Possible Problems in Energy Calculations

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Abstract

The application of food-specific Atwater factors to the calculation of energy in complex foods requires knowledge of the types and quantities of ingredients present. The well-known general calorie factors 4, 9, 4 for protein, fat, and carbohydrate, developed for application to the typical American diet at the turn of the century, are often applied erroneously to specific foods. Problems arising from their proposed use for food labeling are examined and discussed. Increased demands for reporting carbohydrate by direct analysis rather than by difference will require changes in the method for calculating the energy value of foods. The lack of specific nitrogen-to-protein conversion factors for a large number of foods is another potential problem which is examined. The effect of non-protein nitrogen, organic acids, and alcohol on energy calculations is also discussed. The increased use of artificial sweeteners, fat replacers, and substitutes creates additional problems in energy calculations.

Introduction

This paper examines potential problems in the application of the Atwater system, or modifications thereof, to the calculation of the metabolizable energy of foods. The Atwater system used for the energy assessment was reviewed by Merrill and Watt (1) and by the Life Sciences Research Office of the American Societies for Experimental Biology (Allison and Senti, 2). Allison and Senti (2) and Miles (3) reviewed procedures for calculating the metabolizable energy of foods based on their heats of combustion adjusted for digestibility and corrected for the incomplete metabolism of protein nitrogen.

Proximate Composition

Atwater based his system for the calculation of the available energy on the proximate composition of foods. The moisture, protein, fat, and ash are experimentally determined, and the sum of their values subtracted from 100 represents carbohydrate by difference. The potential for errors begins with the proximate composition and how it is determined.

In Atwater's time fat was determined by extraction with ether, which would not have completely extracted the structural phospholipids and glycolipids. Of concern are lean beef, poultry, and fish. In these, structural lipids range from 1 to 2 grams per 100 grams of tissue. The structural lipids are known to remain relatively constant over a wide range of total lipids. Their presence should not be ignored when they represent more than 30 percent of total lipids. At the turn of the century the structural lipids wound up in the carbohydrate by difference, or in the case of animal tissues, in the protein fraction which was then determined by difference. Because the heat of combustion of the polar lipids is lower than that of triglycerides but higher than that of the carbohydrates or protein, one may expect the energy values that are calculated with food-specific factors to have a positive bias. An examination of the current food-specific factors may reveal that they may need minor adjustments to accommodate the small change in the values of the proximate components caused by modern methods for determining the total lipids.

The more complete accounting for the structural lipids in the proximate components may be a negligible source of error in comparison to the larger variability that exists among the proximate components in fruits, vegetables, meats, and other low-calory foods.

Several sets of energy factors now in use are shown in table 2. Rubner (4) developed his factors from studies with dogs. He made no allowance for digestibility but did correct for incompletely metabolized protein in urine. Atwater's general factors 4, 9, 4 are applicable to typical American diets overall, but may cause considerable errors when applied to individual foods or mixed diets, the composition of which are significantly different from the typical American diets. The British use Rubner's factors for protein and fat and a factor for carbohydrate which equals the heat of combustion of glucose. They also use experimentally determined "available" carbohydrate rather than carbohydrate by difference. The Japanese factors were developed for a low-fat diet with allowance for relatively high amounts of structural lipids in low-fat foods. The food-specific Atwater factor now in use for animal tissues is 9.02. Perhaps a lower factor is needed for lean meats, poultry, lean fish, and shellfish.

The General Factors

The applicability of Atwater's general factors to the modern American diet has been questioned. Food consumption surveys did not begin until the middle of the century. Therefore data on the gross composition of the U.S. food supply (5) are used to detect changes which may be indicative of changes of the American diet. Differences in the U.S. food supply at the turn of the century and in 1988 are examined in figures 1 and 2. Figure 1 shows that the total available food energy is almost the same now as in 1909. Figure 2 shows that in 1909 the available protein was the same as in 1988. The available fat increased by about 35 percent but the available carbohydrate is now about 15 percent lower than in 1909. Given the current recommendations to reduce dietary fat and to increase consumption of complex carbohydrates, the American diet may revert back to that at the turn of the century. The gross composition of the American diet appears to remain similar to that of a century ago and leads us to believe that the general factors are as applicable now as they were then.

The inappropriate use of the general factors to determine the energy of individual foods is illustrated in Table 3. The first column contains the energy values calculated by using food-specific factors. Column two contains the values obtained using the general factors 4, 9, 4, and the last two columns show the difference expressed in calories and as a percentage. The discrepancy for butter is probably due to the relatively low specific factor for butterfat. Large discrepancies are noted in the fiber-containing foods such as whole-wheat flour, snap beans, apples, and lemons. Apples and lemons also contain malic and citric acids, which, because of their low energy content, aggravate the discrepancy.

