Estimating energy requirements in burned children: a new approach derived from measurements of resting energy expenditure[1-3]

Michael I Goran, Lyle Broemeling, David N Herndon, Edward J Peters, and Robert R Wolfe

ABSTRACT We examined the determinants of resting energy expenditure (REE) in 127 observations in 56 burned children. Predicted basal energy expenditure (PBEE), body surface area (BSA), and body weight correlated significantly with REE ($r^2 = 0.76$). Days postburn and burn size (% BSA burned) only accounted for 21%, and 24% of the variation in the elevation in REE above PBEE. The single most powerful predictor of REE was PBEE (REE = 1.29 × PBEE); addition of other variables did not improve the prediction. When our recently described activity factor of 1.2 for burn patients is used, the data predict that the average energy requirement to maintain energy balance is 1.55 × PBEE, which is significantly lower than commonly used recommendations, especially for larger burns. The energy required to ensure that 95% of patients achieve energy balance was $(1.55 \times \text{PBEE}) + (2.39 \times \text{PBEE}^{0.75})$, approximately equal to 2 × PBEE. Because the equations presented are derived from measurements of energy expenditure, they represent the most valid approach to estimating energy requirements. *Am J Clin Nutr* 1991;54:35–40.

KEY WORDS Nutritional requirements, energy expenditure, indirect calorimetry, burns

Introduction

It is generally agreed that aggressive nutritional support has improved morbidity and mortality after severe burn injury. However, it is also evident that in severely stressed patients, excessive energy intake cannot completely overcome the protein catabolic response (1) and can have detrimental physiological effects (2). Consequently, it is important to accurately estimate energy requirements. There is reason to believe that currently used equations significantly overestimate energy requirements to achieve energy balance in burned children, particularly in patients with large burns. This belief has arisen because the popular equations used are not based on measurements of energy expenditure.

The basis for success of these equations has generally been weight maintenance (3, 4). However, it is unclear whether the energy requirements recommended by these equations are actually necessary to avoid weight loss. In fact, patients receiving markedly less energy intake than conventional recommendations maintain constant body weight (4, 5). The situation is complicated by the fact that body weight maintenance is not a suitable indicator of the success of nutritional therapy, mainly because of fluid retention and because excess energy intake would be expected to result predominantly in fat synthesis while catabolism of heavier lean body mass continues (1).

Energy requirements should ideally be predicated by determination of total energy expenditure (TEE). We (6) recently reported that TEE in burned children, as determined with the doubly labeled water technique, is strongly correlated with resting energy expenditure (REE). This observation led us to examine the determinants of REE in many burned children to formulate a new approach to predicting energy requirements.

Methods

The children studied were treated for burn injury at the Galveston Unit of the Shriners Burns Institute between March 1985 and March 1989. All of the patients were treated uniformly with excisional therapy as previously described (7). Nutritional support was standardized according to the equations previously described (4, 8). The majority of energy intake was via enteral fluids, which were either milk, Isocal (Mead-Johnson, Evansville, IN), Prosobee (Mead-Johnson), or, milk-Isocal mixtures. The ethical standards of the Institutional Review Board, University of Texas Medical Branch, Galveston, TX, were followed.

A database was generated from retrospective analysis of 127 measurements of REE in 56 burned children (85 observations in males, 43 observations in females). The independent variables used to predict REE were basal energy expenditure, body surface area (BSA), age, weight, percentage of BSA with 3° burn injury as estimated on hospital admission (% BSA burned), and days postburn. Basal energy expenditure was predicted from the equations of Harris and Benedict (9) and BSA was calculated from height and weight (10). The % BSA burned was estimated by observation on admission in the usual manner, and we made

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[1] From the Metabolism Unit, Shriners Burns Institute, and the Departments of Anesthesiology and Surgery, University of Texas Medical Branch, Galveston, TX.

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[3] Address reprint requests to RR Wolfe, Shriners Burns Institute, 610 Texas Avenue, Galveston, TX 77550.

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TABLE 1
Description of data group analyzed*

Variable	
Age (y)	9 ± 5 (0.33–21)
Weight (kg)	32.6 ± 17.6 (5.6–77.6)
Days Postburn	25 ± 20 (0–99)
BSA (m^2)	1.06 ± 0.39 (0.28–1.94)
3° Burn size (% BSA)	57 ± 24 (4–98)
Predicted BEE	
(MJ/d)	4.76 ± 1.22 (1.78–8.00)
(kcal/d)	1138 ± 292 (426–1914)
Measured REE	
(MJ/d)	6.19 ± 2.58 (1.41–15.70)
(kcal/d)	1480 ± 616 (337–3755)

* $\bar{x}$ ± SD (range). n = 127. BSA, body surface area; BEE, basal energy expenditure as predicted from the Harris-Benedict equations; REE, resting energy expenditure as measured by indirect calorimetry.

