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**Determinants of energy density with conventional foods and artificial feeds**

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CONCEPTS OF ENERGY DENSITY AND ENERGY LOSS

The energy densities of conventional foods (Paul & Southgate, 1978) and artificial feeds (Livesey & Elia, 1985a) are usually calculated from their compositions, i.e. protein, fat and carbohydrate contents, and the energy conversion factors for these components. Most often the factors are metabolizable energy (ME) values; that is an amount of energy thought useful for doing physical or metabolic work. This quantity has been formally equated to the difference in the heat of combustion of food and excreta, faeces and urine, for subjects in nitrogen balance. In animal nutrition (Agricultural Research Council, 1980; Blaxter, 1989) excreta also includes the combustible gases hydrogen and methane, but in human nutrition these losses are usually small and ignored. Energy conversion factors for substrates which undergo fermentation in the human large intestine, the sugar alcohols (Dutch Nutrition Council, 1987) and certain complex carbohydrates (British Nutrition Foundation, 1990) required a different approach. In these cases net energy (NE) values for physical and metabolic work were derived. These values exclude: losses of combustible energy in gases, losses of energy to heat of fermentation (spent on the growth and maintenance of colonic micro-organisms) and losses of energy, relative to glucose or sucrose, on producing ATP during the oxidation of short-chain fatty acids (the products of carbohydrate fermentation absorbed from the colon).

To prevent confusion it is important to distinguish between values for NE, ME, heat of combustion or gross energy (GE) and digestible energy (DE), in human nutrition the last usually discounts losses to faeces only. This distinction is made here by including abbreviations with units. When the values (NE, ME, DE, GE) are thought to be similar more than one abbreviation may appear with the units. Here NE always refers to energy useful for physical and metabolic work and should not be confused with values used in animal production such as NE for growth, reproduction, lactation etc. (Blaxter, 1989). Further, in modern scientific works it is preferable to use kJ rather than kcal, an exception is made here because of the historical perspective on which the review is built.

Presently, there remains only one well-established energy loss not embodied in an officially recognized food energy assessment system; it is the loss due to urea synthesis

and gluconeogenesis following the catabolism of protein or amino acids. This loss is obligatory assuming optimal gluconeogenesis from protein (Krebs, 1964). Although the precise loss is uncertain (Livesey, 1984), use of an approximate estimate would involve less bias than use of no estimate at all, and a suggestion of how to discount this loss has been made (British Nutrition Foundation, 1990).

Another mechanism of energy loss is becoming evident, it is that due to small intestinal 'malabsorption' induced both by the sugar alcohols (van Weerden *et al.* 1984*a,b*; Livesey, 1990*a*) and by non-starch polysaccharides (NSP; Isaakson *et al.* 1983; British Nutrition Foundation, 1990; Reads, 1990). This malabsorption possibly results from an increased osmotic load and viscosity in the small intestine. With sugar alcohols the osmotic effects are greater when taken in a drink than in a meal due to more rapid stomach emptying (Livesey, 1990*a*). Malabsorption of starch, due to retrogradation after cooking and of starch protected by the cell-wall matrix in plant foods, is also suggested to give rise to energy losses and fermentation (Wisker *et al.* 1988; Livesey, 1990*b*; Livesey *et al.* 1990). Factors influencing the passage of combustible substances through the ileo-caecal junction and the salvage of this energy will clearly influence future thinking on the evaluation of energy from human foods, especially ingredients.

Energy in hair and skin can be lost from ME, but being small in amount and difficult to quantify is universally disregarded and may anyway be more related to the characteristic of the individual than to the quantity or composition of food ingested. A quantifiable energy loss related to consumption is alcohol in urine and breath, for which 2% is discounted (Merrill & Watt, 1973). Studies aiming to assess an NE value for alcohol have not been sufficiently convincing to further lower the energy conversion factor of 6.9 (or 7) kcal ME/g below its heat of combustion (7.07 kcal GE/g).

Losses of energy to urine have traditionally been associated formally with the oxidation of protein only (Merrill & Watt, 1955; Alison & Senti, 1983), but now certain sugar alcohols (van Es, 1991) should also be recognized to give these losses. Further, in parenteral nutrition some substrates (e.g. amino acids and sorbitol) may be lost to urine in greater amounts than when administered enterally (Livesey & Elia, 1985*a*).

