

How much food does man require? New insights

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Summary

The transition from hunter gatherers to modern man is categorized by the enormous decrease in the number of plant species utilized today. Four main staples, rice, wheat, corn and potato, feed almost 80% of the world's population. An additional characteristic of our modern diet is the rich energy density of our meals. In order to estimate human energy requirements, new predictive equations to estimate basal metabolic rate have been developed. These equations will enable us to estimate human energy requirements in both developed and developing countries.

Keywords: basal metabolic rate, decline in plant species, energy density, energy requirement, food, nutrition

Introduction

The history of humankind has been shaped by his quest for food. It can be argued that much of human civilization has been profoundly influenced by sporadic cycles of both famine and feast. Unfortunately, we live in a world juxtaposed, with certain nations ravaged by famine and others consigned with over-consumption. This purports the rhetorical question: 'How much food does man require?' To answer this question, one needs to take a closer look at the nutritional needs of man. The history of nutrition can be traced back to the study of energy metabolism. In 1777, Antoine Lavoisier presented his classical study of calorimetry, where a guinea pig was surrounded by an ice calorimeter (Lavoisier 1777 cited in Webb 1991; Klieber 1961). Lavoisier was the first to demonstrate that the energy produced as heat was proportional to the amount of oxygen consumed by an animal as well as the amount of carbon dioxide produced. These principles of direct and indirect calorimetry are still in use today (Westerterp *et al.* 1995). In this early research paper on the principles of energy production, Lavoisier said that 'Life is a fire', which has

the meaning that just as a fire requires fuel to burn, the human body needs food to burn as a source of energy (Lavoisier 1777 cited in Klieber 1961).

What can we learn from our ancestors?

For many millennia, our ancestors were hunter gatherers and it was only around 10 000 years ago that the domestication of plants and agriculture occurred. However, it was not until around 1815 that modern food technology as we know it today was first developed (Henry 1997). Consequently, there was an exponential growth in the human population (that reached 7 billion in 2011) (UNFPA 2011) (as opposed to around 1 billion in 1800) (www.worldometers.info/world-population). This increase in population and ability to live under harsh ecological conditions (*i.e.* in the desert or the arctic) were only possible following the introduction of modern food technology, which enabled foods to be preserved and eaten out of season.

From foraging to farming to food technology

Number of plant species eaten

Getting back to the diet of early man, the hunter gatherer's strategy was to consume a large number of plant

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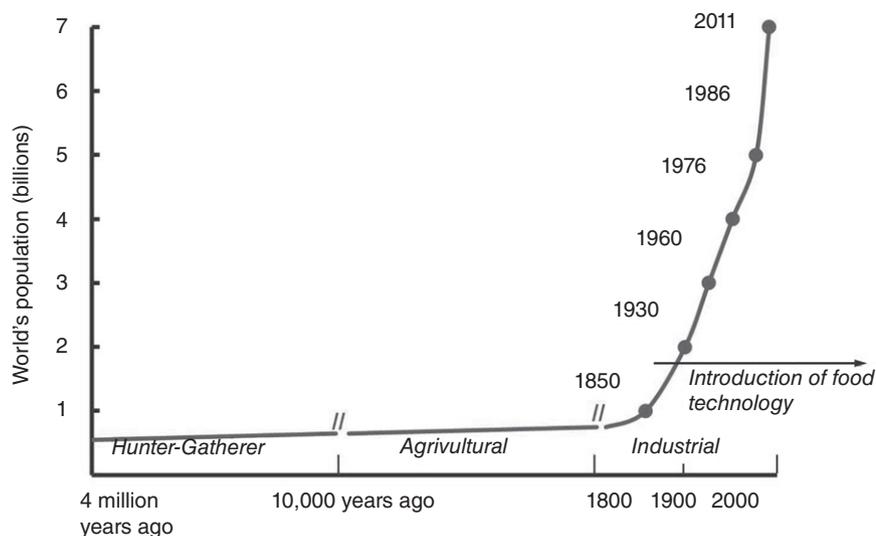


Figure 1 Foraging to farming to food technology. Source: Henry (1997).

species, mainly fruit, tubers, seeds and vegetables (Henry 1997). For example, the Alyawara tribe (Central Australia) used 92 plant species and the Tlokwa tribe (Botswana) used 126 (Grivetti 1979; O'Connell *et al.* 1983). Yet, in contrast, with the advent of food processing in the 21st century, food processing is largely based on just six cereals (wheat, rice, corn, barley, oat and rye), with 80% of the global population living on only four principle staples, namely wheat, rice, corn and potatoes (Henry 1997). This highlights the remarkable truncation of the number of plant species eaten by humans to meet their nutritional needs (See Figure 1).