TABLE 2
Individual correlations between Resting energy expenditure and potential predictors

Independent variable	r^2
PBEE (MJ/d)*	0.76
BSA (m^2)	0.76
Weight (kg)	0.76
Age	0.73
Days postburn	−0.28
% BSA burned	0.15

* PBEE, basal energy expenditure predicted from Harris-Benedict equations.

no attempt to adjust this factor to account for coverage and healing of wounds.

Oxygen-consumption and carbon dioxide–production rates were measured by indirect calorimetry by use of a Beckman metabolic cart (Fullerton, CA) with a face mask for gas collections as previously described (1). REE was derived by using the equation of Weir (11). Measurements were performed in the early morning. Continuous feeding was not interrupted and no attempt was made to control for standardizing conditions (with respect to fever, infection, antibiotics, pain medication, etc) around the time of measurement. Our rationale for this approach was to examine the determinants of measured REE under the usual clinical conditions. When repeated measurements were available in the same patients, they were treated as independent measurements.

Equations for predicting REE were constructed by use of stepwise-linear-regression analysis by using the measured value of REE as the dependent variable. The independent variables were the potential predictors of REE and were the usual anthropometric measurements observed in burn patients [predicted basal energy expenditure (PBEE), BSA, weight, age, % BSA burned, and days postburn]. A predictive analysis was used to compare the forecasting precision of the equations developed.

To predict energy requirements, equations for predicting REE were multiplied by the activity factor 1.2. This activity factor was derived in our recent study in which the doubly labeled water technique was used in burn patients (6).

Three components of energy expenditure are discussed: PBEE predicted (by use of the Harris-Benedict equations); REE measured by indirect calorimetry; and TEE derived by multiplying REE by an activity factor of 1.2. Energy expenditure and intake are expressed as MJ/d and are accompanied by the caloric equivalent (kcal/d) in parentheses.

All statistical analyses were performed by using either the Lotus 1-2-3 *Spreadsheet* software (Lotus Development Corporation, Cambridge, MA) or the *BMDP* statistical software (BMDP Inc, Los Angeles).

Results

Data set

Table 1 summarizes the data for 127 measurements of REE in 56 burned children. We treated the data as one entire group, which was diverse with respect to anthropometric variables (eg, age 3 mo–21 y; body weight 5.6–77.6 kg; BSA 0.28–1.94 m^2); and burn injury (3° burns covering 4–98% of BSA). The data set included measurements made between 0 and 99 d after burn injury.

Prediction of resting energy expenditure

Table 2 summarizes the correlation analysis between REE and the independent variables. The correlation coefficients (r^2) ranged from 0.15 (% BSA burned) to 0.76 (PBEE, BSA, and weight). The observed rate of REE in burned children is therefore primarily dependent on body size. The relationship between REE as measured by indirect calorimetry, and basal energy expenditure, as predicted from the Harris-Benedict equations, is shown in **Figure 1**.

The relationships between the ratio of REE to PBEE (REE:PBEE), a reflection of the elevation in REE during treatment and days postburn and % BSA burned are shown in **Figures 2 and 3**, respectively. Days postburn and % BSA burned thus accounted for only 21% and 24%, respectively, of the variation in the elevation of REE above predicted normal.

The single most powerful predictor of REE in this group of patients was the PBEE:

$$\text{REE} = 1.29 \times \text{PBEE} \qquad (1)$$

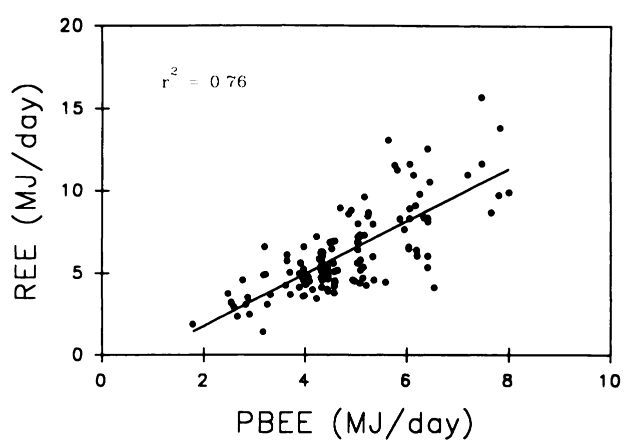

FIG 1. Relationship between resting energy expenditure (REE) measured by indirect calorimetry and basal energy expenditure (PBEE) predicted by the equations of Harris and Benedict (9).

