Disease-Specific Predictive Formulas for Energy Expenditure in the Dialysis Population

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Objective: Metabolic rate is poorly understood in advanced kidney disease because direct measurement is expensive and time-consuming. Predictive equations for resting energy expenditure (REE) are needed based on simple bedside parameters. Algorithms derived for normal individuals may not be valid in the renal population. We aimed to develop predictive equations for REE specifically for the dialysis population.

Design: Two-hundred subjects on maintenance dialysis underwent a comprehensive metabolic assessment including REE from indirec calorimetry. Parameters predicting REE were identified, and regression equations developed and validated in 20 separate subjects.

Results: Mean REE was 1,658 ± 317 kCal/day (males) and 1,380 ± 287 kCal/day (females). Weight and height correlated positively with REE ($r^{2} = 0.54$ and 0.31) and negatively with age older than 65 years ($r^{2} = 0.18$). The energy cost of a unitary kilogram of body weight increased nonlinearly for lower body mass index (BMI). Existing equations derived in normal individuals underestimated REE (bias 50–114 kCal/day for 3 equations). The novel derived equation was REE = –2.497 · Age · Factor_age + 0.011 · height$^{2.023}$ + 83.573 · Weight$^{0.6291}$ + 68.171 · Factor_sex, where Factor_age = 1 if 65 years or older and 0 if younger than 65, and Factor_sex = 1 if male and 0 if female. This algorithm performed at least as well as those developed for normals in terms of limits of agreement and reduced bias. In validation with the Bland-Altman technique, bias was not significant for our algorithm (–22 ± 96 kCal/day). The 95% limits of agreement were +380 to –424 kCal/day.

Conclusion: Existing equations for REE derived from normal individuals are not valid in the dialysis population. The relatively increased REE in those with low BMI implies the need for higher dialysis doses in this subgroup. This disease-specific algorithm may be useful clinically and as a research tool to predict REE.

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Introduction

The primary function of the kidneys is to remove metabolic waste products, and in advanced kidney disease dialysis needs to replace this function. However, methods used to assess dialysis dose in end-stage renal disease (ESRD) do not take metabolic rate into account. Instead, the most commonly used method adjusts urea clearance by dialysis over a single session to the subject’s total body water volume—usually estimated by the Watson equation.1 Dialysis dose is estimated using Kt/Vurea, in which K represents dialyzer urea clearance, t represents the duration of the session, and the denominator V represents body water volume.2 This model assumes that the uremic toxin production rate is a function of body water volume.

There are marked differences in survival in relation to gender and body size in patients undergoing hemodialysis (HD) in contrast to findings in the general population. Despite comorbidities, including diabetes associated with obesity, there is a strong negative association between body mass index (BMI) and mortality in patients on HD,3,4 and the survival advantage of women seen in the general population is not present in those on dialysis. The Dialysis Outcomes and Practice Patterns Study data indicate that women may benefit from a greater dialysis dose than men,5 and in a large HD dose study (the Hemo-dialysis study), women in the higher dialysis dose intervention group (eKt/V = 1.53) had a significantly lower mortality than those in the standard dose group (eKt/V = 1.16).6 These survival differences suggest that defining minimal dialysis requirements in terms of Kt/V may result in a relative underdialysis of women and those with lower BMI.

Morton and Singer hypothesized that metabolic rate unidirectionally defines glomerular filtration rate in normal individuals, suggesting that it may be more physiological to...
adjust the dialysis dose to a measure of metabolic rate \(^7,^8\) rather than body water. However, little attention has been paid to the use of alternative algorithms that adjust dialysis dose to metabolic rate.

To study this, it is necessary to have validated algorithms for basal metabolic rate (BMR) that are specific to the dialysis population. Developing such algorithms would permit retrospective and prospective studies investigating the potential use of Kt/metabolic rate as an alternative to Kt/V\(_{urea}\). Furthermore, they would also find clinical utility in the estimation of dietary requirements in dialyzed patients. Equations derived historically in normal populations \(^9\)-\(^{11}\) may not be applicable to subjects with renal failure given their metabolic disturbance and their burden of comorbidities.

