Clinical Nutrition 38 (2019) 2763–2769

Contents lists available at ScienceDirect

Clinical Nutrition

journal homepage: http://www.elsevier.com/locate/clnu

Original article

Reliability of resting energy expenditure in major burns: Comparison between measured and predictive equations

Jinwoo Jeon [1], Dohern Kym [1], Yong Suk Cho*, Youngmin Kim, Jaechul Yoon, Haejun Yim, Jun Hur, Wook Chun

Department of Surgery and Critical Care, Burn Center, Hangang Sacred Heart Hospital, College of Medicine, Hallym University, 12, Beodeunaru-ro 7-gil (Youngdeungpo-dong 2-ga), Youngdeungpo-gu, Seoul 07247, Republic of Korea

ARTICLE INFO

Article history:
Received 20 August 2018
Accepted 4 December 2018

Keywords:
Resting energy expenditure
Burns
Indirect calorimetry
Predictive equation

SUMMARY

Background & aims: Poor outcomes can result from inadequate energy intake. We aimed to investigate the reliability of resting energy expenditure (REE) measured by indirect calorimetry (IC) with REE calculated using predictive equations for nutritional support in patients with major burns.

Methods: REE was measured using IC and compared with predictive equations in 215 adult severe burns patients from Jan 2011 to Jun 2015. Agreement between IC and predictive equations was assessed using Bland–Altman methods.

Results: All predictive equations, including newly developed Hangang equation, were compared with REE measured using IC. The mean measured REE was 1712 kcal/d. Bland–Altman analysis showed that 1.2 times HBE, Thumb 25, and Ireton–Jones equations had higher accuracy and reliability. The concordance correlation coefficient was higher (0.49) in the Ireton–Jones equation, and root mean square error (RMSE) was lowest (471.5) in the Thumb 25 equation. The proportion of patients with predicted REE within ±10% of measured REE was highest with Thumb 25 (52.5%). In the validation set, the Hangang equation showed the highest Lin's concordance correlation coefficient (0.67) and the lowest RMSE (311.4). Other equations for burns patients had higher mean bias and overestimated REE when compared with IC results.

Conclusions: This study suggests that Thumb 25 can be used as an alternative method for estimating energy requirements of patients with major burns when IC is not available or applicable. However, for these patients with significant variation in metabolism over time, an alternative equation is the new Hangang equation.

1. Introduction

Metabolic consequences of severe burns are a major and ongoing challenge for successful burns treatment. Failure to meet this energy requirement can lead to impaired wound healing, organ dysfunction, susceptibility to infection, and, ultimately, death. Therefore, targeted nutritional support is the cornerstone of effective burn therapy. The precise determination of protein and energy requirements is clearly important in this clinical setting, because both over- and underfeeding can occur and are associated with poor outcomes [1]. Energy requirements vary from patient to patient, and also vary over the course of an individual patient's care. Acute physiological stresses, such as surgical intervention or sepsis, dramatically change energy demands and the metabolic response. Calorie requirements for patients with severe burns are particularly difficult to predict. Although a variety of equations have been developed to evaluate calorie requirements for patients with burns and are useful for quickly estimating calorie requirements, their predictive ability has been questioned [2].

Abbreviations: AF, activity factor; BEE, basal energy expenditure; BICU, burn intensive care unit; BMR, basal metabolic rate; BSA, body surface area; HBE, Harris–Benedict equation; IC, indirect calorimetry; PBD, postburn day; REE, resting energy expenditure; RMSE, root mean square error; RQ, respiratory quotient; TBSA, total body surface area; TEE, total energy expenditure.

* Corresponding author. Department of Surgery and Critical Care, Burn Center, Hangang Sacred Heart Hospital, Hallym University Medical Center, 94-200, Youngdeungpo-dong, Youngdeungpo-gu, Seoul 07247, Republic of Korea. Fax: +82 2 2678 4386.
E-mail address: maruchigs@hallym.or.kr (Y.S. Cho).
[1] These authors contributed equally to this work as a first author.

https://doi.org/10.1016/j.clnu.2018.12.003
0261-5614/

For the abovementioned reasons, indirect calorimetry (IC) is considered the current gold standard for the determination of energy requirements in both adults and children with burns, as the use of predictive equations can result in underfeeding or overfeeding. However, it is not practical to use IC on a routine basis [3]. In the absence of IC, many equations have been recommended to predict REE, but the use of these equations is still controversial. The aim of this study was to compare the reliability of REE measured by IC with conventional predictive formulas in patients with severe burns and to suggest a new equation fit for patients with burns from our data.

