Atwater: a personal tribute from the United Kingdom

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When Dr Nelson telephoned me and invited me to give the 1986 Atwater lecture, he told me, by way of persuading me, that I could talk about anything I liked. I replied that if I was giving a lecture in honor of Atwater, Atwater should be the cornerstone of it, and that is how it is going to be. More than 30 years ago I wrote “I think I can safely say that Atwater contributed more to our knowledge about the energy value of human foods than anyone who has ever lived, either before or since his time” (1). That is still true and it is also true that he made a great contribution to our knowledge about other aspects of nutrition as well. That is why I am delighted to pay my personal tribute to Atwater from the United Kingdom.

The story of Atwater’s achievements begins in Germany. By the middle of the 19th century, Germany was in the forefront of studies on the metabolism of energy in man and animals and on the energy value of foods. After Atwater obtained his PhD degree in 1869 at the Sheffield Scientific School at Yale, where he worked under Samuel Johnson, he travelled to Germany and spent 2 years in Berlin and Leipzig. Atwater was following the example of his teacher, for Samuel Johnson had previously spent 2 years in Germany, from 1853 to 1855, studying under Erdmann in Leipzig and Liebig in Munich. Travelling to Europe must have been quite an undertaking in those days and time consuming too. Nevertheless, Atwater made several journeys to Germany and on later visits he spent some time in Munich with Voit and Rubner, and this experience shaped the whole of his scientific career. Rubner had done much work on the composition of foods (2, 3). He analyzed foods for water, nitrogen, and fat, calculated protein from the nitrogen, and assumed that the remainder was carbohydrate. He also constructed a bomb calorimeter in which he had measured the heats of combustion of various proteins, fats, and carbohydrates and of the organic material in urine and feces; from these values he calculated the calorific value of foods for man. Voit (4) measured the amounts of food that laborers and other people ate and he used Rubner’s figures to calculate their intakes of protein, fat, carbohydrate, and calories.

By 1873 Atwater had returned to America and was appointed Professor of Chemistry at Wesleyan University. When the Storrs Agricultural Experiment Station was set up in 1887, Atwater became its first director and he remained there for 14 years. It was there that he did his most important work and we can see throughout how his experiences in Germany influenced what he did. We must never forget the debt that Atwater owed to Rubner.

Several aspects of Atwater’s work at Storrs have been of particular interest to me. One was his study of the composition of American food materials. Atwater saw the need for information on the composition of American foods, as he wrote (5) “Until about the year 1880, those who wished to know about the chemical composition and nutritive values of food materials were compelled to depend upon analyses of European products, and most of those analyses had been made in German laboratories.” In 1896 Atwater and Wood (6) published the results of about 2600 analyses of American foods. The Bulletin was revised and extended and a second edition by Atwater and Bryant was published in 1899 (5). A third corrected version appeared in 1906 (7). This version, like the previous ones, was a compilation of analyses made in Atwater’s department and of analytical results from other laboratories. He tells us in the introduction that over 80% of the figures for meat and some 15% of those for other foods came from analyses made by himself and his associates. Atwater died in 1907 at the age of 63, a year after the third revision of his food tables appeared, and for many years his tables were widely used.

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I have told the story before about how RA McCance and I first met at Kings College Hospital in 1933 (12). I was learning to cook in the kitchen in the basement of Kings College Hospital, as a preliminary to taking the first course held in London University leading to an Academic Postgraduate Diploma in Dietetics, while this work on the composition of meat and fish was going on several floors above. The cooking of the meat and fish was done in the kitchen and that is how Dr McCance and I first met. When he told me about his previous study on the available carbohydrate in fruit and vegetables I said that his results for fruit would all have been too low, for he had boiled the material with acid to hydrolyze the starch and sucrose and by doing so he had destroyed some of the fructose. I knew about this because I had just completed my PhD thesis on the carbohydrates in developing apples. He invited me to join him and we reanalyzed fruit and vegetables for the separate available carbohydrates and for other organic and inorganic constituents as well (13). I completed the dietetics course in my spare moments and as part of it I spent 6 weeks in the diet kitchen at St Bartholomew’s Hospital, where much of my time was spent calculating diets for patients with Atwater’s tables as the basis of the calculations. The kinds of food eaten in our two countries differ considerably and, just as Atwater had seen the need for tables of the composition of American food materials in the 1890’s, 40 years later I realized how much we needed comprehensive tables of the composition of British foods. I realized too that with a little more analytical work we should have all the material for making them. The result was the first edition of The Chemical Composition of Foods published in 1940 (14).