The principal aim of this study was to devise bedside algorithms specific to the dialysis population predicting resting energy expenditure (REE), a close marker of BMR. Emphasis was placed on ensuring simplicity in the algorithm to be suitable for bedside use. A secondary aim was to determine the relationship of metabolic rate to gender and body size parameters including BMI, which are important determinants of survival in dialysis patients. This would help to define groups that might benefit from a dialysis algorithm that adjusts dialysis requirements to REE.

### Methods

#### Study Design

After research ethics committee approval, a prospective cross-sectional study was performed on 200 patients established on dialysis. Subjects underwent a single comprehensive metabolic analysis including measurement of REE using indirect calorimetry, fat-free mass (FFM) estimation using bioimpedance, and body size parameters. This permitted the development of an equation to predict REE. This equation was then validated in a further cohort of 20 HD patients.

#### Study Population

Subjects older than 18 years of age on hospital or home HD or peritoneal dialysis (PD) were included. Exclusion criteria were hospital admission in the previous month, active or recent acute infection, chronic infection such as tuberculosis in the previous 12 months, blood-borne virus infection, and untreated thyroid dysfunction.

#### Metabolic Analysis

##### Body Size Parameters and Nutritional Investigations

Height and body weight were measured using calibrated scales. Blood nutrition parameters including blood hemoglobin, serum albumin, and thyroid function were measured on the day of the metabolic study.

##### Indirect Calorimetry

Subjects were requested to refrain from eating and physical activity for 2 hours before the study. For those on HD, measurements were taken before dialysis. Analyses were performed in a room at 21°C to 25°C. Subjects were asked to lie supine and still for 15 minutes before and throughout indirect calorimetry. Measurements were taken in a quiet room ensuring no disturbance.

A VMax 29n metabolic cart (Viasys Healthcare, Yorba Linda, CA) was used with an overhead canopy to collect expired air and perform indirect calorimetry. The mass-flow sensor and gas-analyzer were calibrated for each subject. Calorimetry was performed until steady state was achieved, defined as 5 minutes of less than 5% variation in the oxygen and carbon dioxide production rates (VO\(_2\) and VCO\(_2\), respectively) and the respiratory quotient. This was almost invariably achieved within 20 minutes and usually in less than 15 minutes. In the small proportion of patients (<5%) in which steady state could not be achieved in 20 minutes because of VO\(_2\) or VCO\(_2\) variability, steady state was considered as the first 5-minute period of less than 10% variation in the above parameters. The VO\(_2\), VCO\(_2\), and respiratory quotient for each patient permitted calculation of REE using the Weir equation:

\[
\text{REE (kCal/day)} = 1.44 \cdot [3.9 \text{VO}_2 (\text{mL/min}) + 1.1 \cdot \text{VCO}_2 (\text{mL/min})]
\]

##### Bioimpedance Analysis

FFM was estimated by whole-body bioimpedance using a Xitron Hydra 4200 device with wrist/ankle electrode measurements according to manufacturer guidelines. Bioimpedance analysis was performed in the supine position during the period of rest before indirect calorimetry.

##### Physical Activity Assessment and Estimation of Total Energy Expenditure

Physical activity was estimated from the Stanford 7-day recall questionnaire.\(^{12}\) For each patient, time-averaged metabolic equivalent of task (MET) was calculated from questionnaire data. Time sleeping was considered to have a unitary MET value of 1. Total energy expenditure (TEE) was estimated by multiplying the time-averaged MET by the REE.

#### Derivation of Predictive Equation

Biometric or blood nutrition markers predicting REE were identified using Pearson’s correlation. The relationships of biometric parameters with REE were determined by linear or nonlinear regression. Where linear regression was appropriate, linearity was tested using the runs test. Where linearity was not demonstrated, nonlinear regression was used to mathematically describe the relationship of parameters with REE. The general forms of nonlinear regressions used were \(y = ax^b\) or \(y = ax^b + c\).