Furthermore, advances in culinary skills have enabled over 2000 different foods to be made from just wheat alone, resulting in some remarkable nutritional innovations in the present day (*i.e.* noodles, strudels, pita bread, cakes, cookies) (Faridi & Faubion 1995). All of the foods that humans consume are made up of three simple components, protein, fat and carbohydrates. It is the proportion of these that makes the difference in the amount of energy and nutrients derived from the types of foods consumed (Atwater & Benedict 1902; Widowson 1955). For example, protein and carbohydrate contain 4 kcal/g, whereas fat contains 9 kcal/g; therefore, for every gram of fat that is consumed, almost 2.25 times more energy from a gram of protein or carbohydrate is taken in by the body.

Eating patterns

The second transformation in the transition from hunter gatherers to the diet of humans today, is the change in

eating patterns. Hunter gatherers had to eat when they could, resulting in up to 8–10 feeding occasions in an 18-hour period, compared with only 4 feeding occasions in today's world (breakfast, lunch, tea and supper). Therefore, food consumption or the meal occasion is now much more infrequent. It is argued that reverting back to snacking on the types of foods eaten by hunter gatherers may provide a solution to some of the problems of obesity and weight management (Cordain *et al.* 2000; Milton 2000).

Energy density

Hunter gatherers predominately ate low energy density foods such as fruits, vegetables, plants and tubers (Henry 1997). Energy density is the amount of energy in a given weight of food or drink (kJ/g, kcal/g) (Benelam 2009). For example, a kilogram of boiled carrots contain only 220 kcal and a kilogram of mushrooms contain 90 kcal in comparison to foods typically found in today's diet, such as chocolate, which has an energy density of 5.6 kcal/g. Consumption of only 45 g of chocolate yields over 200 kcal. It is this change in the energy density of the diet that has made it difficult to reduce energy/calorie intake because foods today are typically based on high energy density in contrast to the foods consumed by our hunter gatherers.

What is the requirement for energy?

We live in a world of paradoxes, with under-nutrition in some areas of the world resulting in severe forms of

malnutrition (*e.g.* kwashiorkor and marasmus), while in other parts of the world there is obesity caused by over-consumption. Currently, over 1 billion people (around one-sixth of humanity) suffer from under-nutrition (FAO 2011). Yet, in 2008, the number of people who were overweight and obese was 1.4 billion globally (WHO 2012), a figure that exceeds the number of those who are undernourished.

Why is there a need to estimate energy requirements?

There are three reasons why energy requirements are estimated:

- (1) To enable countries and communities to estimate annual food requirements. To determine the needs of a nation, it is necessary to know the requirements at the individual level.
- (2) To give policymakers and individuals information on how to reduce food intake in those who are obese and overweight.
- (3) To calculate how much food is needed to feed those who are malnourished or need to gain weight (FAO 1947).

As there are both individual and population requirements, a better understanding of how to articulate our energy requirements is required. There are two ways by which energy requirements can be estimated: by measuring food intake or energy expenditure.

Food intake

Measuring food intake is a very unreliable method to estimate energy requirements as it is difficult for people to recall what they have eaten, either intentionally or unintentionally. Food intake is governed predominately by social, cultural and psychological factors, which makes it a difficult conundrum when trying to articulate energy requirements from food intake studies. Historically, until the late 1950s, food intake was the *prima facie* way in which to estimate energy requirements, however, there are enormous pitfalls with this system, such as inaccuracy of reporting food eaten, to estimating portion size. Interest in human energy requirements goes back as far as 1948 when Aykroyd, the Director of Nutrition at the Food and Agriculture Organization (FAO), stated that, 'Even tentative recommendations would be of immediate practical value to the FAO, but also to its member countries' (www.fao.org/ag/agn/nutrition/requirements_background_en.stm), and as

such energy requirements have since dominated our way of thinking for many decades.

Energy expenditure

Total energy expenditure can be broken down into four simple compartments: (1) basal metabolic rate (BMR) (60–75% of total); (2) physical activity (15–30%); (3) diet-induced thermogenesis (DIT) (7–13%); and (4) growth (2–7%).

For those who are no longer growing (*i.e.* adults aged 18+), the growth component for energy expenditure is not relevant. However, even the energy requirements for growth of children and pregnant or lactating women are still very small compared with the amount of energy required to meet our BMR which is the largest component of energy expenditure. Furthermore, even in very active individuals the physical activity proportion of total energy expenditure is typically no more than 30%.