2. Methods

2.1. Patients and clinical care

In this prospective observational study, we included 418 measurements of IC from 215 patients aged over 18 years of age who had burns to greater than 20% of their total body surface area (TBSA) and completed initial fluid resuscitation within 3 days of the burn. All patients were admitted to the burn intensive care unit (BICU) of Hangang Sacred Heart Hospital, Hallym University (Seoul, Korea) from Jan 2011 to Jun 2015. The exclusion criteria were as follows: patients who had any kind of shock, a fraction of inspired oxygen >0.6, within 3 days of surgery, and metabolic diseases such as diabetes mellitus, Cushing syndrome, and liver or kidney diseases which can influenced nutrient metabolism. The train data set included patients who were admitted from Jan 2011 to Dec 2013 and the validation data set included patients who were admitted from Jan 2014 to Jun 2015. All patients admitted to our hospital were treated in a similar way by the same team of burn surgeons. Standard treatment included early excision and grafting with auto- and allografts. Enteral feeding was the first choice of feeding method and began within 48 h if no major contraindications were present. Parenteral nutrition was added if target calories were not reached. Energy needs were estimated according to ESPEN guidelines for intensive care [4]. During the acute and initial phase of critical illness, 20–25 kcal/kg/day was supplied. During the anabolic recovery phase, the aim was to provide 25–30 kcal/kg/day. The protein supplied was 1.2–1.5 g/kg depending on the patient's condition. Non-protein calorie to nitrogen ratio should be maintained 100:1 for major burns. Nitrogen balance measurements were taken once a week. REE measurements by IC were used to guide nutritional management and assess the level of metabolism.

2.2. Indirect calorimetry measurements

Patients had their REE measured by IC 2 times, before and after 14 days from admission, and all measurements of IC were conducted within 28 days. Fourteen days was selected as the maximum metabolic rate is reached at 7–14 days postburn, declining slowly thereafter throughout recovery [5]. REE was measured using a Sensor-Medics Vmax 29 metabolic cart (Yorba Linda, CA). The patients were examined in a supine position with a clean, ventilated hood or connected ventilator in mechanically ventilated patients. In the mechanical ventilated patients, IC was performed when the ventilator was applied for >24 h, with FiO2 < 0.60, and with no ventilator mode changes for 120 min prior to the measurement. The gas analyser was calibrated shortly before each measurement according to manufacturer's instructions. Prior to each measurement, flow sensor and gas calibration were performed at a fixed gas concentration. IC measurements were conducted for 30 min in the morning, non-fasting steady state at least 2 h after any intervention. The same method was applied for patients with continuous feeding. The reference weight was measured using IB800 (DETECTO Co., Webb city, MO, USA) every Monday and Thursday during the patient's dressing change. Expired gas samples were analyzed and only steady-state measurements were included in the analysis. Steady state was defined as the coefficient of variation in VO2 and VCO2 of ≤10% over a period of 5 consecutive minutes. A steady state period of 5 min was considered to predict REE. A respiratory quotient (RQ) was considered accurate between 0.67 and 1.3 (human physiologic range) [6] and REE was calculated using the Weir (1949) equation.

2.3. Predictive equations

The predictive REE equations used in our study were obtained by screening previous publications and these equations are commonly used in the management of critically ill patients and patients with burns (Table 1). We used the Harris–Benedict equation (HBE) multiplied by 1.2 as a stress factor.

2.4. Statistical analysis

Normally distributed quantitative variables are presented as means ± standard deviation (SD) and nonnormally distributed variables as medians (interquartile range [IQR]). The paired *t*-test or Wilcoxon signed rank test depending on normality were used to

Table 1
Predictive REE formulas commonly used in clinical practice.

Formula	Expression
Harris–Benedict [7]	Men BEE = [66 + (13.7 × WT) + (5 × HT) − (6.8 × Age)]
	Women BEE = [655 + (9.6 × WT) + (1.8 × HT) − (4.7 × Age)]
Rule of thumb [8]	TEE = 25 kcal/kg
Ireton-Jones [9]	REE = Ventilated patient: 1784 − 11(Age) + 5(WT) + 229(Sex) + 239(T) + 804(B)
	REE = Non-ventilated patient: 629 − 11(Age) + 25(WT) − 609(O)
Toronto [10]	REE = −4343 + (10.5TBSA) + (0.23CI) + (0.84HBE) + (114T) − (4.5PBD)
Curreri [11]	REE = (25 × WT) + (40 × TBSA)
Milner [12]	REE = [BMR × (0.274 + 0.0079) × TBSA burned − 0.004 × PBD] + BMR] × BSA × 24 × AF
Xi [13]	PBD ≤ 14
	≤70% REE = (1122.4345 + 6.8634 × TBSA + 9.1156 × PBD) × BSA
	>70% REE = (1346.1578 − 0.4040 × TBSA + 32.1819 × PBD) × BSA
	PBD > 14
	≤70% REE = (1326.4286 + 9.8823 × TBSA − 13.8294 × PBD) × BSA
	>70% REE = (1460.5689 + 1.3440 × TBSA + 11.9390 × PBD) × BSA
Xie [14]	REE = (1000 × BSA) + (25 × TBSA)
Carlson [15]	REE = BMR × [0.9 = 89,142 + (0.01335 × TBSA)] × BSA × 24 × AF

Abbreviations: REE, resting energy expenditure; BEE, basal energy expenditure; WT, weight (kg); HT, height (cm); TEE, total energy expenditure; BMR, basal metabolic rate; BSA, body surface area; TBSA, total body surface area; HBE, Harris–Benedict; T, temperature; B, burn (present = 1, absent = 0); O, obesity (BMI > 27 kg/m^2, present = 1, absent = 0); PBD, postburn day; AF, activity factor; V, ventilator (present = 1, absent = 0).

determine differences between the measured REE and the predictive equations. Categorical variables are presented as percentages and were analyzed using the Chi-square test.

