Measuring the thermic effect of food¹⁻³

George W Reed and James O Hill

ABSTRACT  The thermic effect of food (TEF), defined as the increase in metabolic rate after ingestion of a meal, has been studied extensively, but its role in body weight regulation is controversial. We analyzed 131 TEF tests from a wide range of subjects ingesting meals of varying sizes and compositions. Each test lasted 6 h. Of the total 6-h TEF, 60% of the total had been measured after 3 h, 78% after 4 h, and 91% after 5 h. We developed a three-parameter curve to fit the data, which reduced noise and gave additional information about the TEF. The area under this parametric curve was positively correlated with fat-free mass (FFM) and meal size (MS) and negatively correlated with meal size squared (MS²) with an R² of 0.35. The usual area under a curve created by connecting the data points of a line was correlated with the same factors but with an R² of 0.28. The peak of the parametric curve was positively correlated with FFM and MS and negatively correlated with MS², percent body fat, and meal composition. The time at which the peak occurred correlated positively with MS and percent fat in the meal. Our analysis suggests that an inadequate measurement duration of the TEF could lead to errors. In general, we recommend that the TEF be measured for ≥ 5 h.  Am J Clin Nutr 1996:63:164–9.

KEY WORDS  Thermic effect of food, metabolic rate, energy expenditure, obesity

INTRODUCTION

In attempts to understand the regulation of energy balance, investigators have studied all of the components of energy expenditure (EE). EE can be divided into sleeping metabolic rate (SMR), resting metabolic rate (RMR = SMR + arousal), the thermic effect of exercise (TEE), and the thermic effect of food (TEF) (1). The TEF, sometimes also called diet-induced thermogenesis (DIT), is defined as the increase in RMR after ingestion of a meal. Although this component of TEE may account for a relatively small proportion of total EE (3–10%), it could play a role in the development and/or maintenance of obesity (2) because small differences in the TEF over long periods of time could account for large differences among individuals.

Although the TEF has been investigated quite extensively, its role in energy balance in man is still controversial. For example, D’Alessio et al (3) cite 15 papers reporting a reduced TEF in obese subjects as compared with lean subjects and 12 papers reporting no difference in the TEF between the two groups. Such discrepant results suggest that methodologic differences between studies may be important. Except in the three studies with 24-h measurements, the TEF was measured for from 60 to 360 min after the meal. Similarly, Kinabo and Durnin (4) and Weststrate (5) point out numerous studies showing discrepancies concerning the influence of various factors (age, exercise, nutritional status, energy content of a meal, and meal composition) on the TEF.

Many of these discrepancies may be the result of methodologic differences, particularly differences in the time taken to measure TEF. Weststrate (5) suggests that the TEF can be accurately assessed within 3 h for meals providing ~ 2508 kJ. Kinabo and Durnin (4) showed that the TEF did not return to baseline after 5 h for a 5016-kJ meal and their data indicate that the TEF did not return to baseline after 3 h for a 2508-kJ meal. Belko et al (6) showed that the TEF returned to baseline after 3 h for meals containing 15% of energy requirements but not for meals containing 30% and 45% of energy requirements. D’Alessio et al (3) indicated that the TEF could last as long as 8 h after meals providing ≥ 6688 kJ and that the TEF did not return to baseline after 4 h for meals providing 2090 kJ. Welle et al (7) showed that the TEF did not return to baseline after 4 h for a 1672-kJ meal. Hill et al (8) showed that the TEF did not return to baseline after 3 h for meals providing 2090, 4180, and 6270 kJ. Segal et al (9) showed that 70% of a 6-h TEF is measured by 3 h for a 3010-kJ liquid meal and state, "...even a 6-hour period may not be sufficient to quantify the total thermic response to a meal in all individuals. . . ."

Most studies of the TEF have used small numbers of subjects, which likely contributes to the controversy because Weststrate (5) noted that the high intraindividual variation in the measurement of TEF allows for small power in studies with sample sizes of < 10 subjects.

It appears that differences in the duration of the TEF measurement and the amount of variation in measurements are contributing factors to the controversy regarding the importance of differences in the TEF to body weight regulation. In the present study we used an extensive database of TEF tests to evaluate the effect of the duration of measurement on the TEF. A second goal was to develop a model of the TEF to reduce

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some of the measurement variation and thus improve our understanding of the factors that influence TEF.

