by using predictive equations, thereby possibly limiting generalization of the results. Therefore, future studies are required to determine if similar results can be obtained, by using indirect calorimetry with a larger sample size, in LTC settings.

In conclusion, we found that commonly used predictive equations are inadequate for estimating REE in LTC patients with sarcopenia ; our finding is clinically important and consistent with reported findings in older adults. Since older LTC patients may live longer with appropriate nutritional support, their nutritional assessment should be individualized and based on the skills and experience of multidisciplinary experts in clinical nutrition.

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Author contributions :
Anna Yamauchi : concept, data collecting, interpretation, manuscript drafting.
Yoshihiro Yoshimura : concept, interpretation, manuscript drafting, conduct and supervision of study.
Yumi Matsumoto : concept, data collecting, interpretation, manuscript drafting.
Senngwon Jeong : interpretation, manuscript drafting, statistical analysis.

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