##### Design of an Equation to Predict REE

The relationships of body size parameters such as height and weight with REE were nonlinear, and initially
nonlinear regressions for REE of the general form below including height, weight, and age as variables were of the general form

\[ \text{REE} = H \cdot \text{Height}^b + W \cdot \text{Weight}^c + A \cdot \text{Age}^e \]

**Equation 1**

These multiple nonlinear regressions had multiple solutions (multiple global minima); therefore, multiple linear regression was used after linearizing the relationship of weight and height with REE using power function transformations. The relationship of these variables with REE was found to be of the form \( \text{REE} = a \cdot \text{variable}^b \). The optimum power function transformation for each variable was determined separately by plotting \( \log(\text{variable}) \) against \( \log(\text{REE}) \). The slope was used to estimate \( b \) using a linear regression in the form

\[ \ln(\text{REE}) = b \cdot \ln(\text{variable}) + c \]

**Equation 2**

where variable represents height or weight and the slope \( b \) represents the linearizing power transformation that can be applied to the variable to linearize its relationship with REE. Linearity of the transformed function was confirmed using the runs test. In multiple linear regression for REE, gender was treated as a binary variable. Age was considered to have a linear relationship with REE for subjects 65 years of age or older (see Results).

A multiple linear regression equation was constructed for REE by including age, height \( b_1 \), weight \( b_2 \), and gender as factors in the model, where \( b_1 \) and \( b_2 \) represent the linearizing power transformations from **Equation 2**. Multiple linear regression was performed with SPSS v 16 software. The resulting regression equation represented the novel equation for REE on the basis of the previous parameters.

**Validation of an Equation to Predict REE**

The novel equation for REE was validated by 2 methods. First, by comparison in the study population (by the Bland-Altman technique)\(^{13} \) of measured REE and REE predicted by the novel equation and existing equations derived in the normal population (Schofield,\(^6 \) Harris-Benedict,\(^7 \) and Mifflin-St Jeor\(^8 \)). Secondly, the novel equation for REE was applied to a validation cohort (\( n = 20 \)) and predicted REE compared with measured REE using the Bland-Altman technique.

**Results**

**Population Demographics**

Table 1 presents the demographic information for the study subjects: 96.5% were on HD, 3.5% were on PD, and 15.6% were on low-dose prednisolone (5–7.5 mg daily) for reasons including previous transplantation, vasculitis, and polymyalgia rheumatica.

**REE, Physical Activity, and TEE in the Study Population**

REE from indirect calorimetry and physical activity level (time-averaged METs) derived from the Stanford questionnaire are shown in Table 2 along with estimated TEE. Physical activity did not significantly differ between males and females, but REE was significantly higher in males, as was estimated TEE (Fig. 1). REE correlated weakly with physical activity level (time-averaged MET; \( r^2 = 0.03, P < .009 \)). The least physically active tertile had a lower REE than the most active tertile (1,483 vs. 1,636 kCal/day, \( P = .02 \)).

**Relationship of Biometric Parameters With REE**

Variables correlating with REE are shown in Table 3. Age and blood hemoglobin concentrations had inverse correlations with REE. Height, weight, pulse rate, body temperature, mean daily MET, serum creatinine, FFM (bioimpedance), and residual renal urea clearance
correlated positively with REE. Age, height, and weight had the highest correlation coefficients with other parameters, explaining only a small proportion of the variance. Serum C-reactive protein and parathyroid hormone did not correlate with REE. There were no ethnic differences, although our population was predominantly White, with the non-White group constituting a relatively small proportion of the study population (see Table 1).

Height had a nonlinear relationship with REE. The optimum linearizing power transformation derived from the regression $\ln(\text{REE}) = b \times \ln(\text{height}) + c$ for height was 2.023 (95% confidence interval [CI] 1.618–2.428), such that REE could be described as a function of height:

$$\text{REE} = f_n(\text{height}^{2.023})$$

Equation 3

This is shown in Figure 2. The linearity of the transformed data was confirmed using the runs test ($P = .53$).