SUBJECTS AND METHODS

The data consist of 131 independent baseline meal tests conducted in the energy metabolism laboratory at Vanderbilt University over 5 y (1988–1992). The TEF was measured during several series of studies (10–17), although the TEF was only reported in two studies (10, 14). Subjects participated in various studies, with various interventions, but all tests used in these analyses were baseline tests, before any intervention. If a subject was in two separate studies, only the first baseline meal test was used so that the 131 tests represent 131 separate individuals.

All subjects came to the laboratory early in the morning between 0700 and 0800 after an overnight fast. Subjects lay quietly for 45 min, after which their RMR was determined for 30 min with a ventilated-hood indirect calorimetry system (SensorMedics 2900; SensorMedics Corp, Anaheim, CA). Subjects then consumed the test meal within 15 min. The test meal size and composition varied for different studies. In some studies, a fixed meal size and composition were used [eg, 4180 kJ and 40% of energy as fat (10)] and in others the size of the meal was related to the subject’s usual intake based on diet records [25% of usual intake (14)]. All meals contained 15% of energy as protein. RMR was then measured for 10 min every 30 min for the subsequent 6 h, during which time the subject remained lying down but awake. Energy expenditure was calculated from the amount of oxygen consumed and carbon dioxide produced (18). The TEF was calculated as the area under the response curve minus the 6-h RMR (extrapolated from the baseline measurement). Figure 1 illustrates a sample TEF curve that was adjusted for RMR by subtracting the RMR from the energy expenditure measured. The TEF is the area under this curve, calculated by summing each trapezoidal region formed with a base at zero.

There were 77 females (59%) and 54 males (41%). Table 1 lists the subject and meal characteristics and the range of values. Body composition was estimated from body density by using underwater weighing to determine body volume (19). Residual lung volume was determined simultaneously with the underwater weight by using the closed-circuit nitrogen-dilution technique (19). Percent body fat was estimated from body density by using the revised equation of Brozek et al (20).

SAS software, version 6.03 (21), on a digital vaxstation 3100 with a VMS (a standard operating system) operating system was used for all statistical analyses and nonlinear curve fitting described in the results. A nonparametric sign test was used to test whether medians were different from zero; t tests were used to test whether means were different from zero. Multiple-regression analysis was used to compare the TEF area and model parameters with subject and meal characteristics.

RESULTS

How long should the TEF be measured?

To determine the optimum time that it takes to measure the TEF it was necessary to ask two questions. First, was there a positive component to TEF between N hours and 6 h, where N = 3, 4, and 5? And second, what was the correlation between the TEF at 6 h and the TEF at 3, 4, and 5 h?

EE at the end of the TEF test (ie, at 6 h) was compared with RMR (measured before the test meal). The mean difference was 15.9 kJ/h and the median difference was 12.5 kJ/h; both differences were significantly different from zero, P < 0.0001. Seventy percent of the subjects had positive differences at 6 h.

Next, the TEF was computed at 3, 4, 5, and 6 h and expressed as a percentage of the meal size. The distributions of the difference between the TEF over 6 h and the TEF over 3, 4, and 5 h are illustrated in Figure 2. The distribution means are all significantly different from zero (P < 0.0001) and the variation becomes smaller as the time approaches 6 h. A one-sample sign test in each case indicates that the median difference is significantly different from zero (P < 0.0001). Table 2 lists the median differences and the 25th percentiles of the difference distributions to indicate that even between 5 and 6 h > 75% of the subjects had a positive component of the TEF. Assuming that the TEF at 6 h indicates the total TEF, we computed the percentage of the total TEF that had not been measured if the measurement were stopped at 3, 4, or 5 h. The median percentage of TEF “missed” at each stopping point is
listed in Table 2. At 4 h, > 20% of the TEF is not measured for one-half of the subjects.

The TEF is related to meal size, but even for meals providing \( \leq 3344 \text{ kJ} \) \((n = 39)\] the mean and median differences in the TEF at 6 and 5 h are significantly positive and the 25th percentile is positive. For these smaller meals \(~10\%\) of the total TEF was not measured at 4 h.

