Original Article

Energy requirements for ICU burn patients in whom the total body surface area affected exceeds 50 percent: a practical equation

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Background and Objectives: Energy requirement estimations are crucial for major burn patients' nutrition management. To find a practical equation for patients with burns over >50% of their total body surface area (TBSA) in an intensive care unit (ICU). **Methods and Study Design:** We conducted a six-week follow-up study of 21 ICU burn patients aged 17-28 years (second- and third-degree burns, TBSA: 50-90%) who were prescribed enteral nutritional support. The energy consumption ratio (ECR) was calculated by dividing the actual energy intake by the estimated energy requirement. Linear regression was used to evaluate the stability of each equation and the wound healing rate over time. **Results:** All included patients survived. On the fifth day, among the seven equations used, the ECRs of those dependent on the basal metabolic rate and body weight, namely, 35 kcal/kg BW, BMR × 1.5, and the Toronto formula, reached 74%, 71% and 69%, respectively. The ECRs for the above-mentioned formulae achieved nutritional support goal sufficiency (0.9-1.1) from the third week. Additionally, with every 1% increase in the Energy Consumption Increase Rate per week, the wound healing rate increased from 0.35% to 0.80% per week. Both the 28 and 35 kcal/kg BW formulas had the smallest regression coefficients (0.46) over 6 weeks. **Conclusion:** The 35 kcal/kg BW equation was suitable for young patients with burns over >50%TBSA in the ICU because it could be applied without equivocation, in time, and with acceptable wound healing rates. Additionally, it was well tolerated and contributed to stable management with feeding simplicity.

Key Words: burns, critical care, energy requirements, equations, ICU

INTRODUCTION

Major burns result in abnormal physiological metabolism, which is the most serious and persistent condition among critically ill patients. The hypermetabolic status can last for 2–3 years.[1] Nutrition therapy is crucial in the clinical management of burns. In the past, a high-energy and high-protein diet was the nutritional support principle for burn patients. In 2009, the American Society of Parenteral and Enteral Nutrition (ASPEN) recommended that the high-energy strategy for critically ill patients (including those with burns) should no longer be applied. The current emphasis is on early nutritional interventions and support, which should provide 50-65% of the target energy intake for the clinical benefit of enteral nutrition (EN) to be evident over the first week of hospitalization.[2,3] Timely administration of enteral nutrition can maintain gut integrity, modulate metabolic stress, facilitate the systemic immune response, and attenuate disease severity.[4,5] Patient nutritional requirements depend on the degree of disturbed physiology. Severe burns affecting more than 40% of total body surface area (TBSA) are typically followed by a period of metabolic stress, inflammation, and hypermetabolism, which peak at approximately 5-10 days after injury.[6] Hypermetabolic reactions are mainly due to increased production of catecholamines, cortisol, and inflammatory cytokines as part of the neuroendocrine response.[7,8] These catabolic hormones accelerate lipolysis of adipose tissue, proteolysis of skeletal muscle, and internal organs, and promote gluconeogenesis. Substantial weight loss can be expected among those with a large TBSA and long-term bacterial infection which may result in cachexia.[9,10] Increased dietary protein can attenuate the negative nitrogen balance and prevent tissue wasting.[11]

Determining energy requirements is key to rational nutritional support for burn patients. Indirect calorimetry

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Manuscript received 31 July 2018. Initial review completed 05 August 2018. Revision accepted 22 August 2018.
doi: 10.6133/apjcn.201811_27(6).0003

(IC) is the standard method for determining energy requirements in health and clinical practice.[12-14] In the absence of IC, clinicians use equations to estimate energy requirements in order to avoid both extreme hunger and overfeeding.[15]

In 2013 and 2016, respectively, the European Society for Clinical Nutrition and Metabolism (ESPEN) and ASPEN made recommendations for the use of energy requirement calculations in burn patients.[16,17]Additionally, more equations have been proposed by other groups. However, these equations were used among patients with a wide TBSA range of approximately 20-70%; most were used among those with a TBSA less than 50%.[18] None of the formulas were specific for severe burn patients with burns over >50% TBSA. Therefore, the aim of this study was to reevaluate the utility of total energy requirement estimation equations for patients with burns over >50% TBSA in an intensive care unit (ICU).