We evaluated the accuracy of the equations mentioned in Table 1 using the root mean square error (RMSE) and Lin's concordance correlation coefficient. The Bland–Altman method was used to further assess agreement between the measured REE and REE predicted by each equation [16,17]. Accuracy was also determined using the proportion of patients with a predicted REE within ±10% of the measured REE. *P* values < 0.05 were considered statistically significant. Analysis was conducted using computing statistical R-project program version 3.3.4.

2.5. Ethical statement

The study protocol was approved by the Institutional Review Board of Hangang Sacred Heart Hospital. We obtained written informed consent from all patients. If the patients were not able to give consent, consent was obtained from each patient's spouse, a parent, or the child older than 18 years in order.

3. Results

3.1. Demographics and measured and predicted REEs

Among all 215 patients, 155 patients were enrolled in the train data set and 60 patients in the validation data set. The median age was 43.0 years, 163 patients (75.8%) were male, and the mean weight and height was 65.8 kg and 170.0 cm, respectively. The cause of the majority of burns was flame burn (84.7%) and 85 patients (39.5%) had inhalation injuries. The median TBSA burned was 50.0%. The overall mortality rate was 23.3% (50 out of 215) (Table 2). In the train set, a total of 301 measurements were recorded; 146 patients were measured twice but 9 patients were only measured once due to death. In the validation set, a total of 117 measurements were recorded; 57 patients were measured twice but 3 patients were only measured once due to death. The mean day that the first and second REE measurements were obtained using IC was 9.9 ± 2.7 days and 21.4 ± 4.3 days, respectively. The mean interval between the 2 measurements was 11.4 ± 4.3 days. Demographics, clinical characteristics, anthropometric measurements, predicted REE, and measured REE were not significantly different between the 2 data sets (Tables 2 and 3).

3.2. Development of a new equation (Hangang)

Backward stepwise multiple linear regression analysis was performed to select variables for developing the new Hangang equation using age, sex, weight, height, TBSA, postburn day (PBD), calorie intake, and ventilator use as independent variables and measured REE as the dependent variable in the training group. To detect multicollinearity in this model, we used variance inflation factors. Age, weight, TBSA, PBD, and ventilator use showed statistical significance. From these results, the new Hangang equation is as follows: REE = 867.542 − 5.546 × age + 13.297 × weight + 4.879 × TBSA − 9.844 × PBD + 500.612 × V (1 = ventilator use, 0 = non-use)

3.3. Accuracy of existing predicted equations in burns

Nine predictive equations were compared with REE measured using IC in the train data set. Mean measured REE was 1712 kcal/d.

Table 2
Clinical characteristics of patients and comparisons between the train and validation groups.

	Train (n = 155)	Validate (n = 60)	All subjects (n = 215)	*P*-value
Age (years)	43.0 [35.0–50.0]	43.0 [34.0–52.5]	43.0 [35.0–50.0]	0.566
Sex (male, %)	117 (75.5%)	46 (76.7%)	163 (75.8%)	0.997
Height (cm)	169.0 [162.0–174.0]	170.0 [162.0–172.5]	170.0 [162.0–174.0]	0.706
Type (FB:SB:EB:ChB:CoB)	128:13:11:1:1	54:2:4:0:0	182:15:15:1:1	0.620
TBSA (%)	51.0 [40.0–62.0]	49.5 [37.5–59.5]	50.0 [40.0–62.0]	0.265
Inhalation	60 (38.7%)	25 (41.7%)	85 (39.5%)	0.809
ABSI	10.0 [9.0–11.0]	9.5 [8.0–11.0]	10.0 [8.5–11.0]	0.811
Mortality	37 (23.9%)	13 (21.7%)	50 (23.3%)	0.870

Abbreviations: *n*, number of patients; FB, flame burn; SB, scalding burn; EB, electrical burn; ChB, chemical burn; CoB, contact burn; TBSA, total body surface area.

Table 3
Predictive equation and measured values between the training and validation group.