#### PIONEERING WORK AND VARIABLE VALUES

The energy conversion factors finding use in the USA, Europe and other world regions (Pèrissè, 1983) originate from the pioneering work of Rubner (1901) in Germany and of Atwater (1910) in the USA. The Atwater factors, 4 kcal ME/g protein, 9 kcal DE,ME/g fat and 4 kcal DE,ME/g 'carbohydrate' have often been regarded as constants. These pioneers, especially Atwater, recognized and indeed determined, the values as weighted averages of variable values.

The variations in the heat of combustion of 101 food proteins and 116 fats, in the current edition of *McCance & Widdowson's The Composition of Foods* (Paul & Southgate, 1978) have been estimated from amino acid and fatty acid composition data (Livesey, 1984, 1988), a method which agrees well with directly determined values (Livesey, 1984; Livesey & Elia, 1985*a*). Using each different food amino acid composition as an observation, the distribution for protein is almost 'normal' with mean 5.6 kcal GE/g, coefficient of variation of about 3% and range 5.1–6.0 kcal GE/g (i.e. about  $\pm 10\%$  of the mean). These compare with the 5.65 kcal GE/g value on which is based the

Atwater factor of 4 kcal ME/g protein. Where foods are mixed in diets and the values averaged, this range of energy densities is small. For the purposes of compiling food tables it is not evident that specific energy conversion factors would be needed. However, with artificial enteral and parenteral feeds used in hospital practice, a different conclusion must be drawn (Livesey & Elia, 1985a).

Variation in the composition of artificial amino acid mixtures is not limited as in conventional foods by the physiological need of food organisms to collect a range of functional proteins. Because of a perceived need for a higher proportion of essential amino acids, artificial mixtures tend to have a higher heat of combustion (per g true protein) than conventional food protein. Values range from 5.1 to 6.8 kcal GE/g mixture as protein; examples between 6.6 and 6.8 kcal GE/g include Amin Aid, Dialamine, Nefranutrin and Nephramine (Livesey & Elia, 1985a). The need to adopt specific energy values for these mixtures arises both because of the unconventional compositions and because these materials may be the only 'protein' nutrition source received by patients so 'value averaging' cannot occur.

The distribution of the heats of combustion of triacylglycerols in the 116 conventional foods is skewed tailing towards lower values, with a median of about 9.4 and range between 8.8 and 9.5 kcal GE/g (Livesey, 1988). The smaller values arise from fatty acids of lower chain length. Further, phospholipids have energy densities less than triacylglycerols of similar fatty acid composition and may be as low as 8.1 kcal GE/g as in the light meat of chicken and liver of beef (Miles *et al.* 1984). The median value of 9.4 kcal GE/g triacylglycerol is identical to that for fats from which the Atwater conversion factor of 9.0 kcal DE,ME/g is derived (Merrill & Watt, 1973). With artificial feeds the range for triacylglycerol is again appreciable (Livesey & Elia, 1985a), from 8.3 to 9.5 kcal GE/g, due almost entirely to inclusion of medium-chain triacylglycerol (8.3 kcal/g). It ought to be recognized that parenteral long-chain triacylglycerols have an ME value of 9.4 and not 9 kcal ME/g as often supposed since loss to faeces cannot usually occur.

The second determinant of the energy value is digestibility or losses to faeces. With fats, for example, digestion is less efficient along the series adults > infant child > newborn baby > premature baby (Department of Health and Social Security, 1980; Brook, 1985; Schutz & Dècombez, 1987). The energy conversion factor for protein applies only to subjects in N balance (Atwater, 1910; Merrill & Watt, 1973) so does not apply to rapidly-growing babies (Schutz & Dècombez, 1987). In infants especially, carbohydrate intolerance of a primary or a secondary nature is well recognized (Kumar *et al.* 1977; Lifshitz, 1982).

The energy conversion factors determined in adults, while not necessarily applicable to the very young, appear suitable for normal children (Macy, 1942; Macy *et al.* 1943). The factors are considered applicable to normal adults, and obese and anorexic subjects seem not to differ from normal with respect to digestibility of total energy, protein, fat and carbohydrate (Heymsfield *et al.* 1987). Abnormalities of digestion arise, for example, in non-specific tropical enteropathy (Chacko *et al.* 1984), alcoholic liver disease and inflammatory bowel disease (Heymsfield *et al.* 1987). The extent of losses to faeces may depend on the severity of the disease condition as noted by Heymsfield *et al.* (1987) in subjects with pancreatic carcinoma. Abnormal losses to urine include uncontrolled diabetes and ketoacidosis (Schutz & Ravussin, 1980). However, it is the food-related determinants of digestibility that are usually relevant to the energy conversion factors.