The relationship of weight with REE could be similarly described. The optimal power transformation for weight to linearize its relationship with REE was 0.629 (95% CI 0.548–0.710). The linearity of the transformed data was confirmed using the runs test ($P = .74$). Consequently, REE could be described as a function of weight (Fig. 3) as

$$\text{REE} = f_n(\text{weight}^{0.6291})$$

Equation 4

The relationship of age with REE was more complex, with REE decreasing as age increased. This relationship could be explained using a power function, but the CIs were very wide. Therefore, it was decided to describe the relationship using a linear regression. A cutoff age above which age correlated best with REE was calculated and determined to be 65 years or older. For those 65 years of age or older, the relationship of REE with age could be considered linear (runs test $P = .99$), with REE decreasing as age increased ($r = -0.428, P = .009$; Fig. 4). For those younger than 65 years of age, there was no significant relationship of age with REE ($r = .064, P = .55$).

**Energy Cost of Body Weight and Its Relationship to BMI**

The energy “cost” of a unitary kilogram of body weight was determined for each patient from the ratio of REE to body weight (kCal $\cdot$ day $^{-1}$ $\cdot$ kg $^{-1}$). The relationship with BMI is shown in Figure 5. The relationship was nonlinear: for lower BMI, the REE per kilogram increased.

**Predictive Equation for REE in Dialysis Patients**

*Multiple Linear Regression to Generate a Predictive Equation for REE*

The multiple linear regression for REE included the parameters height$^{2.023}$, weight$^{0.6291}$, age (if $\geq 65$ years), and gender in the form

$$\text{REE} = A \cdot \text{Age} \cdot \text{Factor}_{\text{age}} + H \cdot \text{height}^{2.023} + W \cdot \text{Weight}^{0.6291} + S \cdot \text{Factor}_{\text{sex}}$$

Equation 5

where A, H, W, and S are constants in the linear regression, and height is in centimeters, weight is in kilograms, and age is in years. Factor$_{\text{age}}$ is 0 if the age is less than 65 years or 1 if 65 years or older and Factor$_{\text{sex}} = 0$ if female or 1 if male.

Parameter estimates for A, H, W, and S are shown in Table 4 with CIs. All were significant predictors of REE in the model. The regression explained 66.3% of the variance in REE ($r^2 = 0.663$); therefore, the final predictive equation for REE was

$$\text{REE} = -2.497 \cdot \text{Age} \cdot \text{Factor}_{\text{age}} + 0.011 \cdot \text{height}^{2.023} + 83.573 \cdot \text{Weight}^{0.6291} + 68.171 \cdot \text{Factor}_{\text{sex}}$$

Equation 6

![Figure 1. Total energy expenditure in the study population was considered to be a combination of resting energy expenditure and exercise-related energy expenditure. Error bars shown represent the standard error of the means.](image)
The addition of a constant did not improve the variance in REE explained by the model. When other variables correlating with REE (Table 3) were added to this regression model they were not found to be significant predictors of REE, except for addition of pulse rate, which improved the model marginally ($r^2 = 0.674$). However, we did not include this parameter in the final model because its measurement may be difficult to standardize. Exclusion of patients on PD from the regression model did not significantly improve the variance in REE explained by the model ($r^2 = 0.664$).

### Validation of the Novel Predicted Equation for REE and Performance of Existing Equations Developed in Normal Individuals

The performance of Equation 6 and existing equations for REE in the study population ($n = 200$) are shown in Table 5 compared with measured REE using Bland-Altman analyses. Existing equations had a tendency to underestimate REE in this population (Table 5). The performance of Equation 6 against measured REE is also shown graphically in Figure 6.

The performance of Equation 6 in the validation study ($n = 20$) is shown in Figure 7. Bias was $-22$ kCal/day (95% CI of bias $-118$ to $-591$), which was not significantly nonzero. The upper 95% limit of agreement was $380$ kCal/day (95% CI of upper 95% limit of agreement 214-546), and the lower 95% limit of agreement was $-424$ kCal/day (95% CI of 95% lower limit of agreement $-258$ to $-591$). Bias was not significantly correlated with the average of the measured and predicted REE ($r = 0.30$, $P = .2$). The correlation $r^2$ coefficient of predicted REE to measured REE was 0.64 in the validation group.