There was one person we were afraid would be critical of our tables and that was Miss Charlotte Chatfield. She worked in the USDA in Washington and so far as food composition was concerned Atwater’s mantle had fallen on her, though she made no analyses herself and was a compiler rather than an analyst. Atwater’s tables were still the most important source of information about the composition of American foods. I visited Miss Chatfield and Dr Georgian Adams in Washington in 1936, when we were in the midst of our food analysis,
and they were preparing their *Proximate Composition of American Food Materials* (15). We had a great discussion about the relative merits of food tables being compiled by people working in an office, which Miss Chatfield supported, or by those who had actually analyzed the foods, which was what Atwater had to a large extent done and which we had ourselves followed and naturally I thought to be the best. I, being very much Miss Chatfield's junior, got the worst of the battle, so it was with considerable fear and trepidation that we sent her a copy of *The Chemical Composition of Foods* (14). However in her reply she said, "I am especially impressed with the fact that there is nothing wrong with it so far as I can tell." So all seemed to be well. But there was something wrong with it that she did not spot and that brings us back to Atwater and to Rubner once again. As we all know, the number of calories the body can derive from a food is less than the number of calories produced when the food is burned in a bomb calorimeter because the calorie-producing nutrients, proteins, fats, and carbohydrates, are not completely digested and even that part that is digested is not necessarily completely absorbed by the digestive tract. Finally, the part of the protein that is digested and absorbed is not completely oxidized to yield energy to the body but is excreted in the urine as urea, creatinine, and other organic nitrogenous end products.

The number of calories a given weight of food will provide to the body is usually calculated from the amounts of protein, fat, and carbohydrate in it. These are multiplied by factors representing the energy produced when 1 g of protein, fat, and carbohydrate are oxidized in a bomb calorimeter with corrections to allow for losses in the urine and sometimes also in the feces.

The subject is rather complicated but I will make it as brief as I can. As I said earlier, Rubner measured the heats of combustion of a number of different proteins, fats, and carbohydrates in a bomb calorimeter and he also measured the heat of combustion of the urine passed by a dog, a man, a boy, and a baby (2, 3). He found that the man's urine produced 7.8 kcal/g nitrogen, which is equivalent to 1.25 kcal/g protein, and Rubner's caloric factor for mixed animal and plant protein, 4.1 kcal/g, makes an allowance for this. Rubner intended also to make an allowance for losses of nitrogen in the feces but he used too high a factor for converting nitrogen to protein and this cancelled out his allowance for fecal losses. His factor for fat, 9.3 kcal/g, is the mean heat of combustion of animal fat, butter fat, and olive oil and the factor for carbohydrate, 4.1 kcal/g, is the mean bomb calorimeter value for starch and sucrose.

Atwater, following Rubner, and with his colleague Bryant, determined the heats of combustion of various proteins, fats, and carbohydrates in a bomb calorimeter (15). They also analyzed urine from 46 men and measured its heat of combustion. They found that for every gram of nitrogen in the urine there was unoxidized material sufficient to yield an average of 7.9 kcal—not very different from Rubner's single figure of 7.8 kcal. Atwater (16) also concerned himself with losses of caloric material in the feces. He made a total of 50 experiments, each lasting for 3–8 d on three men aged 32, 29, and 22 yr. The subjects ate what were described as *mixed diets*, which varied in the amount of fat and carbohydrate they contained, but none of them contained much dietary fiber. The foods were analyzed for nitrogen and fat and the feces were analyzed also. Carbohydrate in the food was estimated by difference. Individual foods vary in the digestibility and availability of their nutrients, and the most important factor in this is the amount of dietary fiber. The more dietary fiber the quicker the passage through the digestive tract, the greater the bulk of feces, and hence the greater the losses of caloric material in them.

Atwater and Bryant (15) collected what they could find in the literature, including the results of their own work (16) on the availability to man of the nutrients in single foods. From these they prepared tentative coefficients of availability for the protein, fat, and carbohydrate in common classes of food and they applied these coefficients to the food in the mixed diets that their own subjects had eaten. They then compared the calculated availability of the protein, fat, and carbohydrate in the mixed diets with the availability in the mixed diets as determined by experiment, and they found that the results agreed very well.

