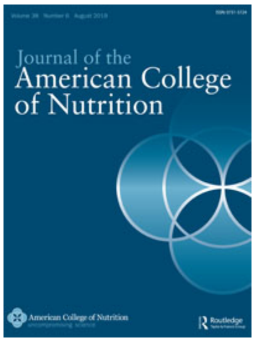

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The Thermic Effect of Food: A Review

Manuel Calcagno[a], Hana Kahleova[a], Jihad Alwarith[a], Nora N. Burgess[a], Rosendo A. Flores[a], Melissa L. Busta[a], and Neal D. Barnard[a,b]

[a]Clinical Research, Physicians Committee for Responsible Medicine, Washington, DC, USA; [b]Adjunct Faculty, George Washington University School of Medicine and Health Sciences, Washington, DC, USA

ABSTRACT

Two-thirds of U.S. adults are overweight. There is an urgent need for effective methods for weight management. A potentially modifiable component of energy expenditure is the thermic effect of food (TEF), the increase in the metabolic rate that occurs after a meal. Evidence suggests that TEF is increased by larger meal sizes (as opposed to frequent small meals), intake of carbohydrate and protein (as opposed to dietary fat), and low-fat plant-based diets. Age and physical activity may also play roles in TEF. The effects of habitual diet, meal timing, and other factors remain to be clarified. Further research into the factors that affect TEF may lead to better treatment methods for improved weight management.

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KEY TEACHING POINTS

- Measurement of the thermic effect of food.
- Physiological determinants of the thermic effect of food.
- The effects of meal variations on postprandial thermogenesis.
- Effect of age and physical activity on the thermic effect of food.

Introduction

Two-thirds of U.S. adults are overweight, and weight problems are increasingly common in much of the rest of the world (1). There is an urgent need for effective methods for prevention and treatment. Because obesity develops over time as energy intake exceeds output (2), factors that influence energy expenditure, even modestly, may be clinically important over time.

Total energy expenditure has several components. Basal metabolism is energy expended at rest and accounts for approximately 60% of total daily energy expenditure. The thermic effect of food (TEF), also called specific dynamic action or dietary induced thermogenesis, is the increase in metabolism after a meal and accounts for approximately 10% of total energy expenditure. It represents the energy expenditure of processing and storing food, as well as the metabolic effects of the influx of nutrients. Intentional (e.g., sports-related) exercise accounts for between 0% and 10% of total energy expenditure (3). Non-exercise activity thermogenesis (e.g., daily living activities, fidgeting, maintenance of posture) accounts for the remaining roughly 20% of total energy expenditure (4).

Evidence suggests that it may be possible to alter TEF as a weight-loss tool in both research and clinical settings. This article describes the factors that influence TEF and outlines potential areas for further research.

Measurement of the thermic effect of food

Body metabolism is measured by several methods with varying degrees of accuracy and cost-effectiveness (Table 1) (5). In the doubly labeled water method, nonradioactive hydrogen and oxygen isotopes are measured in body fluids (e.g., urine), allowing for extended measurements under free-living conditions (3). Direct calorimetry measures the loss of body heat using an isothermal system, a heat sink (adiabatic) system, or a convection system. It is accurate, but expensive to build and maintain (3). Indirect calorimetry, the most widely used method, measures oxygen consumption and carbon dioxide production (6, 7). Other methods are used less frequently due to expense or impracticality. TEF is typically reported as the area between the energy expenditure and basal metabolic curves (3).

Physiological determinants of the thermic effect of food

In order for food to contribute to energy expenditure, it must be digested and absorbed and its components (e.g., glucose) must enter cells to be metabolized. When cells are insulin resistant, glucose is less able to enter muscle and liver cells. Insulin sensitivity and, to a lesser extent, abdominal adiposity appear to be the principal factors regulating TEF (8).

CONTACT Hana Kahleova, MD, PhD hkahleova@pcrm.org Director of Clinical Research, Physicians Committee for Responsible Medicine, 5100 Wisconsin Ave. NW, Suite 200, Washington, DC 20016, USA.

Table 1. Methods Used to Measure the Thermic Effect of Food (TEF).