It is interesting to note that some people can eat large quantities of food without gaining weight, possibly because they may have up to a 10% increase in BMR compared with others. To illustrate this, a 10% increase in BMR means that energy consumption could rise from 1 to 1.1 kcal/min. As this is happening continuously throughout the day, it can add up to a considerable amount over the course of a day (DH 1991).

Diet-induced thermogenesis, which is the increase in energy expenditure after the ingestion of food, occurs at every eating occasion; as you eat, you increase your energy expenditure. Because the hunter gatherers ate up to eight times a day, this led to an increase in their thermogenesis at each eating occasion. However, this form of feeding is not recommended today because of differences in the composition of the diet between now and then.

Which organs in the body contribute to BMR?

The BMR is the minimal rate of energy expenditure compatible with life (*i.e.* the minimal energy requirement needed to sustain life in the resting state, *e.g.* for the cellular and tissue functions required for the functioning of the heart, lungs, nervous system, liver, kidneys, sex organs, muscles and skin) (Schofield *et al.* 1985). One problem with measuring BMR is that specialized equipment is required. Two centuries ago, Lavoisier suggested that the amount of oxygen consumed and the carbon dioxide produced can be used to calculate energy expenditure (Lavoisier 1777 cited in

Table 1 Organ size and metabolic rate in adults

Organ	Weight (kg)	% body weight*	OMR	OMR/BMR (%)*
Liver	1.60	2.3	464	26.1
Brain	1.40	2.0	414	23.2
Heart	0.30	0.4	182	10.2
Kidney	0.30	0.4	116	7.1
Total	3.60	5.1	1177	66.7
Skeletal muscle	28.30	40.4	500	28.1
Total	31.90	45.5	1677	94.2

Source: Holliday *et al.* (1967).

*Based on a 70-kg man.

BMR, basal metabolic rate; kg, kilogramme; OMR, organ metabolic rate.

Table 2 Brain size and brain metabolic rate during growth in humans

Body weight (kg)	Life stage	Brain weight (g)	Brain weight/body weight (%)	BrMR (kcal/day)	BrBMR/BMR (%)
3.5	Baby	475	14	140	67
11	1 year	1045	10	311	53
19	5 years	1235	6.5	367	44
31	10 years	1350	4.4	400	34
70	Adult	1400	2.0	414	23

Source: Holliday *et al.* (1967).

BrMR, brain metabolic rate; BMR, basal metabolic rate; g, gram; kcal, kilocalorie; kg, kilogramme.

Klieber 1961). The same principles are used today; however, trying to measure BMR in a large group of people is impractical. Therefore, studies of metabolic rate around the world have been collated and used to derive BMR predictive equations. Despite the human brain representing a small proportion of body weight, it still contributes a large proportion of energy expended as BMR (see Table 1). No other animal brain uses as much energy as that of the human brain (Holliday *et al.* 1967) (see Table 2).

The liver, brain, heart and kidneys collectively represent approximately 5% of our body weight (based on a 70-kg man). They also represent almost 70% of total energy expenditure of BMR (liver 26.1%, brain 23.2%, heart 10.2% and kidneys 7.1%) compared with skeletal muscle, which represents 40% of body weight but uses only 28% of BMR. Therefore, the liver and brain expend the same energy as the entire muscular system at rest. One possible explanation for individual variations in BMR may be a difference in organ size, possibly by only a few grams, which may alter the BMR because

these four organs contribute such a large amount to total energy expenditure (Holliday *et al.* 1967).

The British scientist, Bedale, suggested as early as 1923 that BMR could be used to estimate energy expenditure and energy requirements (Bedale 1923). Historically, until the 1950s, BMR was used in clinical settings to try and diagnose whether a person was suffering from hypo- or hyperthyroidism, as the latter is associated with an increased BMR and thyroxin measurement was not possible at that time. Therefore, BMR, which was once used in a clinical setting, is now used to measure people's energy requirements and therefore their food requirements.

How constant is BMR within a subject, and are the BMRs of men and women different?

In men, BMR is remarkably constant and variability between months and years is quite modest. In 1933, Benedict measured his own BMR over the period of a month and a half and the results showed a robust consistency (Benedict 1935). Women experience changes in their BMR during the menstrual cycle with a lower BMR occurring during the early follicular phase than the late luteal phase. Some women exhibit consistency and tight control of BMR, while others demonstrate higher intra-individual variability. Interestingly, women with a large variability in their BMR have been shown to maintain their body weight more effectively.

Energy requirement

In 1985, the FAO, the World Health Organization (WHO) and the United Nations University (UNU) proposed using energy expenditure rather than food intake to estimate energy requirements and also developed a series of predictive equations to estimate BMR (Schofield *et al.* 1985). This was the first move towards using BMR for predicting energy requirements.