Figure 3 illustrates the correlation between the TEF at 6 h and the TEF at 3, 4, and 5 h. The variance explained is noted on each graph. At 4 h 90% of the variance of TEF6 is explained. There is still variation and hence information about differences among individuals in the TEF from 4 to 6 h.

A measure of the TEF

To reduce the noise and further describe the TEF, a threeparameter curve was used to describe each TEF curve over the 6-h period. Figure 4 illustrates the parametrized TEF model curve. Each TEF curve was assumed to be of this form, the equation for the curve being

\[
A + Bte^{-\theta C}
\]

where \( t \) is the time in hours. The three parameters have the following interpretation: \( A \) is the intercept, a term used for adjustment for error in the measurement of RMR; \( Bt \) is the maximum value or peak value on the curve; and \( C \) is the maximum time or the time at which the peak value occurs.

For a given subject's TEF values, the parametric curve was fit as illustrated in Figure 5. SAS proc NLIN was used to fit each curve. Because the fit of the curve in some cases could be sensitive to the initial values, a matrix of initial values was considered, and the set that minimized the mean squared error was used. (\( A \) was set at 0, \( B \) went from 0 to 40 in steps of 5, and \( C \) went from 0.5 to 4.5 in steps of 1.) This automated curve-fitting method was used on all TEF curves. Of the 131 subject curves, 128 were fit by the automated program. The three curves that did not converge or converged to a degenerate curve were essentially flat curves. When the initial values were adjusted and the program was rerun, these curves could be fit but this was felt to bias the fitting process. The analysis was

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**TABLE 2**

<table>
<thead>
<tr>
<th>TEF</th>
<th>Median</th>
<th>25th Percentile</th>
<th>Median percent of TEF</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEF63</td>
<td>0.0252</td>
<td>0.0125</td>
<td>40.0</td>
</tr>
<tr>
<td>TEF64</td>
<td>0.0128</td>
<td>0.0057</td>
<td>22.5</td>
</tr>
<tr>
<td>TEF65</td>
<td>0.0054</td>
<td>0.0021</td>
<td>9.1</td>
</tr>
</tbody>
</table>

\(^1\) The median and 25th percentile of the difference between TEF measured at 6 h and that at 3 (TEF63), 4 (TEF64), and 5 (TEF65) h. The difference is also expressed as a percent of TEF at 6 h. TEF is measured as a proportion of meal size.
FIGURE 4. An example of the form of the parametrized curve used to fit the TEF (thermic effect of food) data. Equation: $175.9 \times T \times e^{-n^2}$, where $T$ is time and $e$ is the base of the natural logarithm. RMR, resting metabolic rate.

done using the 128 fitted curves. The average mean squared error of the fitted curves was 336. The curve depicted in Figure 5 has a mean squared error of 546.

Using the fitted curves, TEF could be computed by finding the area under the smooth curve (smoothed area). The smoothed area, the trapezoid area (original TEF), and the smooth-curve parameters were compared with subject (FFM, fat mass, percentage fat, age, and sex) and meal characteristics (size and content) by using multiple-regression analysis.

Table 3 shows the characteristics that were significantly related to the trapezoid area and the smoothed area. It also illustrates whether the relation was positive or negative. The results for both the trapezoid area and the smoothed area were similar. The TEF was related to meal size in a quadratic fashion and was related to the subject’s FFM; however, the $R^2$ value was $\sim 25\%$ higher for the model area. This indicates a reduction in noise when the TEF model is used.

Table 4 shows the characteristics that were significantly related to the parameters of the smooth curve that describes TEF. The intercept was not correlated with any of the factors. This was expected because the intercept represents an adjustment for error in the initial RMR measurement. The peak EE was related to meal size and FFM just as the smoothed area was related to these factors; however, EE also correlated negatively with the subject’s percentage body fat. There was a trend ($P = 0.06$) for the peak to decrease with increases in the relative fat content of meals. The time of the peak was related to meal size in a positive linear fashion and to amount of body fat (kg) of the subject in a positive fashion. Figure 6 illustrates how the TEF curve shifts depending on the meal and subject characteristics.