Method	Complexity	Cost	Measurement time (hours)	Accuracy	Reliability
Indirect calorimetry					
1. Confinement system	High	Moderate/high	1–48	80%	100%
2. Closed circuit system					
• Respiratory chamber	High	Moderate/high	1–100	90%	75%
• Spirometry	Moderate	Moderate	0.3–2*	50%**	25%
3. Total collection system					
• Flexible	Moderate	Moderate	0.3–2*	60%**	25%
• Rigid	Moderate	Moderate	0.5–2	40%	25%**
4. Open circuit system					
• Ventilated hood/canopy	Moderate	Low/moderate	0.2–6	80%	75%
• Ventilated chamber	Moderate/high	Low/moderate	1–48	80%	75%
• Expiratory collecting system	Low	Moderate	0.3–48	50%**	25%
5. Isotope dilution	Low	High	48–240	70%	75%
Direct calorimetry					
1. Isothermal system	Moderate/high	Moderate/high	0.3–1.5	100%	100%
2. Heat-sink/Adiabetic system					
• Chamber	High	Moderate/high	2–48	90%	100%
• Suite	Moderate/high	Moderate/high	2–48	70%	50%
3. Convection system	High	Moderate/high	2–48	80%	75%
Noncalorimetric methods					
1. Physiologic measurements					
• Heart rate	Low	Moderate	1–72	10%	10%
• Electromyography	Moderate	Moderate	1–24	10%	10%
• Pulmonary ventilation	Moderate/high	Moderate	1–24	10%	10%
2. Physiologic observations	Not applicable	Low	N/A	10%	10%

*Multiple readings.
**Highly variable.

A 1984 study ($n = 15$) monitored the rate of glucose storage in lean and obese individuals at a constant rate of glucose uptake (0.624 g/min). The obese group displayed delayed glucose metabolism compared with the lean group (2–5 mg/kg-min and 7 mg/kg-min, respectively). At 3 mg/kg-min, glucose oxidation is saturated, and glucose storage continues to rise. Thus, approximately 4 mg/kg-min is allocated to glucose storage in lean subjects; in obese individuals only a small amount of glucose is stored as glycogen through the energy-requiring process, conserving the remaining energy (9).

A 1992 study compared 24 moderately obese women who first underwent a weight-reduction program until they reached normal body weight versus 24 never-obese women, matched for body weight, fat mass, and age. TEF was 1.6% lower in the formerly obese group (8.2%) when compared to never-obese participants (9.8%) ($p = 0.043$), but the lower TEF in the formerly obese group remained relatively unchanged even after weight loss (8.7%) ($p = 0.341$). Researchers concluded that a reduction in TEF is a contributing factor to obesity rather than a consequence of obesity (10).

The effects of variations in body composition on TEF have not been fully characterized, but multiple factors that are found in overweight individuals (e.g., less physical activity, insulin resistance, and differences in meal composition) are likely to reduce TEF in this group, compared with lean individuals.

A 1992 study ($n = 32$) documented the independent effects of obesity and insulin resistance on postprandial thermogenesis. After a euglycemic hyperinsulinemic clamp was administered, insulin-resistant individuals (both lean and obese) displayed reduced glucose storage compared with their insulin-sensitive counterparts. A positive correlation ($r = 0.5$) between thermogenesis and the rate of glucose storage was observed ($p < 0.01$) (11).

In summary, insulin sensitivity seems to play a role in metabolism, particularly affecting TEF. Individuals with excessive body weight tend to have a higher risk of developing insulin resistance, thus increasing their chances of having decreased TEF. It is not yet clear how much it actually affects TEF, and more research is needed in this area.

Factors influencing the thermic effect of food

Age, physical activity, and meal size, composition, frequency, and timing all influence the thermic effect of food and are described next.

a. ***Age:*** TEF may decrease with age. A 2014 Mayo Clinic study comparing 123 older (60–88 years) adults to 86 younger (18–35 years) adults found that, expressed as a percentage of meal size, TEF was lower in older adults (6.4% versus 7.3%, $p = 0.02$). The difference remained after adjustment for fat-free mass, fat mass, and subcutaneous fat (12). Two smaller studies made similar observations (13, 14). The result of reduced TEF, along with decreased physical activity, may be an increased fat storage with age. However, the observed fall in TEF may not reflect the aging process per se; it may reflect other changes in metabolism occurring over time (e.g., those resulting from meal composition, described in the preceding).

b. Physical activity: A study ($n = 36$) comparing active and sedentary men in both younger and older age groups found TEF to be 45% higher in the active, young group (323.42 kJ) and 31% higher in the active, older group (292.04 kJ), compared with their respective sedentary groups (222.17 kJ and 215.47 kJ, respectively) ($p < 0.01$).