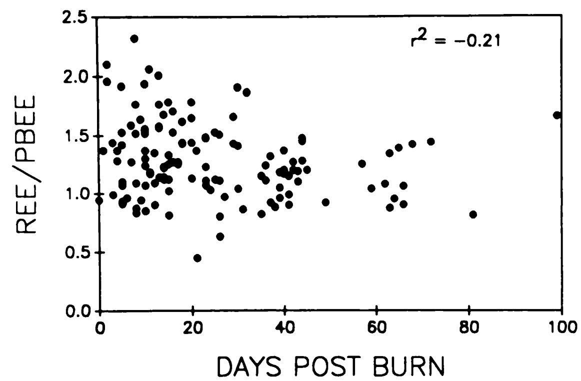

FIG 2. Elevation in REE above predicted value (REE/PBEE) as a function of days postburn.

where $r^2 = 0.96$ when the intercept is fixed at zero. Addition of any other variables into the equation did not improve the prediction.

The reliability of equation 1 in predicting REE in the 127 measurements in 56 burned children was determined. Fifty percent of the predicted values for REE were within ±17% of the measured value, 75% of the predictions were within ±30%, and 90% of the predictions were within ±45% (**Table 3**). The residual energy expenditure (measured minus predicted), expressed as a percent of measured REE, is displayed in **Figure 4** as a function of PBEE. As seen in Figure 4, these residuals show random variation with respect to predicted basal energy expenditure.

Prediction of total energy requirements

Use of the activity factor 1.2 from our previous publication (6) allowed derivation of an equation to predict the average TEE:

$$\text{TEE} = 1.55 \times \text{PBEE} \quad (2)$$

Because this equation is the average value for TEE for a given value of PBEE, approximately one-half of the patients would have a TEE that was less than the value given in equation 2. If the average value of TEE and the standard deviation of TEE for a given value of basal energy expenditure are known, then the 95th percentile, the value of TEE that is exceeded by 5% of the patients, can be derived by using weighted linear regression. In our analysis, the standard deviation of TEE predictions was estimated as $1.452 \times \text{PBEE}^{0.75}$. When this value was multiplied by the upper 5% point of the standard normal distribution, the 95th percentile was found to be

$$\text{TEE} = (1.55 \times \text{PBEE}) + (2.39 \times \text{PBEE}^{0.75}) \quad (3)$$

This equation predicts the energy required to ensure that 95% of patients receive at least enough energy to reach a state of energy balance. The resulting value for an average patient in this study (Table 1) is 9.32 MJ/d (2229 kcal/d), which is approximately equal to twice the PBEE [9.51 MJ/d (2276 kcal/d)].

Figure 5 displays the energy requirements that would be predicted by four other equations currently in use in addition to our new equations 2 and 3. The energy requirements were predicted for the average patient in the present study with a burn injury covering either 30% or 80% BSA. As seen in Figure 5, our predictions are well below the lowest value. The equation designed to include 95% of patients (Eq 3) is approximately equal to the value of equation 2 × PBEE, promulgated by Wolfe (12), which predicts energy requirements that are ~20% lower than those predicted by the Long equation (13).

TABLE 3
Percent relative error in predicting resting energy expenditure*

Percent of patients	Percent relative error†
%	
0	0.41
10	4.42
25	9.34
50	17.08
75	30.10
90	44.84
100	189.0

* Values determined by using the equation 1.29 × PBEE.
† The median percent relative error of 127 predictions. Thus, 50% of predictions deviated by ≤ 17% from the observed rate of resting energy expenditure.

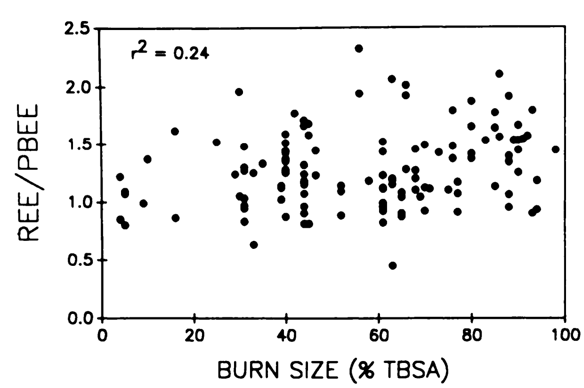

FIG 3. Elevation in REE above predicted value (REE/PBEE) as a function of burn size [% total body surface burned (% TBSA)].