	Train (n = 301)	Validate (n = 117)	All subjects (n = 418)	*P*-value
Weight (kg)	65.6 ± 10.9	66.4 ± 12.0	65.8 ± 11.2	0.498
BMI	22.9 [21.0–24.9]	23.2 [21.2–25.4]	23.0 [21.0–25.1]	0.530
BSA	1.76 [1.64–1.86]	1.76 [1.65–1.86]	1.76 [1.64–1.86]	0.745
Measure day	14.0 [10.0–21.0]	14.0 [9.0–19.0]	14.0 [10.0–20.0]	0.148
Ventilator	234 (77.7%)	86 (73.5%)	320 (76.6%)	0.430
Calorie intake	2147.0 [1725.0–2665.0]	2254.0 [1735.0–2545.0]	2164.0 [1735.0–2602.0]	0.568
RQ	0.9 [0.8–1.0]	0.9 [0.8–1.0]	0.9 [0.8–1.0]	0.539
REE	1635.0 [1330.0–2026.0]	1617.0 [1347.0–1933.0]	1627.5 [1336.0–1990.0]	0.521
HB	1795.8 ± 254.4	1799.6 ± 270.8	1796.9 ± 258.8	0.895
Thumb 25	1639.5 ± 273.1	1660.3 ± 300.8	1645.3 ± 280.9	0.498
IJ	1898.0 [1660.0–2215.0]	1916.0 [1715.0–2368.0]	1903.5 [1679.0–2259.0]	0.320
Toronto	2102.2 ± 359.1	2092.6 ± 324.6	2099.5 ± 349.4	0.801
Milner	2439.5 ± 448.2	2415.1 ± 445.1	2432.7 ± 446.9	0.617
Peng	2703.6 ± 387.1	2698.2 ± 367.3	2702.1 ± 381.2	0.896
Xei	3044.8 ± 491.3	2990.6 ± 445.0	3029.6 ± 478.9	0.300
Currei	3723.4 ± 787.2	3639.4 ± 729.6	3699.9 ± 771.6	0.319
Carlson	4139.0 [3375.0–5062.0]	4084.0 [3274.0–4790.0]	4127.0 [3358.0–5016.0]	0.442

Abbreviations: *n*, number of measurement; FB, flame burn; SB, scalding burn; EB, electrical burn; ChB, chemical burn; CoB, contact burn; TBSA, total body surface area.

Mean predicted REE calculated using the Thumb 25 equation was 1639.5 kcal/d and did not show a statistical difference. The concordance correlation coefficient was higher at 0.49 in the Ireton–Jones equation, and RMSE was lowest at 471.5 in the Thumb 25. The proportion of participants with a predicted REE within ±10% of measured REE was highest with the Thumb 25 equation (52.5%) (Table 4). Figure 1 shows the plot of Bland–Altman analysis for each equation in the train data set.

3.4. Validation of new Hangang equation with existing equations

We validated the Hangang equation in the validation data set and also compared this with the top 5 equations with high accuracy in the train data set. The Hangang equation showed the highest Lin's concordance correlation coefficient, at 0.67, and the lowest RMSE, at 311.4. There were no significant mean differences, with 4.3 kcal between the measured REE with Thumb 25 ($P = 0.474$) and the proportion of participants with a predicted REE within ±10% of the measured REE was the highest with Thumb 25 (61.5%) (Table 5). Figure 2 shows the plot of the Bland–Altman analysis for each equation in the validation data set.

4. Discussion

Our study suggests that none of the conventional equations and formulas used to predict REE in patients with major burn are in good agreement with the actual REE measured using IC. Moreover, previously published equations significantly overestimated REE compared with the values measured using IC.

Metabolic consequences of major burns are profound and are a constant challenge to successful treatment of burns. Failure to meet energy and protein requirements results in poor prognosis [13]. Predicting calorie requirements is important to fulfill the increased caloric requirement caused by the hypermetabolic state, while avoiding overfeeding, for major burn patients [3]. Overfeeding can cause a number of complications, including difficulties caused by respirators, fatty liver, hyperlipidemia, and hyperglycemia [3]. Therefore, all protocols that nourish patients with burns should begin by estimating nutritional requirements. A series of equations have been developed for this purpose, although the accuracy of these equations have been questioned.

The present study aimed to compare the reliability of REE measured using IC with existing conventional equations in major burns and, if lack of fit was indicated, develop a new equation. In our study, the Ireton Jones and Thumb 25 equations and 1.2 times the HBE showed higher accuracy than other equations, and the new Hangang equation was a reasonable equation with a high concordance correlation coefficient (0.67). Other equations for patients with burns overestimated REE and could lead to overfeeding of such patients. The HBE is an accepted standard for estimating basal energy expenditure (BEE). For patients with burns, multiplying the BEE by an arbitrary factor introduces significant inaccuracy. A factor of 1.2–1.5 is considered to be sufficient, except for the largest burn injuries. Rimdeika R et al. reported that nutritional requirements calculated on the usual ICU fixed weight based equation (25–30 kcal/kg/d) results in underfeeding [18]. The Ireton Jones equation allows for the calculation of energy requirements for trauma and burns patients, and includes a factor for obesity and considers ventilatory status [9]. However, the major drawback of these predictive equations is that the equations are fixed, and do not integrate changes over time. It is very important to determine the patient's ongoing energy requirements to avoid excessive caloric debt during hospitalization [6]. This means that static formulas cannot be used to accurately estimate nutritional requirements at all points throughout the course of burns treatment. Therefore, we believe that the new Hangang equation is more accurate because we have created a new formula considering the interval from the burned day and ventilatory status.

In the acute postburn injury phase, patients with >40% TBSA burned have a REE between 40% and 100% above normal [19,20]. However, since most of these studies have been in burned children, the generalizability to adults may be limited. Also, modern methods of burns treatment do not appear to have altered the nature of burn-induced hypermetabolism but have significantly reduced its magnitude. Ventilator care using sedatives, wound coverage with auto-/allograft or artificial substitutes after early excision, and high temperature and adequate humidity environments can reduce hypermetabolism [21–23]. For this reason, the existing equations made in the past these treatments were not performed properly seems to be overestimated. We believe that the energy demand will decrease accordingly.