The researchers concluded that, regardless of age or body composition, physical activity increases TEF (15).

c. Energy content of meals: A 1990 study ($n = 16$) reported that a higher energy intake, regardless of meal composition, results in increased TEF ($p < 0.001$) (16). One study compared three different meals of 2092 kJ, 4184 kJ, and 6276 kJ. The corresponding TEF values were <10%, 21%, and 33.5% from baseline, respectively (17). A meta-analysis of 27 studies showed a significant increase in TEF of 1.1–1.2 kJ/h for every 100 kJ of energy intake ($p < 0.001$) (18). A similar study ($n = 10$) compared a low-energy, high-fat meal (818 kJ) with a high-energy, low-fat meal (2,929 kJ), finding higher TEF values with the high-energy meal (19).

d. Meal composition: Three studies have compared the effects of high-carbohydrate versus high-fat meals. Two of these ($n = 12$, $n = 24$), providing similar caloric content meals, found TEF to be 96% (26.8 kJ/h) (20) and 16% (8 kJ/h) (21) higher on the high-carbohydrate meal, compared with the high/moderate fat group, respectively, but did not provide data on statistical significance. A 2005 study of lean young men ($n = 14$) also found TEF to be 32% higher on the high-carbohydrate meal (43.1 kJ/h), compared with a high-fat meal (32.6 kJ/h) with isoenergetic content (3,255 kJ) ($p < 0.05$) (22).

In contrast, a crossover study ($n = 19$) compared isoenergetic high-protein, high-fat, and high-carbohydrate meals, finding no difference between the high-carbohydrate (39.2 kJ/h) and high-fat (39.2 kJ/h) meals, while TEF was 17% higher on the high-protein group (45.9 kJ/h) ($p < 0.01$) (23).

The type of dietary fat may make a difference. A 2013 study ($n = 7$) provided isoenergetic meals with similar macronutrient composition with either medium-chain (20 g) or long-chain (18.4 g) triglyceride and found TEF to be 34% higher (7.5 kJ/h) in the medium-chain triglyceride meal group ($p < 0.005$) (24). Another study ($n = 8$) similarly found TEF to be 132% higher with meals containing medium-chain triglyceride alone (11.1 kJ/h higher) ($p < 0.01$) and 110% higher with both medium-chain and long-chain triglyceride (9.3 kJ/h) ($p < 0.01$) as opposed to long-chain triglyceride alone (25).

Additionally, a study ($n = 29$) comparing meals containing polyunsaturated, monounsaturated, and saturated fat reported thermogenesis of 37.2 kJ/h, 36.8 kJ/h, and 30.0 kJ/h, respectively ($p < 0.05$) (26). In contrast, a previous small ($n = 14$) study comparing MUFA from extra virgin olive oil versus saturated fat from cream found no significant difference in thermogenesis between groups (27).

Vegetables, fruits, whole grains, and legumes have higher fiber content, compared with refined grains or animal-derived products, and may require more energy to digest. A 2005 randomized, controlled study ($n = 64$) compared a low-fat vegan diet to a control diet (National Cholesterol Education Program guidelines) in overweight, postmenopausal women. Researchers measured TEF after consumption of a 720-calorie test meal, then asked participants randomized to the vegan diet to follow the diet for 14 weeks. Repeat TEF testing showed a 16% increase in TEF within the vegan group ($p < 0.05$) In a regression model, thermic effect of food emerged as a significant predictor of weight change ($p < 0.05$) (28).

e. Processed versus unprocessed foods: Milling of grains leads to a loss of dietary fiber (from bran) as well as a loss of protein (from the germ). A crossover study ($n = 17$) comparing isocaloric meals consisting of sandwiches made with either refined or unrefined grains showed a greater thermic effect (46.8% higher) from the unrefined grain product ($p < 0.001$) (29), presumably related to changes in fiber and macronutrient content.