The heats of combustion of organic acids and alcohol are shown in table 4. If the content of organic acids is known, corrections should be made for their presence to avoid a positive error.

Nonprotein Nitrogen

A problem that concerned Atwater when he derived his energy factors was nonprotein-nitrogen-containing compounds, some of which are shown in table 5. Because these compounds produce less energy than protein, their presence could be a problem in lean tissues of meats, poultry and fish. Methods for their determination were lacking at the turn of the century, but should be available now. The quantitative determination of nonprotein-nitrogen-containing compounds should be carried out for foods in which their presence is suspected. Quantitative data on these compounds are essential for the assessment of any problems their presence may cause in the calculation of energy for proteins.

Nitrogen-to-Protein Conversion Factors

Another problem with the calculation of available energy from protein is the selection and the availability of appropriate nitrogen-to-protein conversion factors, also called Jones' factors (6). I have chosen white bread, commercially prepared, NDB No. 18069 from Agriculture Handbook No. 8-18 (7), to illustrate the effect of using different Jones' factors. The data in table 6 were obtained by converting nitrogen to protein by a factor of 5.70 in column A and by a factor of 6.25 in column

B. The fat value remains unaffected, but the difference in the protein value is reflected in the carbohydrate by difference value.

Table 7 contains the specific energy factors which were applied to the proximate data shown in columns A and B of the previous table. The differences between the values obtained by the two Jones' factors is shown in grams and as a percentage. It is evident that choosing an inappropriate nitrogen-to-protein conversion factor will affect the energy values of protein and carbohydrate, but because the values differ in the opposite direction any error will be canceled in the total energy. Atwater used the term "compensating error." It may be concluded that using an inappropriate Jones' factor will have a negligible effect on the total energy value provided carbohydrate by difference are used. However, the use of inappropriate Jones' factors may create considerable errors when carbohydrate by analysis are used. In this latter case compensating errors would no longer exist.

Dietary Fiber

The addition of dietary fiber to foods to raise the fiber content and lower the calorie content is a recent development that presents a novel problem in the calculation of total energy of such foods. The commercially prepared white bread will serve as an example to show the effect of using three different procedures to calculate the total energy. The values shown in column A (table 8) were obtained by using the food specific factors 3.9, 8.7, and 4.1. These factors were developed specifically for foods with relatively high natural fiber contents. The values in column B were obtained using the general factors 4, 9, and 4. In column C the general factors were applied after the value for total dietary fiber (2.3 grams) was subtracted from carbohydrate by difference (as would be required by the proposed procedure for food labeling). The value for total energy in column C is 12.3 kilocalories or 4.6 percent lower than that in column A.

Reduced-calorie white bread (NDB No. 18057) was chosen to illustrate the difference in the calculated energy using food-specific factors and that obtained by the proposed labeling procedure (table 9). This bread is fiber fortified with alpha cellulose to a dietary fiber content = 9.3 percent. The food-specific factor for carbohydrate of 3.4 was derived as described by Stewart (8) by considering alpha cellulose as an added ingredient in the recipe for this bread and assigning a caloric content of zero to it. The procedure suggested for labeling was followed for obtaining the values in column B (subtracting dietary fiber from carbohydrate before applying the general factors 4, 9, 4). The procedure for labeling gives an energy value that is 9.9 kilocalories, or 4.8 percent, lower than the value calculated with the food specific factors. The differences in the calculated values for these two examples are apparently due to the difference in the treatment of the native dietary fiber by the Atwater and the labeling calculation procedures. Atwater made allowances for partial digestibility of fiber, while the labeling procedure considers dietary fiber indigestible.

Fat Substitutes and Replacers

The quest for low-calorie versions of "regular" foods has led to the appearance in foods of many substances of low caloric content that were designed to take the place of fats. Some are gums such as carrageenan and guar gum and others are new formulations that may be divided into two categories: Those that are fat based and those that are protein or carbohydrate based. There is evidence that the presence of these compounds may affect the absorption of other components of foods which contain them. Simply applying their fuel value as if they were just another ingredient may not be sufficient to estimate the available energy content of mixtures.

The description and claimed fuel values for a few fat substitutes are given in Table 10. Caprenin® and Olestra® are fat based and have the properties of fat except that Olestra® is indigestible in the human digestive tract and Caprenin® is claimed to be only partially digestible. Simplesse® and Lita® are protein based and Polydextrose is a polymer of dextrose which would be less digestible than dextrose.