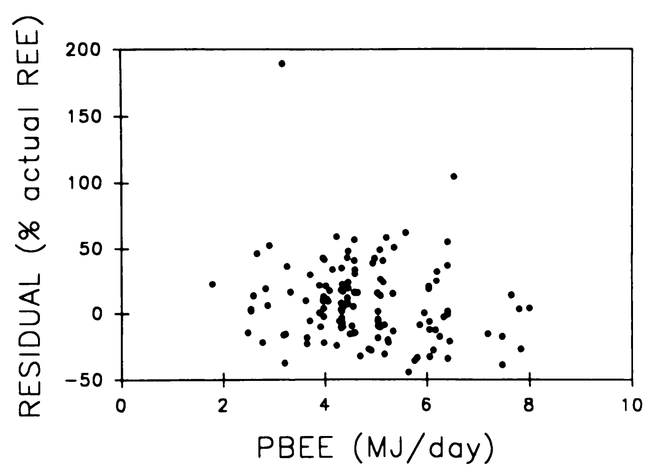

FIG 4. Residual of the predicted REE vs PBEE. The residual is the difference between the observed REE and the REE predicted by equation 1 (REE = 1.29 × predicted basal) and expressed as a percentage of the measured REE.

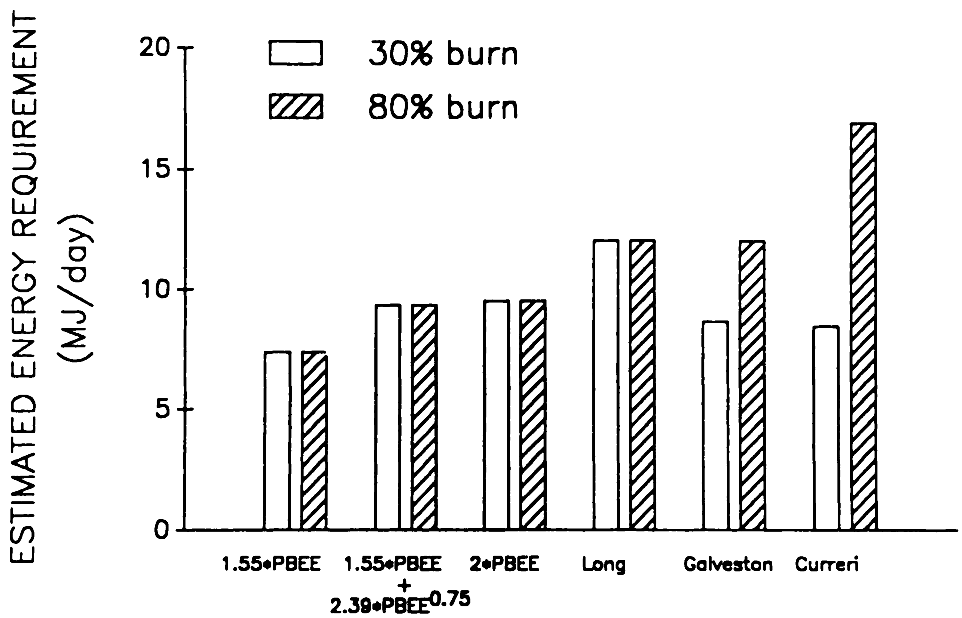

FIG 5. Total energy requirements (1 MJ/d = 239.2 kcal/d) for energy balance in burned children, as predicted by various equations. Energy requirements were estimated for the average patient in this study with either a 30% or an 80% burn. Requirements were estimated by using the following equations: 1.55 × PBEE, equation 2; (1.55 × PBEE) + (2.39 × PBEE$^{0.75}$), equation 3; 2 × PBEE, reference 12; 2.52 × PBEE, Long equation (13); Galveston equation (4); MJ/d = (6.27 × BSA) + (6.27 × burn in m^2), kcal/d = (1500 × BSA) + (1500 × burn in m^2), Curreri equation (3); MJ/d = (0.105 × weight) + (0.167 × % of BSA burned), kcal/d = (25 × weight) + (40 × % of BSA burned). PBEE, basal energy expenditure predicted from Harris-Benedict equations (9); BSA, body surface area (m^2); weight, body weight (kg).