#### SPECIFIC ENERGY DENSITIES AND THE RELATION TO UNAVAILABLE CARBOHYDRATE

Merrill & Watt (1955) in their USA food tables used Atwater's (1910) original idea of specific energy conversion factors. For example, rather than the generally applicable 4 kcal ME/g protein, they used 4.37 for meat and butter, 3.36 for fruits and 2.44 for vegetable proteins. For fats, rather than the generally applicable 9 kcal DE,ME/g fat, values of 8.79 for butter, and 8.37 for fruits, vegetables, certain cereal and vegetable fats were adopted. Specific factors varied largely due to specific digestibilities. For example, the general value of 0.98 for food carbohydrate was replaced by 0.97 in legumes and 0.90 in fruits, and the generally applicable digestibility coefficient for protein of 0.92 in the average food was replaced by 0.97 in meats and 0.85 in fruits. Specific digestibility factors for fat were sometimes difficult to obtain and these coefficients with cereals were unusually small and often negative (Merrill & Watt, 1973). This difficulty may be attributed to a relatively small fat content together with the relatively high NSP content in cereals. In other studies NSP has been shown to increase losses of fat to faeces both in mixed or high-fruit diets (Southgate & Durnin, 1970; Kelsay *et al.* 1978) and especially in high-cereal diets (Judd, 1982; Wisker *et al.* 1988). There is only limited information on the cause of the variability in energy values of different foods. With wheat flour the degree of extraction is important (Merrill & Watt, 1973). Variability in energy values of whole diets has been formally associated with their content of complex carbohydrates that resist digestion in the small intestine and the susceptibility of these carbohydrates to fermentation (Livesey, 1990*b*).

#### SPECIFIC PROTEIN:N RATIOS AND VALUES FOR ARTIFICIAL FEEDS

A further key development in the determination of energy values of proteins was the introduction to food tables by Merrill & Watt (1955) of specific protein:N ratios. Instead of a general value of 6.25 g/g, values were as low as 5.18 for gelatine and as high as 6.38 for milk. Specific ratios were also introduced in Britain (Paul & Southgate, 1978). With artificial feeds used in hospitals it is often assumed that the ratio is 6.25 but it can differ, for example from 4.81 for Trophysan to 7.37 for Amin-Aid (Livesey & Elia, 1985*a*).

#### DIRECT ANALYSIS OF CARBOHYDRATE, CONFUSION ON LABELS AND ERROR IN FOOD TABLES

A key development by Southgate & Durnin (1970) showed the direct analysis of available carbohydrate (that considered to be digested and absorbed before the end of the small intestine) in mixed diets was of practical value when estimating the availability of dietary energy. The energy conversion factor 3.75 kcal GE,DE,ME/g available carbohydrate expressed as monosaccharide applied. This differed from the 4.0 kcal DE,ME/g 'carbohydrate by difference' and the change in standard approach while important has unavoidably created additional room for confusion. For example, with artificial feeds there is confusion over what is carbohydrate and what value should be applied (Livesey & Elia, 1985*a*). Thus, a value of 3.75 has been applied to polymeric carbohydrate of 4.1 or 4.2 kcal GE,DE,ME/g and a value of 4.0 kcal DE,ME/g has been applied to glucose monohydrate of 3.38 kcal GE,DE,ME/g. These errors emphasize the

need to avoid reliance on food labels when performing accurate studies. Such caution applies also to food tables (Blaxter, 1989). In general the USA and UK food tables tend to agree on the energy contents of cereals (brown bread being an exception), whereas the energy available from certain fruits and vegetables is tabulated at up to twice greater in the USA than in the UK tables.

#### THE ENERGY DENSITY OF UNAVAILABLE CARBOHYDRATE

Southgate & Durnin (1970) found that unavailable carbohydrate measurement appeared not to be of practical help when calculating energy values of whole diets using calorie conversion factors. The latter observation has often been interpreted as 'the energy value of dietary "fibre" is zero'. However, it must not be assumed that a zero value can be appended to, for example, the British system of food energy assessment (Livesey, 1990*b*; British Nutrition Foundation, 1990). This is because the zero value accounts for faecal energy losses of fat and protein in the energy conversion factor for the unavailable carbohydrate, whereas, these losses are already largely accounted for in the factors for protein and fat when a diet contains about 20 g unavailable carbohydrate daily.