MATERIALS AND METHODS

Data collection

This 6 week follow-up study aimed to appraise the appropriateness of various formulas for estimating the energy requirements for major burn patients in the ICU using available clinical information. This study was conducted at the Tri-Service General Hospital (TSGH), a major medical center in Taipei, Taiwan, and the study design was approved by its ethical committee (2-105-05-094). The participants had suffered a major fire accident caused by a flammable starch-based powder in June 28, 2015, 61 patients aged 18–27 years who were involved in the accident were sent to TSGH for emergency treatment. Among them, 40 patients had major burn injuries (second to third degree, more than 25% TBSA) and 22 had burns up to 50% of their TBSA. With the exception of one patient who was transferred to another institution within 7 days, 21 patients (11 women) had respiratory problems and were treated in the burn ICU.

Procedure

Nutritional support was provided and managed by dietitians specializing in intensive care. Dietary plans and strategies were individualized with the aim of overcoming symptoms or treatment-associated side effects. The patients' nutritional management was conducted according to the written treatment protocol of the ICU at TSGH. The feeding policy there is to start enteral nutrition (EN) via a nasogastric (NG) tube within 24 hours post burn. Bolus feeding of six meals a day is the first choice. When poor gastric emptying is noted, the feeding method is changed to continuous feeding, which delivers formula at a constant rate using a peristaltic infusion pump. All patients received a polymeric diet. The initial target energy requirement was calculated according to the 2013 ESPEN guidelines[16] (i.e., Toronto formula) for adult burn patients. The protein requirement was 1.5 to 2 g/kg BW within the first 48 hours after admission. After 2 days, if the digestive and metabolic conditions were acceptable, nutritional support was modified according to the physician's judgment. In addition, 20 g glutamine per day was administered via the feeding tube unless acute renal failure or septic shock occurred.

The gastric residual volume (GRV) was measured by aspirating gastric fluid using a 60-mL syringe every 8 hours and before starting EN. Prokinetic agents were introduced on confirmation of feeding intolerance, which was defined as a GRV between 250 mL and 500 mL in two consecutive measurements. EN was discontinued if the GRV was >500 mL or the patient vomited. If feeding intolerance lasted for more than 72 hours, EN was replaced by nasoduodenal (ND) feeding. EN was stopped 6 hours before operation/surgery for patients with a NG tube but not for those with a ND tube.

To ensure consensus, quality, and equality in patient management, a team comprising practitioners from the internal medicine and surgical departments, including infectious, rehabilitation, anesthesia, and other medical professionals, as well as dietitians, pharmacists, psychologist, and respiratory therapists, was formed. Each patient's progress was discussed in a daily morning meeting chaired by the superintendent of TSGH with the relevant team members. Two bottles of human albumin (100 mL in total, equivalent to 25 g protein) were infused intravenously into each patient daily to raise their serum albumin levels (Figure 1).

Data calculation and analysis

All information used for analysis was retrieved from medical records in the ICU up to 6 weeks. Demographic data included sex, age, and education level. Anthropometric measures including height, initial weight, and body mass index (BMI, kg/m^2) were calculated accordingly. The severity of the burn (site, area, stage [I to IV]) and weekly changes in the burn, operation frequency, and length of stay, as well as the date of the patient's admission to the hospital, propofol dose, and volume of enteral feeding, were recorded. The "rule of nines" was used to estimate the burn area.[19] The body temperature was calculated as the average of the four measurements taken in a day.

The patient's actual daily energy intake was assessed by multiplying the enteral feeding volume with the strength of the formula (range, 1 to 2 kcal/mL). The energy consumption ratio (ECR) was calculated by dividing the actual energy intake by the total energy requirement (estimates from different equations).Energy Consumption Increase Rate per week was the slope of weekly energy intake over time (obtained via a linear regression, using week of ICU stay as the independent variable to predict weekly average energy consumption). The fluctuation in energy intake up to 6 weeks after ICU stay was presented according to the coefficient of variation (CV) for energy intake. The CV was the ratio of the standard deviation (SD) for the mean weekly energy intake multiplied by 100. The wound healing rate was the slope of the weekly burn area reduction (calculated via linear regression, with week of ICU stay as the independent variable to predict weekly burn area). Sufficient nutritional support was defined as reaching 90–110% (ratio 0.9–1.1) of the total energy recommendation.