The 1985 FAO/WHO/UNU report produced a whole range of predictive equations based on age and gender (FAO/WHO/UNU 1985). Accordingly, a linear equation relating body weight in kg was used to predict BMR. In order to calculate total energy expenditure, it is necessary to take into account factors related to physical activity, DIT and growth. Physical activity is classified as light, moderate or heavy, based on the level of occupational work carried out. For example, if a man doing light work has a BMR of 1000 kcal, this would need to be multiplied by a factor of 1.55 to obtain his total energy expenditure of 1550 kcal.

Table 3 Prediction equations for BMR*: Henry weight†

Gender	Age (years)	BMR (MJ/day)	BMR (kcal/day)
Men	<3	0.255w - 0.141	61.0 w - 337
	3-10	0.0937 w + 2.15	23.3 w + 514
	10-18	0.0769 w + 2.43	18.4 w + 581
	18-30	0.0669 w + 2.28	16.0 w + 545
	30-60	0.0592 w + 2.48	14.2 w + 593
	>60	0.0563 w + 2.15	13.5 w + 514
	60-70	0.0543 w + 2.37	13.0 w + 567
	>70	0.0573 w + 2.01	13.7 w + 481
Women	<3	0.246 w - 0.0965	58.9 w - 23.1
	3-10	0.0842 w + 2.12	20.1 w + 507
	10-18	0.0465 w + 3.18	11.1 w + 761
	18-30	0.0546 w + 2.33	13.1 w + 558
	30-60	0.0407 w + 2.90	9.7 w + 694
	>60	0.0424 w + 2.38	10.1 w + 569
	60-70	0.0429 w + 2.39	10.2 w + 572
	>70	0.0417 w + 2.41	10 w + 577

Source: †(Henry 2005).

*Coefficients and constants shown for equations of the form BMR = weight coefficient × weight (kg) + constant.

BMR, basal metabolic rate; kcal, kilocalorie; kg, kilogramme; mj, megajoule; w, weight.

Predicting BMR

One problem with the predictive equations of the 1985 report (FAO/WHO/UNU 1985) was that they were mostly based on assessments of Western European and North American subjects of whom almost half were Italian, where BMR was estimated using a closed circuit method from the 1930s and 1940s. There was an over-representation of BMR values, especially for people from developed countries. As a result, a systematic review of the literature was undertaken in order to develop a global BMR predictive equation of relevance worldwide.

In 2005, the present author working at Oxford Brookes University collected over 13 000 data sets of BMR from men and women around the world. The database comprised 174 papers published between 1914 and 2002, representing the most comprehensive and extensive coverage of BMR from a global landscape. The 2005 publication (Henry 2005) is international in perspective and can be used anywhere in the world, providing an important advance in knowledge and understanding regarding human energy requirements (Table 3).

When bodyweight and age are known, BMR can be calculated easily. However, to obtain total energy requirements, a certain proportion needs to be added to take into account physical activity and DIT. The

Table 4 Revised BMR equations

Age (years)	BMR (kcal/d)	
	Males	Females
3-10	23.3W + 514	20.1W + 507
10-18	18.4W + 581	11.1W + 761
18-30	16W + 545	13.1W + 558
30-60	14.2W + 593	9.7W + 694
>60	13.5W + 514	10.1W + 569

Source: SACN (2011).

BMR, basal metabolic rate; d, day; kcal, kilocalorie; W, weight.

Scientific Advisory Committee on Nutrition (SACN) compiled a report in 2009 using slightly different values for physical activity levels to calculate total energy requirements or the estimated average requirements for men and women (SACN 2011). This SACN report is the most extensively researched and articulated piece of work carried out in the UK; an attempt to bring together the most current literature, consensus and understanding so as to base energy needs on total energy requirements rather than food intake. In the case of children and adolescents of different ages, the SACN report slightly amended some of the values from those given by the Committee on Medical Aspects of Food and Nutrition Policy in 1991 (DH 1991). (see Table 4).

Conclusion

The question 'How much food does man require?' was posed earlier in the paper. This comes from the title of a research paper written by four giants of nutrition, John Durnin, Otto Edholm, Derek Miller and John Waterlow, published in 1973 in *Nature* (Durnin *et al.* 1973). Within this paper, they commented, 'we believe that the energy requirements of man and his balance of intake and expenditure are not known'. In the intervening years, a greater understanding of energy requirements has been established. As Durnin, Edholm, Miller and Waterlow were very much involved in the study of energy requirements it is a great tribute that some of their predictions, based on their understanding at that time, have been challenged. Consequently, we now have a better understanding of how to estimate energy requirements. Moving forward, there is now an understanding of energy requirements based on BMR and the tools to articulate requirements at an individual, population and national level. Furthermore, food requirements are a symbolic metaphor of social needs. The

journey to establish food requirements carries the hope that it will open the eyes and hearts of many scientists to work towards alleviating hunger in over 1 billion people around the world.