### Discussion

We set out to derive an algorithm specific to the dialysis population to predict metabolic rate using biometric parameters. The parameters best predicting REE were weight and height. These parameters were not linearly related with REE. It is known that weight and FFM closely predict REE in normal individuals. However, FFM estimation is not easily obtainable without the use of bioimpedance; therefore, it is unlikely to be useful in developing bedside predictive equations for REE or for algorithms that may be applied to population- or registry-based studies.

We found a complex relationship of REE with age. Below the age of 65 years, there was no significant relationship of REE with age. Above this cutoff, age correlated negatively with REE, with this relationship being linear. The linear regression line with 95% confidence interval is shown. REE, resting energy expenditure.

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**Figure 2.** Nonlinear relationship of REE and height. The shallow curve shows a nonlinear regression in the form $\text{REE} = \text{height}^{0.023} + c$ (Equation 3). REE, resting energy expenditure.

**Figure 3.** Nonlinear relationship of weight and REE. The curve shows a nonlinear regression in the form $\text{REE} = \text{weight}^{0.626} + c$ (Equation 4). REE, resting energy expenditure.

**Figure 4.** Relationship of age with REE. Using an age cutoff of ≥65 y, below this there was no significant relationship of REE with age. Above this cutoff, age correlated negatively with REE, with this relationship being linear. The linear regression line with 95% confidence interval is shown. REE, resting energy expenditure.

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**Table 3. Factors Correlating Significantly With REE**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$R$</th>
<th>$r^2$</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>-0.35</td>
<td>0.12</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Height</td>
<td>0.55</td>
<td>0.31</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Weight</td>
<td>0.74</td>
<td>0.54</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Pulse</td>
<td>0.25</td>
<td>0.06</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Body temperature</td>
<td>0.14</td>
<td>0.02</td>
<td>.05</td>
</tr>
<tr>
<td>Mean daily metabolic equivalent of task</td>
<td>0.18</td>
<td>0.03</td>
<td>.009</td>
</tr>
<tr>
<td>Serum hemoglobin</td>
<td>-0.19</td>
<td>0.04</td>
<td>.006</td>
</tr>
<tr>
<td>Residual renal urea clearance</td>
<td>0.21</td>
<td>0.04</td>
<td>.003</td>
</tr>
<tr>
<td>Fat free mass (bioimpedance)</td>
<td>0.68</td>
<td>0.46</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Creatinine (predialysis in HD or plateau in PD)</td>
<td>0.20</td>
<td>0.04</td>
<td>.006</td>
</tr>
</tbody>
</table>

HD, hemodialysis; PD, peritoneal dialysis.
such as the Schofield equation, have attempted to address this by developing different equations for REE for different age groups. However, in our dataset, there were limited numbers of younger individuals, which is typical of dialysis populations, making this approach more difficult. The decision to exclude age as a factor when less than 65 years was pragmatic.

The Mifflin-St Jeor, Harris-Benedict, and Schofield equations assumed the relationships of weight and height with REE to be linear, although we have shown these to be nonlinear. Hence, their approach risks systematic bias as is demonstrated in our Bland-Altman analyses. We attempted to use multiple nonlinear regression to predict REE using functions including weight and height as power functions. However, there were wide CIs for iterated parameters. Therefore, we used linear regression after applying linearizing transformations to height and weight. This may be criticized because there is colinearity between height and weight. This limitation should be considered, but it is not easily resolved given the constraints of subject numbers that can be recruited in such studies for regression models.

The final equation developed for REE from multiple linear regression (Equation 6) included height, weight, gender, and age. The addition of further parameters (Table 3) to the model was possible, but it was without substantial improvement in the variance explained by the model, with the exception of pulse rate, which improved the model very marginally. Pulse rate was excluded from the final model because its measurement requires careful standardization, and its inclusion in the model would have limited the usefulness of the equation in registry datasets. Residual renal urea clearance correlated significantly with REE, but it was not included in the final regression because its inclusion did not improve the model.

Performance of Equation 6 in the original study population compared with existing equations developed in normal individuals showed no significant bias and improved limits of agreement. However, this should be interpreted with caution because this validation procedure was performed in the same study population as that from which the formula had been derived. Consequently, a second validation was performed in 20 separate subjects using the Bland-Altman technique. REE predicted from Equation 6 again showed similar limits of agreement and no significant bias as in the first Bland-Altman plot, although the CIs were wider because of the smaller number of subjects in this validation study. Therefore, we conclude that the novel equation for REE performs at least as well as existing equations for REE in terms of limit of agreement, and it reduces bias when compared with the Schofield, Mifflin-St Jeor, and Harris-Benedict equations.