Equations for estimating energy requirements

The following are the seven commonly used equations for calculating the energy requirements for burn patients.[20,21]

1. Harris-Benedict: Basal metabolic rate × activity factor × injury factor (1.5).
2. Harris-Benedict: Basal metabolic rate × activity factor × injury factor (2).
3. Toronto formula: −4343 + (10.5 × %TBSA) + (0.23 × energy intake in kcal) + (0.84 × Harris-Benedict) + (114 × T) − (4.5 × days post-burn). (This formula uses the information of the previous day, where T is body temperature in °C.)
4. Curreri formula: (25 kcal × BW) + (40 kcal × %TBSA) (when the TBSA is >50%, it is calculated as 50%.)
5. 28 kcal/kg BW (take the median by ASPEN: 25–30 kcal/kg BW in this paper)
6. Ireton–Jones formula: 1784 − 11 × age (yr) + 5 × BW + 244 (if men) + 239 (if trauma) + 804 (if burn)
7. Calculated directly at 35 kcal/kg BW

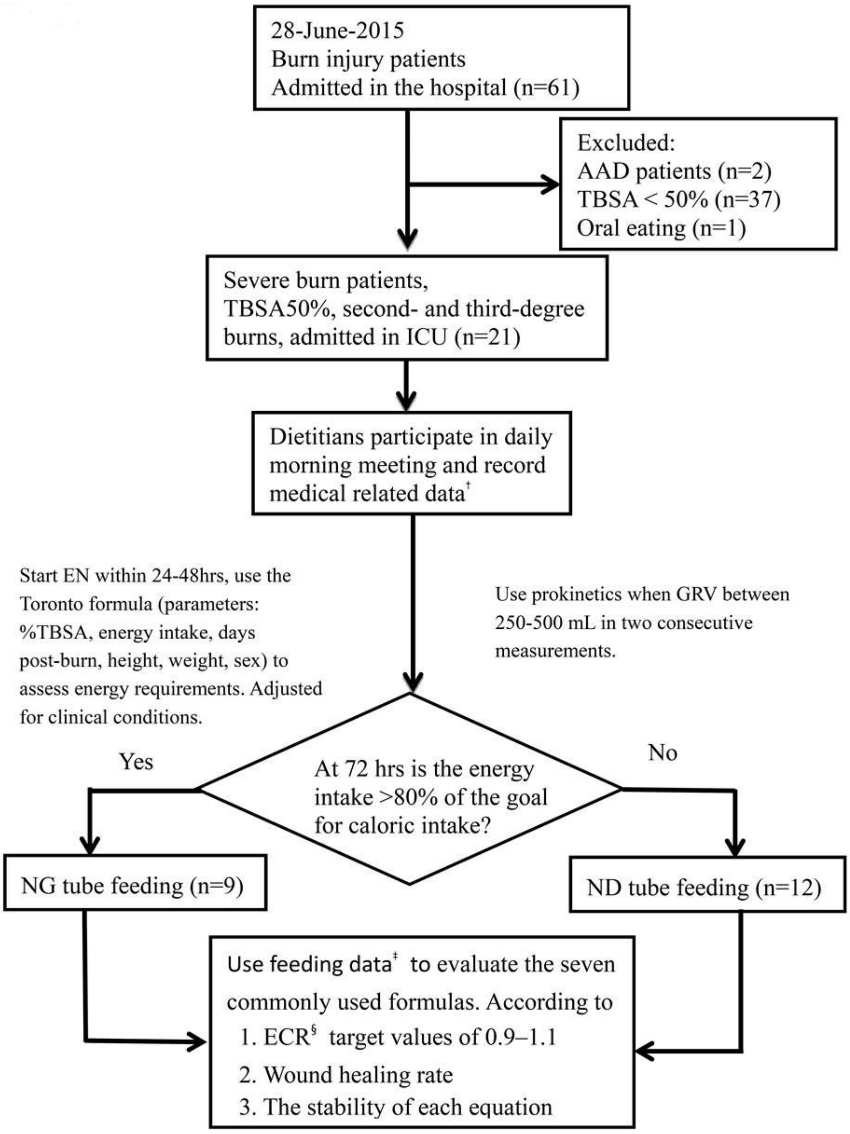
Statistical analysis

Continuous variables, including age, BMI, and length of ICU stay, were expressed as means ± SD. Multiple linear regressions were applied to estimate variance explained by various equations for wound healing. The variables in the core model were initial burn area, energy intake ratio in the first week, and ICU length of stay (week). The R-squared change was the difference in R-squared between the full model (with energy increase rate or CV by various equations). All statistical analyses were two-sided and conducted using SPSS 20.0 (SPSS Inc., Chicago, IL, USA). The level of significance was set at 0.05.