For calculating the *available* energy from mixed diets, Atwater and Bryant (15) suggested...
the use of the average factors 4.0, 8.9, and 4.0 for protein, fat, and carbohydrate, respectively. The figure 8.9 was later rounded off to 9. These factors, which Atwater had intended should be used only for mixed diets, later came to be used by others for calculating the energy values of individual foods in spite of the fact that Atwater and Bryant in their *Chemical Composition of American Food Materials* (5) had used the Rubner factors. I think Sherman was responsible for starting this misinterpretation of Atwater's teaching, and it was perpetuated by Chatfield and Adams in their *Proximate Composition of American Food Materials*, published in 1940 (17).

When we were preparing the first edition of our *Chemical Composition of Foods* (14), which was also published in 1940, we had to decide what factors we should use for calculating the energy value of different foods. We decided we could not do better than follow the master and we also used the Rubner factors. However, we made a serious mistake, the mistake Miss Chatfield failed to spot. We had abandoned the method of calculating carbohydrate by difference. We determined the separate sugars, dextrin, and starch directly and expressed the sum of these in terms of glucose, but Rubner's factor, 4.1 kcal/g carbohydrate, was the calorific value of 1 g of a mixture of equal parts of sucrose and starch. One gram of glucose produces only 3.75 kcal. We had, therefore, overestimated the calories in all the foods containing carbohydrate. This mistake would never have been made by Atwater. We corrected it in the second edition of our tables (18).

We considered the whole question of calorie conversion factors once again when we were preparing the third edition of our tables, published in 1960 (19). In 1959, when we were trying to decide what to do, I came to the United States for the first time since 1936. I made my way to USDA in Washington to see Bernice Watt and Annabel Merrill, who had the responsibility of compiling the then current American tables, still, I may say, based largely on the work of Atwater, and generally known as *Handbook no 8* (20). I travelled to Washington by train and Bernice and Annabel came to meet me, holding up a copy of our *Chemical Composition of Foods* by way of identification. They had written an article recommending the use of different factors for calculating the energy value of different foods (21), as proposed by Atwater but not used by him. In the end we decided that this was unnecessarily complicated and we decided to stay with the Rubner factors as Atwater had done. Bernice, Annabel, and I became great friends and I visited them a number of times in Washington and later in Beltsville. They, like Miss Chatfield, were compilers of food tables rather than food analysts and Atwater's figures were still their mainstay. I was surprised, however, that they seemed to have no facilities whatever for getting a food analyzed. I last stayed with Bernice in her home in McLean, VA in December 1982. She became ill soon after and, sadly, she died in March 1984. This brought to an end a friendship with a very dear American colleague, and to my personal links with American food tables and *Handbook no 8*.

We had often wondered how far Atwater's factors would apply to mixed diets containing more unavailable carbohydrate or dietary fiber than his experimental diets had contained. We also wondered whether they were appropriate for women as well as men and whether they could be applied to the elderly as well as the young. Accordingly, in 1970 David Southgate, working with us in Cambridge, and John Durnin, in Glasgow, set up an experiment to test this (22). As subjects they had 12 young men and 14 young women in their twenties and 11 elderly men and 12 elderly women all over 70 years of age. Each group was studied on two diets, one low in dietary fiber the other containing considerably more. Each balance study lasted for 7 days, and losses of nitrogen and energy in feces and urine as well as dietary intake were measured. Their main conclusions were, first, that neither age nor sex of adults made any significant difference to the ability to digest and absorb the nutrients in the diet and, second, that an increase in the intake of dietary fiber increased the losses of energy in the feces but that the necessity for making any correction of the Atwater factors to allow for this was far outweighed by the errors inherent in measuring the total intakes of protein, fat, and carbohydrate in dietary surveys. As the authors say: "The accuracy of any method for calculating the metabolizable energy of a diet is largely determined by the accuracy with which the method is capable of predicting the
gross energy of the diet.” In other words, it doesn’t much matter whether you use Atwater’s or Rubner’s factors for calculating the energy from protein, fat, and carbohydrate. The differences are small compared with the far bigger error in assessing the intakes of protein, fat, and carbohydrate in the first place.

There was one occasion when the use of different factors on the two sides of the Atlantic did matter, and that was when food supplies in Britain became short during the Second World War and wheat was sent from the United States to help us out. Calculations were made of the calories from the wheat exported from the United States using the Atwater factors and of the calories imported into the United Kingdom by the Rubner factors. It was discovered that the results did not agree and there was great consternation all round. Fortunately the difference was in the right direction, for the calorie value of each consignment increased by about 3% in its passage across the Atlantic and all was well.