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Conflict of interest

There are no conflicts of interest.

References

- Atwater WO & Benedict FG (1902) Experiments on the metabolism of matter and energy in the human body, 1898–1900. *US Office of Experiment Stations Bulletin* No. 109, Government Printing Office, Washington, DC.
- Bedale EM (1923) Energy expenditure and food requirements of children at school. *Proceedings of the Royal Society of London* **94**: 368–404.
- Benedict FG (1935) Degree of constancy in human basal metabolism. *American Journal of Physiology* **110**: 521–30.
- Benelam B (2009) Satiety, satiety and their eating effects on behaviour. *Nutrition Bulletin* **34**: 126–73.
- Cordain L, Miller JB, Eaton SB *et al.* (2000) Plant-animal subsistence ratios and macronutrient energy estimations in worldwide hunter-gatherer diets. *American Journal of Clinical Nutrition* **71**: 682–92.
- DH (Department of Health) (1991) *Dietary Reference Values for Food Energy and Nutrients for the United Kingdom*. Report on Health and Social Subjects No. 41. HMSO, London.
- Durnin JVGA, Edholm OG, Miller DS *et al.* (1973) How much food does man require. *Nature* **242**: 418–418.
- FAO (Food and Agriculture Organization) (1947) *Energy yielding components of foods and the computation of caloric values*. Washington, DC, FAO Committee on Calorie Conversion Factors and Food Composition Tables.
- FAO (Food and Agriculture Organization) (2011) *More people than ever are victims of hunger (press release)*. Available at: http://www.fao.org/fileadmin/user_upload/newsroom/docs/Press%20release%20june-en.pdf (accessed 7 November 2011).
- FAO/WHO/UNU (Food and Agriculture Organization of the United Nations/World Health Organization/United Nations University) (1985) *Energy and protein requirements*. WHO Technical Report Series No 724. World Health Organization, Geneva.
- Faridi H & Faubion JM (1995) *Wheat End Use around the World*. American Association of Cereal Chemists: St Paul, MN.
- Grivetti L (1979) Kalahari agro-pastoral hunter-gatherers. *Ecology of Food and Nutrition* **7**: 235–56.
- Henry CJ (1997) New food processing technologies: from foraging to farming to food technology. *Proceedings of the Nutrition Society* **56**: 855–63.
- Henry CJ (2005) Basal metabolic rate studies in humans: measurement and development of new equations. *Public Health Nutrition* **8**: 1133–52.
- Holliday MA, Potter D, Jarrah A *et al.* (1967) The relation of metabolic rate to body weight and organ size. *Pediatric Research* **1**: 185–95.
- Klieber M (1961) *The Fire of Life: An Introduction to Animal Energetics*. Wiley & Sons Inc: New York.
- Milton K (2000) Hunter-gatherer diets – a different perspective. *American Journal of Clinical Nutrition* **71**: 665–7.
- O'Connell JF, Latz PK & Barnett P (1983) Traditional and modern plant use among the Alyawara of central Australia. *Economic Botany* January–March 1983, **37**: 80–109.
- SACN (Scientific Advisory Committee on Nutrition) (2011) *Dietary Reference Values for Energy*. The Stationery Office: London.
- Schofield WN, Schofield ED & James WPT (1985) Predicting basal metabolic rate, new standards and review of previous work. *Human Nutrition: Clinical Nutrition* **39C** (Suppl. I): 5–41.
- UNFPA (United Nations Population Fund) (2011) *State of World Population 2011 report*. Available at: <http://foweb.unfpa.org/SWP2011/reports/EN-SWOP2011-FINAL.pdf> (accessed 8 November 2011).
- Webb P (1991) The measurement of energy expenditure. *Journal of Nutrition* **121**: 1897–901.
- Westerterp K, Donkers J, Fredrix E *et al.* (1995) Energy intake, physical activity and body weight: a stimulation model. *British Journal of Nutrition* **73**: 337–47.
- WHO (World Health Organization) (2012) *Obesity and Overweight, Factsheet No. 311, May 2012*. Available at: <http://www.who.int/mediacentre/factsheets/fs311/en/index.html> (accessed 21 June 2012).
- Widdowson EM (1955) *Assessment of the Energy Value of Human Foods*. Cambridge University Press: London.