RESULTS

Patient characteristics

The patients' average (range) age, BMI, burned area, operation frequency, and total ICU length of stay were 21.7



† Record wound location, times of surgery, and body weight per week. Energy intake, body temperature, biochemical data and medication per day.
‡ ECR, energy consumption ratio , was calculated by dividing the actual energy intake by the estimated energy requirement.
§ Data collect until the patients are discharged from the ICU or up to 6 weeks.

Figure 1.Diagram of research framework. ICU: intensive care unit; ECR: energy consumption ratio; TBSA: total body surface area; AAD: against-advise discharge; EN: enteral nutrition; GRV: gastric residual volume; NG: nasogastric; ND: nasoduodenal.

Table 1. Patient characteristics

	Total (n=21)	Men (n=10)	Women (n=11)
Age, y	21.7 (3.3)	23.3 (3.0)	20.3 (2.8)
BMI, kg/m^2	23.4 (3.3)	24.4 (2.4)	22.6 (3.9)
Burn area, %	63.8 (12.3)	67.2 (12.5)	60.7 (11.9)
Initial estimated energy requirement, kcal/day			
1. 5 × BMR	2368 (362)	2691 (193)	2074 (170)
2 × BMR	3157 (483)	3588 (257)	2765 (227)
Toronto formula	2627 (388)	2930 (238)	2352 (272)
28 kcal/kg BW	1846 (367)	2106 (189)	1609 (329)
35 kcal/kg BW	2307 (459)	2632 (236)	2012 (412)
Curreri	3615 (329)	3832 (208)	3417 (295)
Ireton Jones	3034 (161)	3192 (45.9)	2891 (51.2)
Number of operations, times	9.0 (5.1)	6.8 (4.4)	10.9 (5.1)
Total ICU length of stay, day	40.4 (18.1)	31.6 (14.2)	48.5 (17.9)
Hospital length of stay, day	135 (51.1)	119 (42.5)	149 (55.9)

BMI: body mass index; BMR: basal metabolic rate; ICU: intensive care unit.
All data are presented as mean (SD).