f. Palatability: A 1985 study ($n = 8$) suggested that palatability could possibly increase sympathetic activity, thus increasing TEF (30). However, several subsequent studies found no differences in TEF when comparing palatable to unpalatable meals ($p > 0.05$) (31–33).

g. Meal frequency, regularity, and timing: Four studies compared the effects on TEF of a single large meal versus frequent, small meals with the same total energy density. Two trials found TEF to be higher on the single, large meal, as opposed to several frequent, small meals, during 3- to 5-hour measurements (10.6 kJ/h, or 32%, higher after one large vs. four smaller meals, and 13.3 kJ/h, or 38%, higher after one large vs. six smaller meals, respectively, $p < 0.05$ on both) (34, 35). One study did not detect any difference between one large meal and two smaller meals, potentially due to a relatively small difference between the interventions (36). Another study showed a 30.3% higher TEF on a single, large meal, compared with three smaller meals. Unfortunately, the researchers have measured TEF for only a short period of time, which may have resulted in insufficient power to detect significant differences in response to changes in meal frequency (37). A 2016 meta-analysis that standardized the units concluded that TEF was significantly higher with a single large meal, compared with smaller frequent meals ($p = 0.02$) (18).

A 2003 randomized crossover study ($n = 9$) compared a regular meal plan (6 meals/day) to an irregular meal plan (3–9 meals/day), with the number of meals being the same throughout the week, resulting in a significant decrease in TEF during the irregular meal plan ($p = 0.003$) (38).

The effect of meal timing was examined in a 1993 study ($n = 9$) that found TEF to be higher in the morning as compared to the afternoon ($p = 0.02$) and night ($p = 0.002$), and higher in the afternoon compared to the night ($p = 0.06$) (39). Later studies tested the effects of skipping meals. In a crossover design with 17 participants, comparing a conventional 3/day meal pattern to skipping breakfast or dinner, TEF was higher when a meal had been skipped (+41 kcal/day with breakfast skipping and +91 kcal/day for dinner skipping) ($p < 0.01$), while fat oxidation was only increased when breakfast was skipped ($p < 0.001$). It is also conceivable that prolonged fasting could lead to a state of stress, increasing adrenergic activity, lipolysis, and energy expenditure in those who skip a meal (40). However, a small 2014 study ($n = 9$) found no relationship between skipping breakfast and TEF (41).

h. Meal duration: Two studies ($n = 21$, $n = 9$) investigated the effect of meal duration on TEF, but only one reached statistical significance. One study ($n = 21$) recorded meal duration and number of chews in men, showing that slow eating was associated with a considerable increase in TEF at 90 minutes ($p < 0.05$), possibly due to postprandial splanchnic circulation after the meal (42). The other study ($n = 9$) showed that slow eating tended to increase TEF in females by 32% (10.3 kJ/kg/h) at 180 minutes compared to fast eating ($p > 0.05$) (43).

In summary, TEF tends to decrease with age. In contrast, physical activity, higher energy meals, high-carbohydrate and high-protein meals as opposed to high-fat meals, and single large meals tend to increase TEF. In addition, high consumption of fruits, vegetables, and high-fiber-content meals also seem to have a positive effect on TEF. Meal timing and meal duration might play a role but to what extent is not yet clear, while palatability does not seem to have an effect on TEF. More research with larger sample size would be beneficial.

Conclusion

TEF is a significant part of energy expenditure and can be to a certain degree increased by factors that are under individual control, such as by eating larger meals and meals high in carbohydrates and protein, and by increased physical activity. Although the effects of such manipulations are small, they may play an important role over the long term, suggesting that they may have value as part of the management of obesity and obesity-related conditions, such as type 2 diabetes (44).

The body of literature on TEF is limited. Many studies are small in size, and methodology varies considerably between studies. Nonetheless, to the extent that postprandial energy expenditure can be increased, weight-control efforts may be facilitated. More research studies with larger sample sizes and appropriate controls are needed.

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ORCID

Manuel Calcagno http://orcid.org/0000-0002-2419-6402

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