Previously published equations, including the Curreri formula, generally overestimate current metabolic requirements, and more sophisticated formulas with different variables have been proposed. Table 1 reviews some popular formulas for adult nutrition. As shown, the equations use a variety of variables to predict calorie requirements and calculate very different estimates of energy requirements. In addition, these static formulas do not necessarily account for the major differences between types of patients and within individuals and ever-recorded energy consumption over time. As a result, there has been demand for a more accurate measurement of energy requirements. In our study, Bland–Altman plots for all equations and IC (Fig. 1) show negative and high heterogeneous values of measured REE-predicted REE differences and that the measured REE value is low relative to the predicted REE. However, the highest accuracy was achieved using 1.2 times HBE, Thumb 25, Ireton Jones, and lower mean bias using Bland–Altman analysis. All other equations (Toronto, Milner, Peng et al., Xie, Currei and

Table 4
Comparison between measured REE and predicted REE (nine equations) in the train group.

	Mean ± SD	*P*-value	Bland Altman analysis		CCC	RMSE	Accuracy
			Bias, Mean	Limits of agreement			
Measured REE (kcal/day)	1712.8 ± 498.8						
HBE [7]	1795.8 ± 254.4	<0.001	83.1	−831.9 to 998.1	0.30	473.4	19.6%
Thumb 25 [8]	1639.5 ± 273.1	0.079	−73.3	−987.7 to 841.1	0.32	471.5	52.5%
Ireton Jones [9]	1951.8 ± 432.2	<0.001	239.0	−624.3 to 1102.4	0.49	500.5	48.2%
Toronto [10]	2102.2 ± 359.1	<0.001	389.5	−575.5 to 1354.4	0.26	627.1	34.6%
Milner [12]	2439.5 ± 448.2	<0.001	726.7	−268.8 to 1722.2	0.20	886.1	12.6%
Xi et al. [13]	2703.6 ± 387.1	<0.001	990.9	20.5 to 1961.2	0.11	1107.3	7.6%
Xie [14]	3044.8 ± 491.3	<0.001	1332.0	236.8 to 2427.3	0.08	1444.1	4.0%
Currei [11]	3723.4 ± 787.2	<0.001	2010.6	524.1 to 3497.0	0.06	2148.4	1.0%
Carlson [15]	4229.3 ± 1247.5	<0.001	2516.6	300.0 to 4733.1	0.06	2758.2	2.0%

Abbreviations: RMSE, root mean square error; CCC; concordance correlation coefficient; HBE, Harris–Benedict equation.