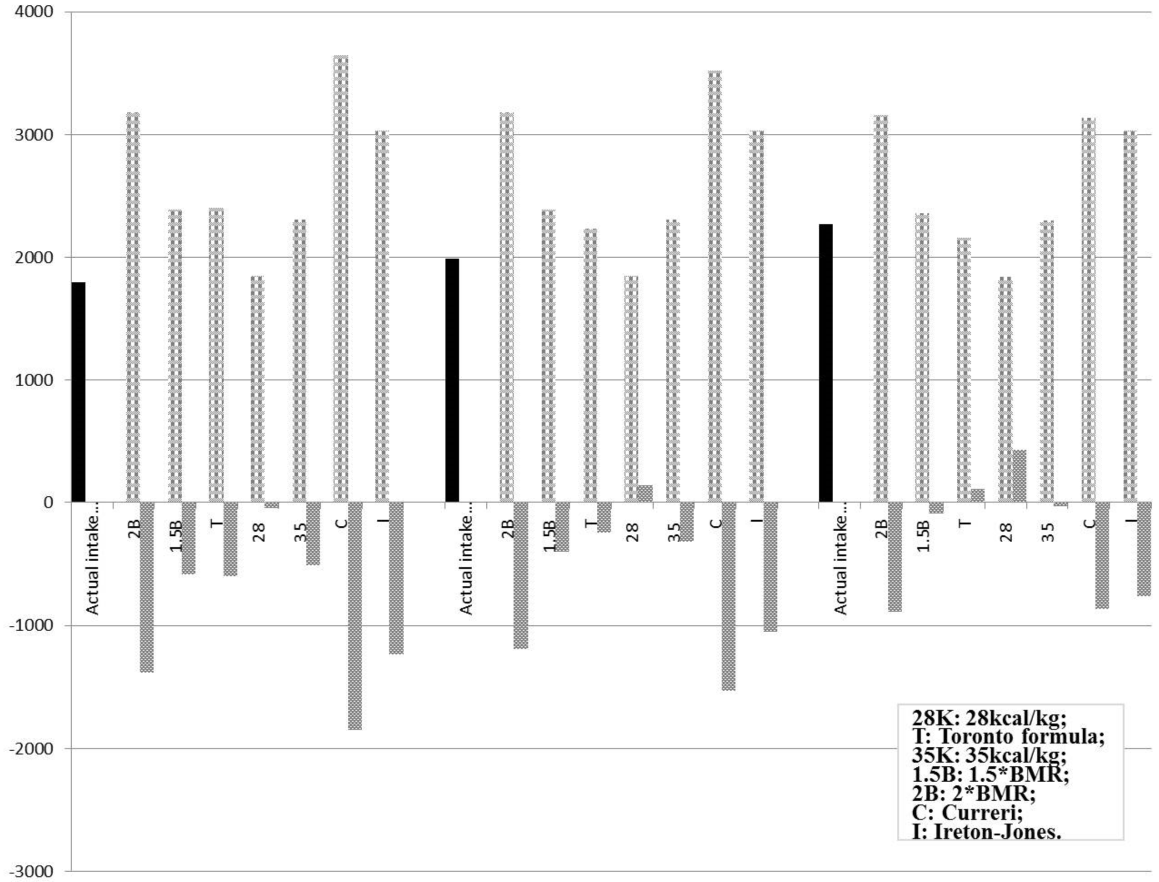


Figure 2. Bar graph depicting the predicted calorie requirement and actual caloric intake (positive y axis) and the caloric deficit (negative y axis) for each equation on the fifth, tenth and fifteenth days (x axis).

years (18–27), 23.4 kg/m^2 (17.6–29.3), 63.8% (50–90), 9.0 (4–20), and 40.4 days (20–76), respectively (Table 1).

Energy and protein intake

The average protein intake accounted for 22% of the total energy requirements (1.9 g/kg BW). Similar to energy, the protein intake requirement was reached in the third week (Figure 2). Despite the extra protein (25 g/d) from human albumin, the average protein intake did not exceed the recommended level of 2 g/kg BW (data not shown).

Applicability of energy requirement-estimating equations

During the first week, among the seven equations, the ECRs of the BMR×1.5 and the 35 kcal/kg BW were within the expected range of 0.5–0.65. Afterward, ECRs where markedly increased and reached a steady state in the third week. The ECRs of the 35 kcal/kg BW, BMR × 1.5, and Toronto formulas achieved the sufficient nutritional support goal (0.9–1.1) up to the sixth week (Figure 3).