**DISCUSSION**

Analysis of this database of meal tests strongly indicates that the TEF lasts beyond 6 h for the majority of subjects. The TEF is commonly measured for periods as short as 3 h. A 3-h TEF measurement can miss > 40% of the total TEF, and a 4-h TEF measurement can miss 22.5% of the total TEF. Even for meals providing 3344 kJ, 10% of the 6-h TEF is left between 4 and 6 h. Most studies indicate that a positive component exists beyond 3 h. Segal et al (9) indicate that 60–70% of the measured TEF is sufficient for comparison of the TEF across subjects. We feel that there is important information contained in the remaining unmeasured TEF. Although the 3-h and 4-h TEFs are significantly correlated with the total 6-h TEF, our curve fitting indicates that many factors can produce differences in the shape of the TEF curve. Thus, by not measuring to ± 5 h it is possible that important effects could either be masked or misinterpreted. For example, our new summarization of the TEF indicates that nonobese subjects show an earlier and higher peak TEF than do obese subjects. Our analysis suggests that the shorter the duration of measurement, the more likely it is that the total TEF will differ between

**TABLE 3**

Regression analysis of trapezoid area and smoothed area TEF

<table>
<thead>
<tr>
<th>Variable</th>
<th>$P$</th>
<th>Relation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trapezoid area ($R^2 = 0.28$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meal size</td>
<td>0.02</td>
<td>+</td>
</tr>
<tr>
<td>Meal size squared</td>
<td>0.03</td>
<td>−</td>
</tr>
<tr>
<td>FFM</td>
<td>0.0001</td>
<td>+</td>
</tr>
<tr>
<td>Smoothed area ($R^2 = 0.35$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meal size</td>
<td>0.0001</td>
<td>+</td>
</tr>
<tr>
<td>Meal size squared</td>
<td>0.0002</td>
<td>−</td>
</tr>
<tr>
<td>FFM</td>
<td>0.0001</td>
<td>+</td>
</tr>
</tbody>
</table>

$^1$ Results of multiple-regression analysis using the usual trapezoid area measure of the TEF (thermic effect of food) and the area under the smoothed curve. The $R^2$ values indicate that the relation of the smoothed-area TEF is stronger with increased meal size and fat-free mass (FFM) than the usual trapezoid area TEF measure.
TABLE 4
Characteristics related to peak energy expenditure and time of peak

<table>
<thead>
<tr>
<th></th>
<th>Variable</th>
<th>P</th>
<th>Relation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak energy expenditure (maximum; $R^2 = 0.39$)</td>
<td>Meal size</td>
<td>0.0001</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Meal size squared</td>
<td>0.0001</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>FFM</td>
<td>0.001</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Percentage body fat</td>
<td>0.004</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Meal composition</td>
<td>0.06</td>
<td>-</td>
</tr>
<tr>
<td>Time of peak (maximum time; $R^2 = 0.09$)</td>
<td>Meal size</td>
<td>0.003</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Fat</td>
<td>0.004</td>
<td>+</td>
</tr>
</tbody>
</table>

1 Meal and subject characteristics were significantly related to the parameters of the TEF (thermic effect of food) curve, by multiple-regression analysis.

obese and nonobese subjects. A measurement lasting an additional 2 h may wipe out that difference. It is of interest to note that if the smooth curve for the TEF is projected to 8 h, the total TEF would increase an average of 7% and that the increase is correlated with meal size ($r = 0.28$, $P < 0.002$).

We used our database to show how a three-parameter curve fit to TEF data will give a more detailed summary of these data points. The curve is not intended to predict the individual TEF based on subject and meal characteristics anymore than subject and meal characteristics can predict TEF measured by the trapezoid area under the curve. Each individual with different meal tests would have different parameters in the same way that they would have different areas. The purpose of the curve fitting is to give a more detailed description of the measure of the TEF. The usual area under the curve can be thought of as a single-parameter description of the TEF. The new curve can be thought of as distilling the curve to two parameters (plus one parameter for noise reduction). We believe two individuals can have the same area under the curve, but drastically different TEF curves. The usual trapezoid area method of measuring the TEF would not pick this up. The new method can pick this up. The data illustrate that the shape of the TEF curve may differ between lean and obese individuals. If the shape of the curve differs, but the total TEF does not, this might explain why some studies find differences in the total TEF between lean and obese individuals and others do not. When the TEF is measured to 3 h, there may be differences in the TEF curve between lean and obese subjects; however, when the TEF is measured to 6 h, these differences may disappear.