This author feels that the claimed fuel values should be confirmed by acceptable standardized procedures. The effects of the addition of these new foods to more conventional foods and their possible effects on the metabolizable energy of other components of mixtures that contain them need to be investigated.

Summary

Potential problems in the application of the Atwater system for calculating the available energy content of foods were examined. The proximate composition has changed somewhat in that structural lipids are now included in total lipids and not in the protein or carbohydrate fractions as they were when the food specific factors were developed. The factors in use today need to be corrected for this difference in order to avoid a positive bias in the calculated energy values.

A comparison of the gross nutrients in the U.S. food supply in 1909 and 1988 showed that available calories and protein were the same. Fat was somewhat higher and total carbohydrate somewhat lower in 1988. These differences in the American diet do not appear to invalidate the general factors 4, 9, 4 if they are properly applied. When they are misapplied to fiber containing foods such as cereal products, legumes, fruits, and vegetables, large deviations from the values obtained with food specific factors will occur.

The presence of organic acids may lead to small positive errors if their presence is ignored. The presence of compounds containing nonprotein nitrogen may be a problem in some animal tissues. The kind and amount of nonprotein-nitrogen-containing compounds should be analytically determined for proper adjustments to be made and to avoid possible overestimation of available energy. The inappropriate use of Jones' factors will affect the protein values and carbohydrate by difference values and the calculated energy values for these proximate components; however, the errors cancel each other so that the total estimated energy content is unaffected. A change to carbohydrate by analysis will not contain the compensating feature and may lead to considerable error due to the use of inappropriate Jones' factors.

Discrepancies were found in the energy values calculated by the food specific-factors and the values obtained by a proposed procedure for food labeling. The latter tended to underestimate the energy content of fiber-containing foods by about 5%. It is recommended that the fuel value claimed by manufacturers be used for fat substitutes and fat replacers, but that the claimed values be confirmed by tested analytical procedures. Like fiber, some of these compounds are either sparingly digestible or totally indigestible, and like fiber they may have an effect on the metabolizable energy of other food components in mixtures and diets. The possibility and extent of such effects need to be investigated.

References

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Possible Problems in Energy Calculations

Table 1.

Proximate Composition

Water		
Protein		
Total lipid (fat)	------>	= 100%
Carbohydrate, total		
Ash		
Fiber		

Table 2.

Energy Conversion Factors Now in Use

Nutrient Japanese	Rubner's factors	Atwater's general factors	British factors	general factors
Protein	4.1	4	4.1	4.1
Fat	9.3	9	9.3	8.5
Carbohydrate	4.1[1]	4[1]	3.75[2]	4.1[1]

1 Carbohydrate by difference.
2 Available carbohydrate.

Table 3.

General Factors and Specific Factors Comparison of Calculated Energy Values (Cal/100g Food)

Food	Specific factors	General factors 4, 9, 4	Difference	
			Cal.	%
Beef	273	268	-5	2
Eggs	162	158	-4	2
Butter	726	733	17	2
Whole-wheat flour	333	355	22	7
Snap beans	35	42	7	20
Apples	58	64	6	10
Lemons	32	44	12	38

Adapted from ref. 1.

Table 4.

Heat of Combustion of Organic Acids and Alcohol

	Calories per gram
Acid:	
Acetic	3.5
Citric	2.5
Lactic	3.6
Malic	2.4
Alcohol	7.07

Adapted from ref. 1.

Table 5.

Nonprotein-Nitrogen-Containing Compounds

Creatine

Creatinine

Ammonia

Aliphatic and aromatic amines

Nucleic acids

Nucleotides

Table 6.

Proximate Composition of
Bread, White, Commercially Prepared

	(A)	(B)
	g	g
Water	36.7	36.7
Protein	8.2	9.0
Total lipid (fat)	3.6	3.6
Carbohydrate, total	49.5	48.8
Ash	1.9	1.9
Dietary fiber, total	2.3	2.3

Jones' Factor = 5.70 (A) and 6.25 (B)

Table 7.

Energy Content of
Bread, White, Commercially Prepared

Nutrient	Atwater spec. fact.	(A)	(B)	Difference	
		Calories		g	% of total
Protein	3.9	31.98	35.10	+3.12	+1.17
Fat	8.7	31.32	31.32	0	0
Carbohydrate	4.1	202.95	200.08	-2.90	-1.09
Total		266.3	266.5	+0.2	+0.08

Jones' Factor = 5.70 (A) and 6.25 (B)

Table 8.