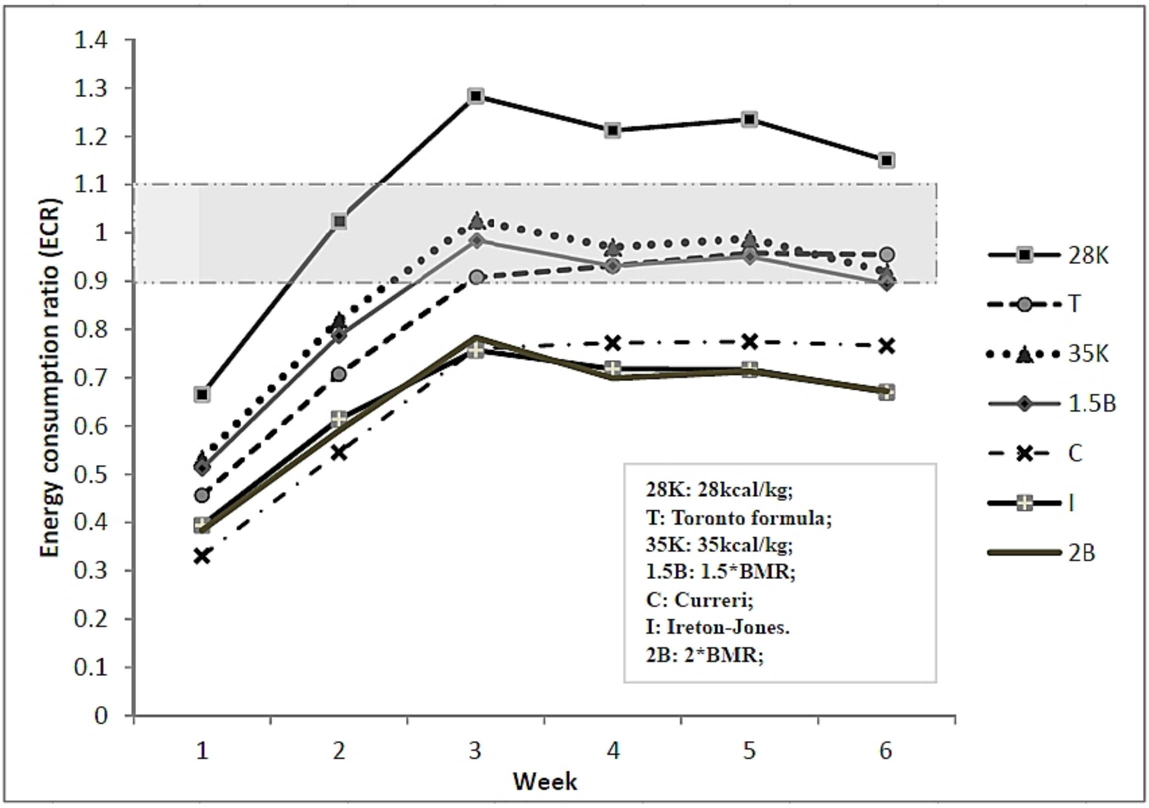


Figure 3. Energy consumption ratios from the different equations. Gray area means patients got sufficient nutritional support (ratio in 0.9–1.1), when the feeding caloric intake reached 90%–110% of the total recommended energy requirement.

Table 2. Effect of energy consumption increase rates on wound healing rate (%/wk)

Equations	Adjusted regression coefficient (95% CI)	*p*-value	R-square change[†]
1.5 × BMR	0.47 (0.35 to 0.58)	<0.001	0.73
2 × BMR	0.62 (0.47 to 0.72)	<0.001	0.73
Toronto formula	0.80 (0.54 to 1.06)	<0.001	0.64
28 kcal/kg BW	0.35 (0.25 to 0.44)	<0.001	0.70
35 kcal/kg BW	0.43 (0.31 to 0.55)	<0.001	0.69
Curreri	0.64 (0.22 to 1.06)	<0.01	0.33
Ireton Jones	0.54 (0.41 to 0.67)	<0.001	0.73

CI: confidence interval; BMR: basal metabolic rate.

[†] The variables in the core model are initial burn area, energy intake ratio in the first week, and ICU length of stay (week). The R-square change is the difference in R-square between full model (with energy increase rate by various equations) and the core model by multiple linear regressions.

Wound healing and survival rate

All patients included in the study survived. The average wound healing rate was 6.8% per week, and no difference was noted between men and women (data not shown). Regardless of the formula used, Energy Consumption Increase Rates were positively correlated with the wound healing rates. With every 1% increase in Energy Consumption Increase Rate per week, there was a corresponding wound healing rate increase from 0.35% to 0.80 % per week after controlling for potential covariates (Table 2).

In terms of the variation in energy consumption over time, the CVs of all formulas, except the Curreri formula were significantly correlated with the wound healing rates. Both the 28 kcal/kg BW and the 35 kcal/kg BW formulas had the smallest regression coefficients (0.46) after controlling for covariates (Table 3).

DISCUSSION

The Toronto is a validated formula; thus, we initially used this method. However as there are many shortcomings in practice (because it requires a lot of data) when using this formula we had to subsequently modify our approach. After a comparison with other formulas, we determined that there were simpler methods with the same effect that could be employed. We found that 35 kcal/kg BW was a better option for determining the total energy supply for major burn patients in the ICU. This was because of the ECR achievements at different time points meet the ASPEN recommendations and in wound healing, the stability (tolerance) in feeding, and simplicity.