The most important difference between the new equations presented and the popular Galveston (4, 8) and Curreri et al (3) equations is that the latter equations are dependent on the size of the burn. The discrepancy between the estimations derived from the various equations is particularly evident with large burns, such as the 80% burn chosen as representative for illustrative purposes in Figure 5.

Discussion

This study represents the most extensive analysis of REE in burned children. The analysis revealed that REE in burned children is primarily dependent on body size, and the magnitude of the elevation in REE above predicted normal cannot be reliably predicted from the extent of burn injury.

In examining the elevation in REE in response to burn injury, we expressed the data as a function of basal energy expenditure as predicted by the equations of Harris and Benedict (9). These equations were formulated from observations in an older population and may not be appropriate for children. We compared the Harris-Benedict predictions with those generated by the only other set of equations that we are aware of that have been specifically designed for predicting basal energy expenditure in children (14). The equations recommended in the World Health Organization (WHO) report (14) are based on actual measurements of energy expenditure in children aged 10–18 y. For the entire data set, the Harris-Benedict predictions were 6.2 ± 12.6% greater than WHO predictions. This difference was reduced to 3.1 ± 7.5% when we excluded children < 2 y of age from the comparison. The equations available thus give similar predictions of basal energy expenditure, and we chose the Harris-Benedict equations in our analysis because they are more familiar and used more frequently in a clinical setting.

The ideal index for comparing measurements of REE during recovery should be based on measurements performed after full recovery from burn injury. However there is an insufficiency of data during this period although in a recent report from our laboratory, REE was 1.12 ± 0.055 times Harris-Benedict predicted basal energy expenditure in four children studied at a mean of 271 d after injury (1).

It may seem surprising that neither time after injury nor burn size was useful in predicting the magnitude of the elevation in REE. The failure to detect an obvious decline in the ratio between REE and PBEE by using cross-sectional analysis reflects the fact that there is not a smooth transition from the hypermetabolic state to the recovered state. Uncovering the relationship between REE and days postburn would involve longitudinal measurements of REE in individuals throughout the course of treatment. We did not have enough data on an individual basis to perform such an analysis.

Similarly we did not observe an important role for the degree of burn injury (Fig 3). The relationship between the elevation in REE and burn size was alluded to in the studies of Wilmore et al (15). They interpreted the data by suggesting that the elevation in REE was curvilinear, leveling off at a burn size of 50% BSA. The patients studied by Wilmore et al (15) were treated without excisional surgery or use of occlusive dressings, which have been shown to reduce metabolic rate (16, 17). It is perhaps more important that Wilmore et al (15) never claimed that there was a relationship between burn size and REE at burn sizes

> 50% of BSA. Similarly, in the many studies of carbohydrate, fat, and protein metabolism conducted in our laboratory (1, 2), we never observed a significant effect of burn size in patients with a burn size > 40% of BSA. Equations estimating energy requirements based on percent burn size in patients with large burns are thus not based on established metabolic processes.

It is unclear how much of the elevation in REE is due to the presence of burn injury itself and how much can be potentially explained by energy expenditure associated with the thermic effect of feeding. For example, Allard et al (18) accounted for the entire elevation in REE in burn patients by the thermic effect of feeding. We have indirectly accounted for the energy expenditure associated with the thermic effect of feeding in derivation of the new equations by using the relationship between REE and TEE. This factor (1.2) was determined experimentally in a limited number of patients by using the doubly labeled water technique to measure TEE (6). Although this factor was derived in a patient group studied in the latter stages of recovery, we feel that it is appropriate for other patients. This is because physical activity increases with convalescence so that the ratio of TEE to REE will generally be higher later in recovery than during the initial stages. Therefore the factor 1.2 may tend to overestimate the prediction of TEE from REE measurements in the early stages of recovery.

The Galveston equations (4, 8) and the Curreri et al equation (3) are probably the most commonly used means of predicting energy requirements in burned children. Whereas both equations contain a factor for burn size, neither equation was derived from actual measurements of energy expenditure. Using our database, we rederived equations with similar general structures to the Galveston and Curreri equations.