Now a word about infants. Young infants retain about 50% of the nitrogen in breast milk for growth, and their urine contains oxidizable nitrogenous material equivalent to only half of the nitrogen in the milk (23). Rubner’s and Atwater’s correction factors for losses in the urine are intended for adults who are in nitrogen balance. What correction to the gross energy intake from protein in breast milk should be made for babies and is their absorption from the intestine similar to that of adults? This was also put to the test by Dr Southgate with Miss Barrett and they made an investigation on infants 2-weeks old, some breast-fed, some fed on cows’ milk formula with a higher concentration of protein (24). The babies absorbed fat less well than adults, particularly the fat of cows’ milk, so they derived a smaller percentage of energy from it than adults do. On the other hand they excreted a smaller proportion of their energy intake from protein as nitrogenous substances in the urine, so they derived more energy from protein than adults. Thus, although the factor for available calories for fat should be < 9 and for protein > 4, the end result is not very different than if the Atwater factors had been used and Atwater is vindicated once again.

There are two other aspects of Atwater’s work that I should like to mention briefly, for they both were of great interest to me. In 1886 Atwater had become involved in studies of family food consumption. He used the inventory method and over 15 years made 350 studies in which the food entering into the family diet was measured. He had available his own figures for the amounts of protein, fat, and carbohydrate in foods just as Voit had had Rubner’s figures some years earlier. Atwater was thus able to calculate the family’s intake of nutrients. The results aroused general interest in nutrition problems in USA and encouraged the government to increase support for investigations on food and nutrition (25).

Fifty years later I was in the same fortunate position of having our own figures for the composition of foods, some of which had not yet been published. Up to the 1930’s almost all dietary surveys had been made on families as Atwater had done. I realized that we needed information about the intakes of the individuals within the families, and I started my individual dietary surveys (26, 27). The first was on 63 men and 63 women, all of whom weighed all the food they ate for a week. This was when I discovered the astonishing variations in the intakes of energy and of nutrients between one individual and another. I followed this up with a study of the individual weighed dietary intakes, over a period of 1 week, of more than 1000 children between 1 and 18 years, and again I found that in any group of 20 or more children of the same age and sex there was always one taking, and presumably needing, twice as much energy as another (28). I would love to have discussed all this with Atwater.

A very important part of Atwater’s work was his studies with Benedict on the energy exchanges for men (29). They used a large calorimeter built by Rosa in which a man could live for several days (30). Their conclusion that the law of conservation of energy applies to the human body was of fundamental importance and followed Rubner’s equally fundamental observation that it applied to dogs. Among the many studies they made was one on students whom they persuaded to take their examinations sitting inside the calorimeter. They found that very little energy was required for mental activity. I have no experience of direct calorimetry, but we did make some studies in the 1950’s on the energy intakes and
oxygen consumption of military cadets (31). Dr Edholm came to us one day and told us that the General who had recently inspected the cadets, aged 18.5–20 years, was convinced that they were not gaining weight as they should, and this was because they were not getting enough good red meat. We made two investigations at Sandhurst, where the cadets were receiving their military training. We found they were getting far more red meat than the rest of the population. We had also been led to believe that they lived lives of ceaseless strenuous activity. In fact we found that they spent 8.5 hours out of the 24 in bed and 9.5 hours sitting, some of it at lectures, and these two activities accounted for 50% of their total energy expenditure. Dressing, cleaning uniforms, and getting about the grounds accounted for another 28% and drill, sport, and parades, which were regarded as so important in their training, took up only 7% of their time and 12% of their energy. From Atwater’s studies and our own it seems as though students, military or otherwise, do not spend much of their energy either on mental effort or strenuous physical activity. They expend most of their energy like the rest of us do, just going about our daily activities.

Atwater paid one more visit to Europe, in 1903, to discuss the possibility of setting up international nutrition experiments. Universities were interested in his proposals but, sadly, Atwater became ill in 1904 and was not able to follow this through. Nowadays, with easy and quick travel, there is international collaboration, discussion, and passing on of information such as Atwater would have delighted in were he alive today. He had the vision and we are enjoying its realization.

I am pleased and honored to have been able to tell you a little of Atwater’s great contribution to nutritional science and how he has influenced my scientific life in the United Kingdom over many years. I pay my personal tribute to him.

References