Our parametric curve fitting reduces some of the variation in TEF measurements and opens a new avenue of investigation of the TEF. Our method demonstrates the same relation between factors such as FFM and meal size and TEF as the conventional measurement, but the $R^2$ value increases. If the new model was not a closer approximation to TEF, it is possible that the variation could increase. Thus, our smooth curve increases the power to identify factors that influence the TEF. Both the trapezoid area and smoothed area are positively related to a subject’s FFM and to meal size. However, the smoothed area identifies a negative quadratic relation between TEF and meal size. This positive linear and negative quadratic effect was reported previously (6, 8, 22) and could be an indication of a meal-size threshold effect. Once the meal reaches a certain size, no increase in meal size will increase the TEF. It is also possible that this resulted because the TEF was only measured for 6 h and that the total TEF was underestimated for large meals as suggested by D’Alessio et al (3). However, the small positive difference between the TEF at 6 h and RMR was not correlated with meal size ($P = 0.43$, $r = 0.07$) whereas the positive difference between the TEF at 5 h and the RMR was significantly correlated with meal size ($P = 0.002$, $r = 0.26$).

We present an alternative to the standard way of assessing the area under the TEF curve. Our three-parameter curve summarizes other information in addition to total TEF and thus provides a means of better assessing the ways in which characteristics of the subject and of the diet effect the TEF. For example, we found that whereas total TEF may not be influenced by the subject’s body fat content, the shape of the TEF curve may differ by the subject’s body fat content. As seen in Figure 6, the peak of the TEF curve moves up as meal size and the subject’s FFM increase. The peak is related positively to meal size and negatively to meal size squared in the same way as for the total TEF. This nonlinear relation to meal size indicates that the peak increases with meal size, then reaches a saturation level. The new factor here is that peak TEF is inversely related to percent body fat of the subject.

Using this three-parameter curve, we can begin to understand how characteristics of the meal and of the subject influence the TEF. As meal size increases, the peak TEF increases and occurs at a later time after meal ingestion, and total TEF increases. The peak (and possibly the total TEF) appears to reach a threshold once the meal reaches a certain size. There is a direct positive relation between the amount of FFM of the subject and both the peak and total TEF. The body fat content

![FIGURE 6. An illustration of how the TEF (thermic effect of food) curve shifts depending on subject and meal characteristics. Meal size and fat-free mass (FFM) tend to increase the peak; subject’s body fat and meal size squared ($MS^2$) tend to lower the peak; meal size and subject’s body fat tend to move the time of the peak further out. There is some evidence that increased fat in the meal may decrease the peak. Illustrated curve equation: $175.9 \times T \times e^{-0.53h}$, where $T$ is time and $e$ is the base of the natural logarithm. RMR, resting metabolic rate.](https://academic.oup.com/jcn/article-abstract/63/2/164/4650492)
of the subjects (either amount or percent) appears to effect the shape of the TEF response but not the total amount of the TEF. As the subject’s body fat content increases, the peak TEF is lowered and occurs at a later time after the meal. Figure 7 illustrates the possible difference in the TEF due to differences in body fat content. The dotted line shows the response of the theoretical lean individual, who will have a high early peak that then drops off. Conversely, the theoretical obese individual (solid line) will have a lower flat curve. The total area under both curves would be the same.

Measuring the TEF for 6 h and using the parametric curve will not resolve all differences. For example, Segal et al (9) measured the TEF for 6 h and found differences in the TEF between lean and obese subjects. In general, we did not find such a difference across a variety of conditions. However, compared with our study, Segal et al used meals that were lower in fat, meals that had a lower energy content, and a liquid diet.

It is likely that the pattern of the TEF is more complicated than is the three-parameter curve presented here; however, a higher-order model is more difficult to fit given 12 data points. Our studies show that a three-parameter curve reduces noise better than does a two-parameter curve (excluding the intercept term) and that a four-parameter curve fits fewer TEF curves (101 of 131).

In summary, our results indicate that the TEF is a response lasting ≥6 h in most people and we recommend that measurements last ≥5 h. Additionally, we demonstrated that variation in the TEF can be reduced by fitting the data to a three-parameter curve. This alternative summary of TEF data provides information not only about total TEF but also about the time course of the TEF and will be useful in understanding how characteristics of the diet and of the subject influence the TEF.

REFERENCES