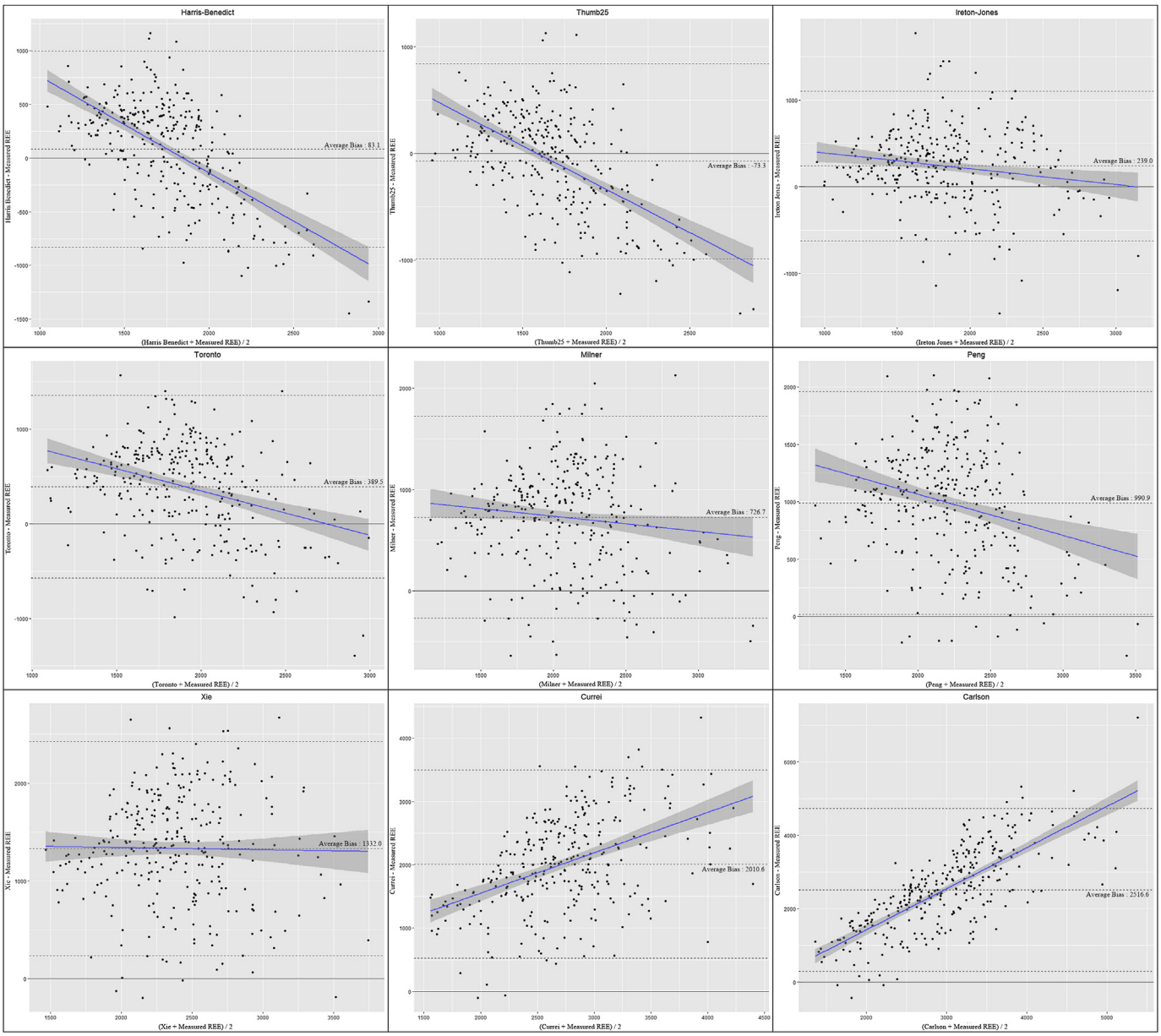

Fig. 1. Bland–Altman agreement assessment using bias plotted against the mean resting energy expenditure (REE) values. The middle horizontal lines represent absolute bias (mean differences between the measured REE and each equation). Upper and lower horizontal lines represent 95% limits of agreement (mean differences ± 1.96 SD). The blue line with grey shade represents the trend line with standard errors. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 5
Comparison between measured REE and predicted REE (Validation in the validation group), $n = 117$.

	Mean ± SD	*P*-value	Bland Altman analysis		CCC	RMSE	Accuracy
			Bias, Mean	Limits of agreement			
Measured REE (kcal/day)	1656.0 ± 438.9						
Hangang	1732.7 ± 309.4	0.002	76.6	−517.4 to 670.7	0.67	311.4	43.6%
HBE [7]	1799.6 ± 270.8	<0.001	143.5	−627.4 to 914.5	0.39	417.1	23.9%
Thumb 25 [8]	1660.3 ± 300.8	0.474	4.3	−734.8 to 743.4	0.50	375.5	61.5%
Ireton Jones [9]	1995.6 ± 438.7	<0.001	339.6	−376.3 to 1055.6	0.50	497.6	44.4%
Toronto [10]	2092.6 ± 324.6	<0.001	436.6	−406.1 to 1279.4	0.23	611.5	35.0%
Milner [12]	2415.1 ± 445.1	<0.001	759.1	−102.4 to 1620.6	0.20	876.2	10.3%

Abbreviations: REE, resting energy expenditure; RMSE, root mean square error; CCC; concordance correlation coefficient; HBE, Harris–Benedict equation.