There is only 1 other study in the literature that describes a predictive equation for REE in the dialysis population. This is a recent pilot study with low numbers (N = 67). The best model included age, REE, serum albumin, and C-reactive protein. The predictive power of this model at an $R^2$ of 0.489 was less than that of the 3 generic equations described here.

Equations for REE derived in normal populations tended to underestimate REE in the dialysis population. However, we caution against a potentially false conclusion that REE is relatively increased in patients on dialysis compared with the general population. This may not be correct because these equations were derived in historic populations of normal individuals that demonstrate little resemblance to a modern dialysis population. Without a control group of normal individuals in this study, it is not possible to draw conclusions about the effect of renal failure and the uremic state on REE. Our own results differ

![Figure 5. Body mass index and its relationship with energy cost of a unitary 1 kg of body weight. REE, resting energy expenditure.](image)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Parameter Estimate</th>
<th>Standard Error</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>-2.497</td>
<td>0.363</td>
<td>-3.213 - -1.78</td>
</tr>
<tr>
<td>Height</td>
<td>0.011</td>
<td>0.003</td>
<td>0.004 - 0.018</td>
</tr>
<tr>
<td>Weight</td>
<td>83.573</td>
<td>6.608</td>
<td>70.541 - 96.605</td>
</tr>
<tr>
<td>Sex</td>
<td>68.171</td>
<td>32.198</td>
<td>4.673 - 131.67</td>
</tr>
</tbody>
</table>

Table 4. Parameter Estimates in a Multiple Linear Regression for Resting Energy Expenditure That Are Based on Age, Height, Weight, and Sex As Described in Equation 5
somewhat from those reported by Kamimura and colleagues of REE in patients with kidney disease in Brazil, where they demonstrated that the Harris-Benedict and Schofield equations tended to overestimate REE. However, this study population was very different from ours in that the gender mix was reversed, ages were considerably lower, ethnicity was different, and the study included subjects with nondialyzed chronic kidney disease (CKD). Limited available data from small studies suggest that REE may be increased in those on HD compared with normal controls but reduced in those with CKD. Reduction in REE in CKD compared with normal controls may be due to a lower level of physical activity. This demonstrates the need to validate equations for REE in the population in which they are to be used.

Equation 6 is likely to be useful clinically, particularly when used in combination with an estimate of mean MET to allow for estimation of total daily energy expenditure. In keeping with previous data, we found low levels of physical activity in this group. The contribution of estimated physical-activity-related energy expenditure to TEE was approximately 1/3 in men and women. Thus, because of the small degree of interindividual variation in physical activity level, it is possible to estimate that TEE is REE*1.44 for men and 1.42 for women (Table 2); therefore, it is possible to obtain a rapid bedside estimate of TEE in patients on dialysis. In the normal population, physical activity is more variable; therefore, this estimation is much less likely to be accurate. Low physical activity level in patients with end-stage kidney failure has also been previously demonstrated in studies assessing physical activity using questionnaire-based techniques and accelerometers. Similar findings have been found with even early CKD. The relationship (although weak) between REE and physical activity level may be related to higher FFM in more physically active individuals.

Use of this equation will allow for the design of retrospective and prospective research studies to examine the hypothesis that dialysis dose would be better adjusted according to metabolic rate rather than Watson volume. It has already been demonstrated that adjusting dialysis dose according to body surface area rather than Watson volume would deliver greater dialysis to women and men of lower BMI—the groups that seem relatively underdialyzed by the current Kt/V algorithm. This may be because of a close mathematical relationship of REE to body surface area.