Timing and stability

Early EN feeding can protect gut integrity by maintaining tight junctions between the intraepithelial cells, stimulat-

Table 3. Coefficient of variation for energy intake on wound healing rate (%/wk)

	Adjusted regression coefficient (95% CI)	*p*-value	R-square change[†]
1.5 × BMR	0.54 (0.36 to 0.72)	<0.001	0.64
2 × BMR	0.54 (0.36 to 0.72)	<0.001	0.63
Toronto formula	0.84 (0.50 to 1.18)	<0.001	0.55
28 kcal/kg BW	0.46 (0.26 to 0.66)	<0.001	0.52
35 kcal/kg BW	0.46 (0.26 to 0.66)	<0.001	0.52
Curreri	0.43 (-0.01 to 0.87)	0.053	0.19
Ireton Jones	0.58 (0.23 to 0.57)	<0.001	0.70

CI: confidence interval; BMR: basal metabolic rate.

[†] The variables in the core model are initial burn area, energy intake ratio in the first week, and ICU length of stay (week). The R-square change is the difference in R-square between full model (with coefficient of variation by various equations) and the core model by multiple linear regressions.

ing blood flow, and inducing the release of trace endogenous agents. In this study, all patients received enteral feeding within 24 hours after admission to the ICU. ICU patients commonly develop gastrointestinal dysfunction;[22,23] therefore, reaching a high energy intake may be difficult and unrealistic. In the first week of treatment, critically ill patients can benefit from nutrition therapy even with as little as 50-65% of the target energy requirements provided.[24,25] In our study, we found that when 35 kcal/kg BW was applied, patients received up to 53% of the total energy requirement within the first week as suggested by the ASPEN. From the third week, the ECRs reached 0.9–1.1, which were considered as sufficient nutritional support by intensive nutrition support guidelines.[2] Among the equations studied, the 35 kcal/kg BW was the only formula that reached the energy consumption goals within a timely manner.

We used the CV of the weekly energy consumption regressed the healing rate to represent the stability of intake. A smaller regression coefficient (slope is flatter) indicated less variation in the effect of energy intake on wound healing over time; thus, energy consumption was closer to the demand from the beginning. In this study, the 28 kcal/kg BW and 35 kcal/kg BW formulae performed better than the other formulae and they had the smallest regression coefficients (0.46) (Table 3).

Mortality and wound healing

Mortality is the most common outcome measure to assess the effect of ICU nutritional interventions. For severe burn patients, the mortality rate ranges from 1.4-18%.[26] The high %TBSA explains the high mortality rate and long hospital stay among fire burn patients.[27,28]Although our patients had second to third degree burns and their %TBSA ranged from 50-90%, they all survived following treatment, indicating that our nutritional support was adequate. Similar to other studies, [29-31] we found that the Energy Consumption Increase Rate was significantly correlated with the rate of wound healing.

We believe that the 35 kcal/kg BW formula is optimal for determining nutritional support; this recommendation is similar to that proposed by Rimdeika et al. Their study included patients with second to third degree burns that comprised 10–80% of the TBSA.[18] They found that the ICU fixed weight-based equations (25–30 kcal/kg BW) were inadequate when considering the infection rate and mortality. Patients who received at least 30 kcal/kg BW of formula during the acute phase had significantly better outcomes. This finding supports our observation that the 35 kcal/kg BW of formula was appropriate for critically ill patients. Our results are also in line with those found in a review in which initially 25 kcal/kg BW (equivalent to 71% of 35 kcal/kg BW) of formula was provided to ICU patients for the first week and thereafter 30 or 35 kcal/kg BW of formula was provided in the subsequent weeks.[32]

Simplicity

Because of their simplicity compared with other equations, fixed weight-based equations (i.e., 28 and 35 kcal/kg BW) are preferred in clinical settings. In our study, from week 3, the values calculated using the 35 kcal/kg BW, BMR × 1.5, and the Toronto formulas were similar. For BMR × 1.5, the Harris-Benedict equation is typically used to multiply a factor, which usually ranges from 1.0 to 2.0; however, this was 1.5 in our study and takes into consideration activity and pressure. However, the factor of choice is subjective and may result in substantial differences in the calculated values if a different factor is applied. The Toronto formula is more complicated than others. Although all factors that may affect metabolism have been incorporated into the formula, these factors represent a condition that has occurred, making the formula a “post hoc” equation. The equation is adjusted according to the daily clinical changes, but calculating the target values in advance can be difficult. Some situations in which patients are on nothing per orem (NPO) because of examination or surgery will result in an extremely low energy requirement prediction for the next day. Moreover, body temperatures vary widely during infection and surgery; thus, determining the representative value of energy intake is difficult, making the computation unpopular.