DE values between  $-5$  and  $+2.4$  kcal DE/g unavailable carbohydrate have been obtained with the highest and lowest values being significantly different from zero. Negative values arise due to energy losses as protein and fat in faeces that exceed the additional GE provided by the unavailable carbohydrate. These positive and negative values have been called partial DE values (Livesey, 1990*a,b*; Livesey *et al.* 1990) by analogy with the term partial digestibility used by Kleiber (1975). The difference between apparent and partial DE values represents the losses of protein and fat to faeces due to the ingestion of the unavailable carbohydrate. Statistically, these losses are greater, per g unavailable carbohydrate ingested, both at lower intakes and with the poorly-fermentable unavailable carbohydrates (Livesey, 1990*b*).

Above a daily intake of about 20 g unavailable carbohydrate from mixed conventional food sources, it seems that only fermentability becomes the major determinant of the energy value of this carbohydrate. Studies of the energy values of enriched sources of complex carbohydrates, should where possible use basal diets already of about 20 g unavailable carbohydrate daily. Also procedures for calculations of energy values need to be formalized to help comparisons between different laboratories (Livesey, 1990*b*) and to avoid certain sensitivity errors (Livesey, 1989).

Losses of energy to faeces due to fermentation of carbohydrate arise largely from the growth and loss of micro-organisms. In general about 0.3 kcal GE faecal energy arises per kcal GE carbohydrate fermented (Cummings, 1983; British Nutrition Foundation, 1990; Livesey, 1990*b*). Since in man usually about 70% of carbohydrate is fermented, 30% of energy fermented is lost to faeces (in addition to the usually unused 30% of unfermented carbohydrate) and 4.1 kcal GE/g unavailable carbohydrate applies, it follows that an energy value of about 2 kcal DE/g is evident (British Nutrition Foundation, 1990; Livesey, 1990*b*). This value of 2 is practically independent of dosage up to 70 g daily. Further, this theoretical approach to calculation of DE values approximately, but adequately, describes the availability of energy from the limited number of isolated sources of NSP investigated in man and rat (Livesey, 1990*b*). It is also found that by appending a 2 kcal DE/g unavailable carbohydrate to the British system of food energy assessment, the energy value of mixed diets can be estimated without bias

when compared with experimentally determined values. By contrast the Atwater (1910) and British systems showed bias but in different directions (Livesey, 1988, 1990b). Furthermore, multiple-regression analysis on over thirty diets of varied unavailable carbohydrate intake similarly indicates a value of 2 kcal DE/g in mixed diets where in general the apparent digestibility of this carbohydrate is about 0.70 (Livesey, 1991; see also British Nutrition Foundation 1990). Losses of energy to urine from unavailable carbohydrates are generally thought to be negligible (Southgate & Durnin, 1970; Kelsay *et al.* 1978; Miles *et al.* 1988; Wisker *et al.* 1988).

With isolates rich in NSP chosen for their solubility characteristics or for their bulking attributes, the apparent digestibility is often either higher or much lower than 70%. For example, gum arabic and guar gum are soluble and completely fermented so theory predicts digestible energy values of about 2.9 kcal DE/g. This value is approximately as found by direct determination (Harley *et al.* 1988; Davies *et al.* 1991) with the more viscous guar gum tending to give the lower value. Crystalline cellulose (e.g. Solka floc) as an example of a bulk material, remains about 90% unfermented *in vivo* and has an energy value close to zero in man and rat, as predicted by theory (Harley *et al.* 1988).

The similarity in man and rat both of DE values and of the apparent digestibilities of NSP has led to the rat being accepted cautiously by consensus as a suitable model (Nyman *et al.* 1986; British Nutrition Foundation, 1990; Livesey, 1990c). There is a need, however, to identify the limits under which this model satisfactorily applies.

#### CONCERN ABOUT ALTERNATIVE CARBOHYDRATES AND SOME DIFFICULTIES WITH CURRENT ASSAY METHODS

Experiments with laboratory prepared uniformly-labelled [ $^{14}\text{C}$ ]Polydextrose in man and rat leads to a view that it should have a low energy value (Rennhard & Bianchine, 1976; Figdor & Bianchine, 1983). However, dietary energy balance trials in the rat indicate a value of 3 kcal ME/g (Cooley & Livesey, 1985). The conflicting observations have fuelled a view that the radiochemical data provide reliable energy values (Hobbs, 1988) and another that it would be preferable to determine energy values on the manufactured product when it is complex (Livesey, 1988).