Potential reasons for the relative underdialysis of certain subgroups by the Kt/V model are suggested in this study. The relationship of BMI with the unitary energy cost of 1 kg of body weight demonstrates that the cost increases at low BMI. At low BMI, the relatively higher metabolic rate per unit of body mass may be reflected in increased uremic toxin generation. This important relationship

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**Table 5. Bland-Altman Analyses Comparing Measured REE With That Predicted by Existing Equations and Equation 6**

<table>
<thead>
<tr>
<th>Parameter from Bland-Altman Analysis</th>
<th>Schofield Equation</th>
<th>Harris-Benedict Equation</th>
<th>Mifflin-St Jeor Equation</th>
<th>Equation 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper 95% CI of upper 95% limit of agreement</td>
<td>503</td>
<td>491</td>
<td>560</td>
<td>426</td>
</tr>
<tr>
<td>Upper 95% limit of agreement</td>
<td>454</td>
<td>443</td>
<td>511</td>
<td>379</td>
</tr>
<tr>
<td>Lower 95% CI of upper 95% limit of agreement</td>
<td>404</td>
<td>396</td>
<td>462</td>
<td>332</td>
</tr>
<tr>
<td>Upper 95% CI of bias</td>
<td>78</td>
<td>83</td>
<td>142</td>
<td>27</td>
</tr>
<tr>
<td>Bias</td>
<td>50</td>
<td>55</td>
<td>114</td>
<td>0</td>
</tr>
<tr>
<td>Lower 95% CI of bias</td>
<td>21</td>
<td>27</td>
<td>85</td>
<td>-27</td>
</tr>
<tr>
<td>Upper 95% CI of lower 95% limit of agreement</td>
<td>-304</td>
<td>-286</td>
<td>-235</td>
<td>-332</td>
</tr>
<tr>
<td>Lower 95% limit of agreement</td>
<td>-354</td>
<td>-334</td>
<td>-284</td>
<td>-379</td>
</tr>
<tr>
<td>Lower 95% CI of lower 95% limit of agreement</td>
<td>-404</td>
<td>-381</td>
<td>-333</td>
<td>-426</td>
</tr>
<tr>
<td>Correlation with measured REE ($r^2$)</td>
<td>0.62</td>
<td>0.65</td>
<td>0.63</td>
<td>0.66</td>
</tr>
</tbody>
</table>

CI, confidence interval; REE, resting energy expenditure.

Bias was significant for the Schofield, Harris-Benedict, and Mifflin-St Jeor equations, which indicated that they underestimate REE. The greatest in terms of $r^2$, the best-performing equation was the novel equation.
requires further exploration and may underlie body size differences in survival.\textsuperscript{3} Our data are supported by a recent study of urea generation rate in patients on dialysis that showed higher urea generation rate per unit body mass in small women.\textsuperscript{29}

A limitation of this study is that the population was largely on HD because our unit has only a small PD program. Although these patients were included in the study, numbers were low and the validity of the novel equation for the PD population cannot be assumed. We thought it advantageous to include a mixture of patients on HD and PD to generate an algorithm for REE that is broadly applicable to the dialysis population. The small size of PD programs in comparison with HD is likely to limit the development of equations for REE specific to the PD population. Most of our subjects were Caucasian, which may limit the applicability of the equation to other groups. If TEE is also estimated from REE, then it should also be considered that there may be variation in physical activity level according to ethnic group.\textsuperscript{30}

A further limitation is that the thermic effect of food was not fully excluded by our instructions that patients fast for 2 hours before the indirect calorimetry, potentially resulting in a slight overestimation of RRE. The thermic effect of food is related to its energy content and is likely to have been of less than a 50-kCal magnitude for patients who ingested food in the 12-hour period before indirect calorimetry.\textsuperscript{31} Considering the high proportion of patients with diabetes, we thought it unlikely that a more prolonged fast would be rigorously adhered to by patients.

In conclusion, this study proposes a novel equation for REE specific to patients on dialysis that may be clinically useful. Its use in registry-based datasets might help determine whether adjusting dialysis dose according to REE might expose relatively underdialyzed groups and the effect of this on their survival.

**Practical Application**  
REE, similar to BMR, is the amount of energy expressed in kilocalories per day required for 1 day in conditions of rest. The algorithm presented, specific to the dialysis population, provides a method of REE estimation that is based on simple body size measures and may be useful for nutritional assessment.

**References**