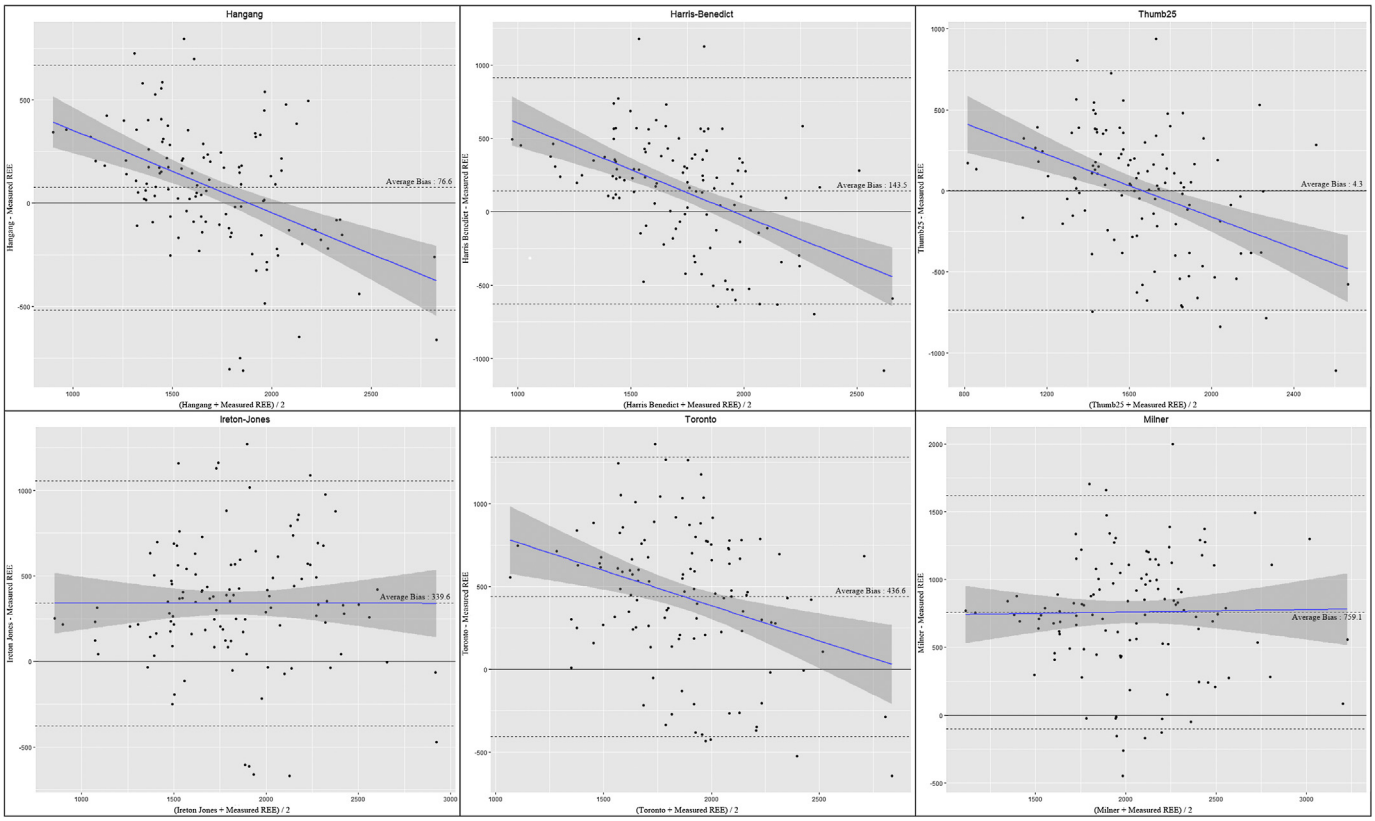

Fig. 2. Bland–Altman agreement assessment using bias plotted against the mean resting energy expenditure (REE) values. The middle horizontal lines represent absolute bias (mean differences between the measured REE and each equations). Upper and lower horizontal lines represent 95% limits of agreement (mean differences ± 1.96 SD). The blue line with grey shade represents the trend line with standard errors. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Carlson) for burns patients had higher mean bias and overestimated REE when compared with our IC results. Overfeeding with these equations can have a very detrimental effect on the prognosis of the patient. Several studies have shown that a hypocaloric feeding regimen may not be harmful and actually be beneficial in the first week of ICU care for previously well-nourished patients [24,25]. In this present study, our results show that the use of previous published equations in the major burns population is fairly restrictive, and has risk of overfeeding. Therefore, we think the Hangang equation, considering the interval from the burned day and ventilator status, can be more accurate and avoid overfeeding. This is also a reason why IC is the current gold standard in critically ill patients. As a result, numerous recent reports using IC document metabolic rates which, though still increased, are now more likely to be approximately 120–150% of the normal REE, rather than the 160–200% previously reported [26].

There are some limitations to our study. The first limitation of our study is that it was performed at a single centre and we did not validate the equation in another centre. This was because we could not find an appropriate external validation group, as our burn centre is the only burn facility operated by the University and has been designated as “The Emergency Center for Burn Care” by the Ministry for Health, Welfare, and Family Affairs in Korea. In addition, IC is not used in most hospitals in Korea due to insurance coverage. Thus, the results may not be generalised to other burns patients, and additional external validation is required. Second, we only measured REE by IC twice for each patient. Therefore, this should be taken into account when applying the Hangang equation in clinical practice, although PBD was a significant variable from our results. Third, in a few instance the patient's actual weight was not available. As mentioned above, reference body weight was measured twice a week on Monday and Thursday in our burn center.

However, the strengths of this study include its prospective design, relatively large sample size to measure the desired outcomes and researchers who were members of the centre's dedicated nutritional support team (NST). Our burn center is the only burn facility operated by the University and has been designated as “The Emergency Center for Burn Care” by the Ministry for Health, Welfare, and Family Affairs in Korea. To our knowledge, this is one of the largest studies comparing measured REE by IC with different predictive REE equations in the burns field. Further investigation is needed regarding optimal nutritional support and accurate caloric needs in patients with major burns.

5. Conclusion

This study suggests that the Thumb 25 equation (25 kcal/kg of actual body weight) can be used as an alternative method for estimating the energy requirements of patients with major burns in cases where IC is not available or not applicable. However, for burns patients whose metabolism varies significantly with the time after burns, the new Hangang equation may be a better alternative as it considers time (PBD) and ventilator status for patients with burns.

Statement of authorship

Jinwoo Jeon – Conceptualization, Data curation, Formal analysis, Writing – original draft.

Dohern Kym - Conceptualization, Data curation, Formal analysis, Writing – review & editing.

Yong-Suk Cho – Supervision, Investigation, Resources.

Youngmin Kim – Investigation, Conceptualization, Data curation.

Jaechul Yoon – Resources, Visualization, Writing – original draft.

Haejun Yim – Data curation, Formal analysis, Software.

Jun Hur – Supervision, Validation, Investigation.

Wook Chun – Funding acquisition, Methodology.

Conflicts of interest

None.

Acknowledgements

This study was supported by the Korean Health Technology R&D Project, Ministry of Health & Welfare, and Republic of Korea [grant number: HI15C1486].

References

[1] Sabatino A, Theilla M, Hellerman M, Singer P, Maggiore U, Barbagallo M, et al. Energy and protein in critically ill patients with AKI: a prospective, multicenter observational study using indirect calorimetry and protein catabolic rate. Nutrients 2017:9.