Energy Content of Bread, White, Commercially Prepared
Calculated Three Ways)

	(A)	(B)	(C)
	food-specific factors	general factors	food labeling
		Calories	
Protein	32.0	32.8	32.8
Fat	31.3	32.4	32.4
Carbohydrate	203.0	198.0	188.8
Total	266.3	263.2	254.0

Total dietary fiber (TDF) = 2.3 g

Table 9.

Energy Content of Bread, White, Reduced-Calorie Calculated Two Ways)

		(A)	(B)	Difference	
	Proximate composition	food-specific factors	food labeling		
	g	Calories	Calories	g	%
Protein	8.7	34.8	34.8	0	0
Total lipid	2.5	21.8	22.5	0.7	3.2
Carbohydrate	44.3	150.6	140.0	10.6	7.0
Total		207.2	197.3	9.9	3.8

TDF = 9.3%
(A) Food-specific factors = 4.0, 8.7, and 3.4.
(B) Factors used = 4, 9, and 4 x (carbohydrate - TDF)

Table 10.

Fat substitutes and replacements

Description	Fuel Value Cal/g
CAPRENIN®- low-calorie fat; fat based (caproic, caprylic, and behenic acids)	5.0
LITA®- fat substitute; protein based (Zein)	1.5
OLESTRA®- fat substitute; fat based (sucrose polyester)	0.0
POLYDEXTROSE®- replacement for sucrose and fat	1.0
SIMPLESSE®- fat substitute; protein based (egg white and casein)	1.3