When TEE is expressed in terms of BSA and m² burn (cf, the original Galveston approach), the following was obtained:

$$\text{TEE (MJ/d)} = (4.93 \times \text{BSA in m}^2) + (3.53 \times \text{burn size in m}^2)$$

$$\text{TEE (kcal/d)} = (1180 \times \text{BSA in m}^2) + (845 \times \text{burn size in m}^2) \quad (4)$$

Both coefficients derived in this equation are substantially lower than those used in the actual Galveston equation [kcal/d = (1800 × BSA in m²) + (2200 × burn size in m²)]. This large discrepancy can be explained by the fact that the original approach described by Hildreth et al (4) was based on observations of fluid loss in burned children during the initial 48-h resuscitation phase. The volume of fluid loss was then multiplied by the energy cost of water vaporization to derive the coefficient. This factor is therefore inappropriate on two accounts. First, it is based only on observations made in patients treated during acute resuscitation, and second, it is not based on actual measurements of energy expenditure.

Similarly, when TEE was expressed in terms of body weight and % BSA burned, an equation comparable to the Curreri et al (3) equation was generated:

$$\text{TEE (MJ/d)} = (0.147 \times \text{weight in kg}) + (0.045 \times \%\ \text{BSA burned})$$

$$\text{TEE (kcal/d)} = (35.2 \times \text{weight in kg}) + (10.8 \times \%\ \text{BSA burned}) \quad (5)$$

Our experimentally determined coefficient for % BSA burned is 27% of the coefficient described in the Curreri et al equation (3). It is difficult to assess the basis for the factors in the Curreri et al equation because no supportive data or even rationale are provided in the original paper (3). Their study was a retrospective analysis of dietary intake and changes in body weight during the first 20 d of recovery in nine burn patients. Change in body weight was plotted against actual dietary intake, expressed as a percentage of ideal caloric intake calculated by the Curreri formula. Even the original data presented by Curreri et al (3) argue against the validity of the equation because patients receiving significantly less energy intake than prescribed by the equation nonetheless maintained body weight. The only patient who lost weight received only 20% of the estimated requirements.

Despite the large database used, the predictive power of the proposed equations 2 and 3 are limited. The observation that only 50% of predictions were within ±17% of the measured value can be explained by a number of factors. First, the predictions of basal energy expenditure that we used were determined by the equations of Harris and Benedict (9), and as already stated, these may be inappropriate for children. Moreover, whichever equation is used, the predictions of basal energy expenditure are body-weight dependent and, as already discussed, the interpretation of body weight in burn patients is complex and may not be an accurate reflection of metabolically active tissue. Second, it is also likely that a combination of factors in addition to PBEE also affect REE. These might include nutritional status of the patient at the time of REE measurement, activity of the subject (eg, dressing change) preceding measurement, time between measurement and most recent surgery, type of medication and therapy involved, use of excisional surgery, hormonal status of patient, and presence of fever or infection. We made no attempt to control for these conditions because our aim was to examine the determinants of REE under natural clinical circumstances as opposed to controlled laboratory conditions. Although our equations were developed in a population of burn children treated with early excision, they are likely to be appropriate in patients treated without excision because a previous report from our Institute could not detect any difference in REE in adults treated with and without excisional surgery (19).

In a recent publication, Allard et al (20) assessed the performance of a complex equation for predicting REE in burn patients, which includes factors to account for % BSA burned, energy intake, PBEE, temperature, and days postburn. This complex equation is cumbersome to use and furthermore it is not clear that significant power is added to the predictions of energy requirements by the consideration of factors other than PBEE. If we had included the additional factors used by Allard et al (20) in our analysis, the r^2 of our predictive equation would have decreased.

In addition to the problems of formulating a good equation, it must be realized that there is a certain amount of variation in REE that is not explained by body size or body composition even in normal volunteers (21, 22). It is of further concern that the error assessment presented in Table 3 does not include the error in predicting TEE from REE. From our previous experiment in a limited number of patients in whom both REE and TEE were measured (6), equation 2 functioned poorly in predicting TEE even though there was a significant correlation between TEE and REE.

In summary, the most reliable estimates of energy requirements are obtained by actual measurements of REE on an individual basis in conjunction with an appropriate activity factor, which is 1.2 in the convalescent burned child (6). If measurement of REE is not feasible, the data in this paper support the notion that if energy is provided at about twice the PBEE, virtually all patients will receive at least an amount of energy intake equal to their expenditure. In severely stressed patients who are unable to tolerate potential side effects of energy excess, it may be more desirable to provide energy according to the equation 1.55 × PBEE because this will be sufficient to maintain most patients close to energy balance.

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