[2] Stucky CC, Moncure M, Hise M, Gossage CM, Northrop D. How accurate are resting energy expenditure prediction equations in obese trauma and burn patients? J Parenter Enteral Nutr 2008;32:420–6.

[3] Clark A, Imran J, Madni T, Wolf SE. Nutrition and metabolism in burn patients. Burns Trauma 2017;5:11.

[4] Kreymann KG, Berger MM, Deutz NE, Hiesmayr M, Jolliet P, Kazandjiev G, et al. ESPEN guidelines on enteral nutrition: intensive care. Clin Nutr 2006;25:210–23.

[5] Long CL, Schaffel N, Geiger JW, Schiller WR, Blakemore WS. Metabolic response to injury and illness: estimation of energy and protein needs from indirect calorimetry and nitrogen balance. J Parenter Enteral Nutr 1979;3:452–6.

[6] Tignanelli CJ, Andrews AG, Sieloff KM, Pleva MR, Reichert HA, Wooley JA, et al. Are predictive energy expenditure equations in ventilated surgery patients accurate? J Intensive Care Med 2017. 885066617702077.

[7] Harris JA, Benedict FG. A biometric study of human basal metabolism. Proc Natl Acad Sci U S A 1918;4:370–3.

[8] Rousseau AF, Losser MR, Ichai C, Berger MM. ESPEN endorsed recommendations: nutritional therapy in major burns. Clin Nutr (Edinb, Scotl) 2013;32:497–502.

[9] Ireton-Jones C, Jones JD. Improved equations for predicting energy expenditure in patients: the Ireton-Jones Equations. Nutr Clin Pract: Off Publ Am Soc Parenter Enteral Nutr 2002;17:29–31.

[10] Allard JP, Pichard C, Hoshino E, Stechison S, Fareholm L, Peters WJ, et al. Validation of a new formula for calculating the energy requirements of burn patients. J Parenter Enteral Nutr 1990;14:115–8.

[11] Curreri PW, Richmond D, Marvin J, Baxter CR. Dietary requirements of patients with major burns. J Am Diet Assoc 1974;65:415–7.

[12] Milner EA, Cioffi WG, Mason AD, McManus WF, Pruitt Jr BA. A longitudinal study of resting energy expenditure in thermally injured patients. J Trauma 1994;37:167–70.

[13] Xi P, Kaifa W, Yong Z, Hong Y, Chao W, Lijuan S, et al. Establishment and assessment of new formulas for energy consumption estimation in adult burn patients. PLoS One 2014;9:e110409.

[14] Xie WG, Li A, Wang SL. Estimation of the calorie requirements of burned Chinese adults. Burns 1993;19:146–9.

[15] Carlson DE, Cioffi Jr WG, Mason Jr AD, McManus WF, Pruitt Jr BA. Resting energy expenditure in patients with thermal injuries. Surg Gynecol Obstet 1992;174:270–6.

[16] Bland JM, Altman D. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1986;327:307–10.

[17] Suman OE, Mlcak RP, Chinkes DL, Herndon DN. Resting energy expenditure in severely burned children: analysis of agreement between indirect calorimetry and prediction equations using the Bland-Altman method. Burns: J Int Soc Burn Injuries 2006;32:335–42.

[18] Rimdeika R, Gudaviciene D, Adamonis K, Barauskas G, Pavalkis D, Endzinas Z. The effectiveness of caloric value of enteral nutrition in patients with major burns. Burns: J Int Soc Burn Injuries 2006;32:83–6.

[19] Hart DW, Wolf SE, Mlcak R, Chinkes DL, Ramzy PI, Obeng MK, et al. Persistence of muscle catabolism after severe burn. Surgery 2000;128:312–9.

[20] Porter C, Herndon DN, Borsheim E, Bhattarai N, Chao T, Reidy PT, et al. Long-term skeletal muscle mitochondrial dysfunction is associated with hypermetabolism in severely burned children. J Burn Care Res: Off Publ Am Burn Assoc 2016;37:53–63.

[21] Wilmore DW, Long JM, Mason Jr AD, Skreen RW, Pruitt Jr BA. Catecholamines: mediator of the hypermetabolic response to thermal injury. Ann Surg 1974;180:653–69.

[22] Bland JM, Altman DG. Measuring agreement in method comparison studies. Stat Methods Med Res 1999;8:135–60.

[23] Rutan TC, Herndon DN, Van Osten T, Abston S. Metabolic rate alterations in early excision and grafting versus conservative treatment. J Trauma 1986;26:140–2.

[24] Alberda C, Gramlich L, Jones N, Jeejeebhoy K, Day AG, Dhaliwal R, et al. The relationship between nutritional intake and clinical outcomes in critically ill patients: results of an international multicenter observational study. Intensive Care Med 2009;35:1728–37.

[25] Rahman A, Corbett C. Nutrition in the acute phase of critical illness. N Engl J Med 2014;370:2450.

[26] Hildreth MA, Herndon DN, Desai MH, Broemeling LD. Current treatment reduces calories required to maintain weight in pediatric patients with burns. J Burn Care Rehabil 1990;11:405–9.