Food Energy per Capita per Day in the US Food Supply - 1909 and 1988

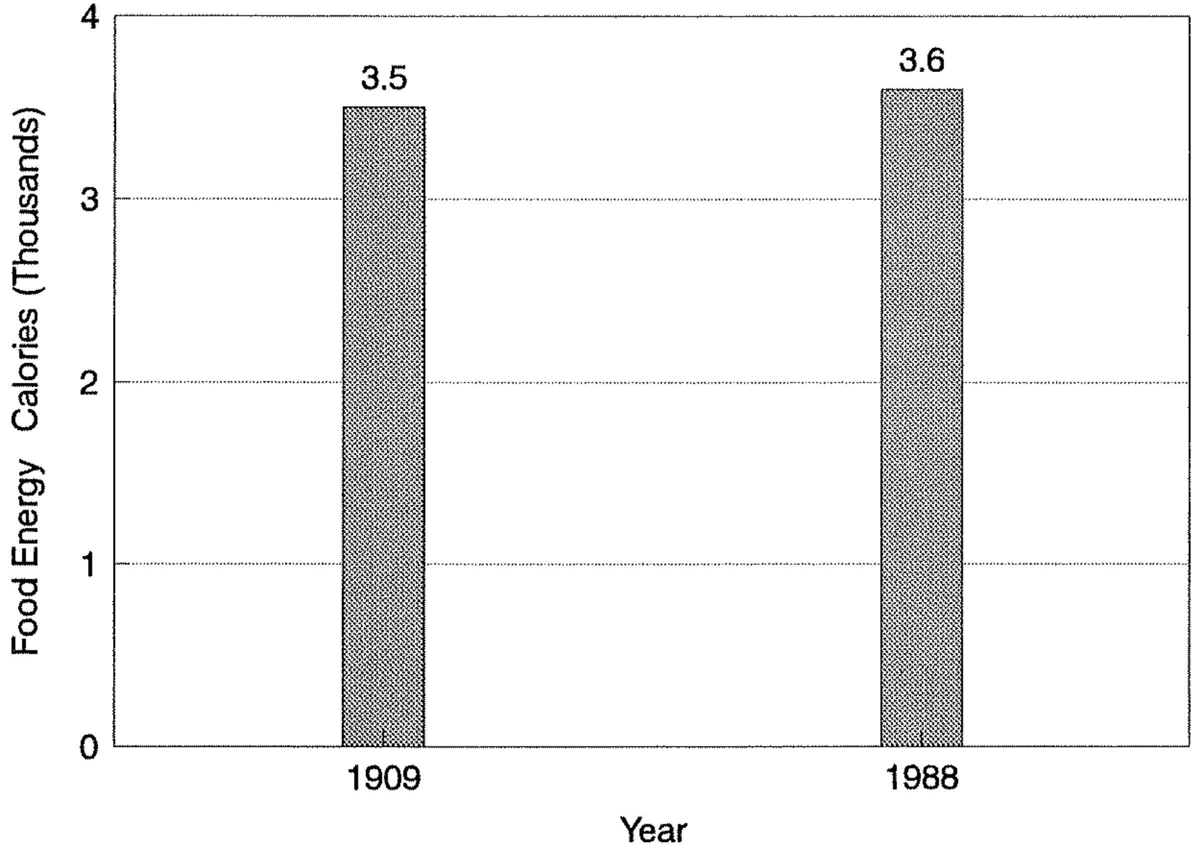

Figure 1

Macronutrients per Capita per Day in the US Food Supply - 1909 and 1988

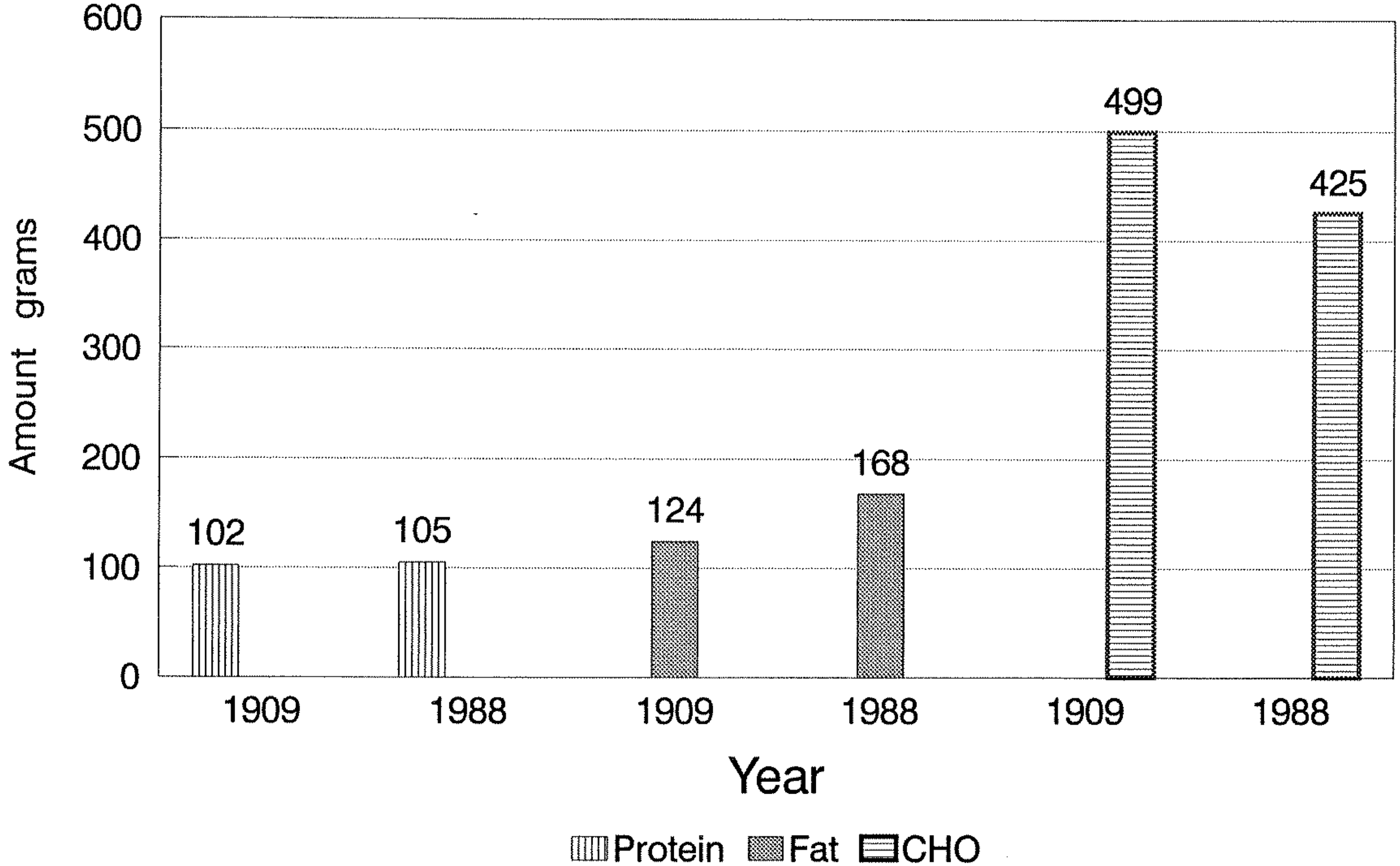

Figure 2