Along with the advantages discussed previously and its easy applicability in clinical practice, we consider that the 35 kcal/kg BW formula is a better option for determining the energy requirements for ICU burn patients.

Considerations among the various formulas

A number of mathematical equations have been developed to estimate the energy requirements of burn patients; however, overestimating the energy demand remains a challenge. Avoiding overfeeding can minimize the risk of hyperglycemia, infection, and increased fat tissue.[33]

Compared with the currently used formulas, the energy requirement estimated using the 35 kcal/kg BW formula was higher and lower than those in the 2016 ASPEN (25–

30 kcal/kg BW formula) and ESPEN (Toronto formula) recommendations. For the former, the reason may be that all patients were severely burned over >50% of their TBSA. For the latter, the reason may be that the subjects were in a critical condition in the ICU rather than in the general ward. Previous studies on the Curreri and Ireton–Jones formulas showed that the values achieved were higher than those estimated via the 35 kcal/kg BW formula. Advances in medical treatment, changes in the concept of medical care, environmental temperature control, improved infection control, and pain management were among the primary reasons for the reduced metabolic response to burns;[34,35] thus, high-calorie diets for major burn patients are no longer required.

The differences in energy requirements computed according to various formulas can be substantial, thus making it hard for dieticians to decide which nutritional diets to recommend. Notably, it has been observed that the smaller the size of the woman, the greater the difference in energy estimation. For example, for a 20-year-old woman with a height of 148 cm, weight of 44 kg, and a second-degree burn area of 58%, the calculated energy requirements were 2470 kcal, 2020 kcal, 1540 kcal, and 3100 kcal using the BMR × 2, Toronto, 35 kcal/kg BW, and Curreri formulas, respectively.

Strengths and limitations

The main strength of this study was that the study population was homogeneous; the patients were similar in terms of their age, severity of illness (burned area more than 50%), ventilator use, absence of chronic diseases, and characteristics of ICU admission. In particular, the study participants were all hospitalized at the same time. These similarities minimized differences between subjects and allowed us to evaluate these formulas with limited confounding factors. In addition, all patients were critically burned, which provided a unique opportunity to explore the appropriateness of the available formulas. Furthermore, all major burn patients survived, indicating that nutritional support was adequate and successful.

However, our study was subject to some limitations. First, this was not a clinical trial. Given that all patients survived, we assumed that their actual daily energy consumptions were in accordance with their energy requirements. Second, because most patients were transferred out of the ICU after the sixth week, this study was not able to evaluate patients after this time point as there were not enough patients with an extended follow-up duration. Third, the patients were approximately in their early twenties thus limiting the generalizability of our findings; the metabolic utilization of nutrients and energy requirements may be different in older adults. Fourth, we did not control for clinical parameters in the analyses, and this may have biased our findings. However, all patients were admitted to the hospital at the same time and the concept of care (such as control of infection and blood sugar) and wound management were the same; therefore, confounding effects were largely reduced.

In conclusion, this study demonstrates that in the absence of IC, 35 kcal/kg BW is the best equation for predicting energy requirements for young patients with burns over >50% TBSA admitted in the ICU. We believe that this formula performs better than others because it allows for the clinical criteria for energy requirements to be met over time, leads to an acceptable wound healing rate, allows for stability (tolerance) in feeding, and is easy to use.

ACKNOWLEDGEMENTS

We would like to acknowledge the course instructors and students of Biostatistics Counseling at the School of Public Health, National Defense Center for their assistance collecting data and conducting statistical analyses. This study was funded by a grant from the Tri-Service General Hospital/National Defense Medical Center (Grant No: TSGH-C106-168, TSGH-C107-120).

AUTHOR DISCLOSURES

All authors are certify that they have NO affiliations with or involvement in any organization or entity with any financial interest in the subject matter or materials discussed in this manuscript.

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