Currently, however, there is no satisfactory procedure for energy evaluation of carbohydrates which make a small proportion of the diet. The  $^{14}\text{CO}_2$  method (Rennhard & Bianchine, 1976) compares  $^{14}\text{CO}_2$  production from orally administered  $^{14}\text{C}$ -labelled carbohydrate with that from [ $^{14}\text{C}$ ]glucose. An early peak in the time-course of  $^{14}\text{CO}_2$  production is said to be indicative of absorption in the small intestine while a late peak is due to fermentation and subsequent oxidation. The difficulty is that the two peaks are not well resolved (Figdor *et al.* 1987). Improved resolution is obtained by administering a bolus of substrate solution intragastrically, rather than adding it to a meal. However, doing so affects both gastric emptying and subsequent flow of digesta making interpretation unreliable. Another difficulty is that the method is of limited use for complex carbohydrates in conventional foods. The method also assumes: the laboratory analogue is identical to the manufactured material; there is no influence of the carbohydrate on the use of other dietary material; a value for  $^{14}\text{CO}_2$  evolved from intestinal micro-organisms: that evolved from the hosts' oxidation of absorbed short-chain fatty acids; that, as in aerobic oxidation,  $^{14}\text{C}$  traces the energy associated with hydrogen which is strictly not true of anaerobic fermentation.

The complete energy balance method for assay of energy value is ideal in theory. It involves assessment of the intake and excretion of energy, energy expenditure, expenditure on physical activity and determination of the change in these variables due to dietary change, for example, the exchange of sucrose with the product of interest (van Es *et al.* 1986). The major limitation is the relatively high coefficient of variation for assessment of energy expenditure, of the order of 2%, by comparison with a desired intake of test substrate which may be as little as 20–50 g daily or equivalent to about 3–8% of daily dietary GE intake. The high variance means many subjects are required to obtain satisfactory precision. Such an onerous task is obviously not suitable for routine use.

The change in body energy brought about by a change in intake of the test material in rat or pig is assessed in the comparative carcass assay. The procedure has not found widespread use and has been criticized on the grounds of difficulty of extrapolation to humans. With pigs a major difficulty is the presence of micro-organisms in the stomach and small intestine which may modify digestion. With rats, coprophagy sometimes may (and sometimes may not) occur to a significant extent so introducing faecal micro-organisms into the upper gastrointestinal tract. These criticisms need to be seen in context. In the rat the ME conversion factors for protein, fat and carbohydrate are not significantly different from those in humans (Metta & Mitchell, 1954; Zuleta & Sambucetti, 1989). The apparent digestibilities and partial DE values of unavailable complex carbohydrates also seem to be similar in man and rat (Nyman *et al.* 1986; British Nutrition Foundation, 1990; Livesey, 1990*b,c*). The efficiency of metabolism of absorbed energy in man and rat is thought to be approximately similar (Blaxter, 1989). However, these similarities do not mean results can be extrapolated to man in every instance without caution. It is often assumed, for example, that a test substrate has no effect on energy used for physical activity. However, this assumption is not a problem of species difference and does not always seem to be a problem (see Fig. 12.4, Blaxter, 1989). For the comparative carcass method used to assay energy from poorly-digested carbohydrates there is too little information either to reject or to fully accept the findings.

The problems of the comparative carcass method apply also to the rat growth assay (Rice *et al.* 1957) whereby growth is restricted by feeding diets reduced in energy but not in other nutrients. Supplementation of the diet with a test substrate produces a change in the rate of growth which is compared with a substrate of known energy values. Additional problems of the growth assay are that the energy content of live-weight gain may not be constant (McCracken, 1986) and often it is not realized that specific dietary protocols need to be adhered to, with growth under inappropriate conditions being mistakenly interpreted.

#### THE HYBRID FACTORIAL HYPOTHESIS

The Dutch Nutrition Council (1987) reported an absence of sufficient comparative information on the variety of sugar alcohols in the numerous procedures for assessing NE values. The Dutch Nutrition Council (1987) preferred a method which marries (hence the term hybrid) what is the 'established' knowledge about the fermentation of carbohydrates, but which is difficult to assess on a routine basis, with the more 'easily' determined losses to urine, to fermentation in the colon (a partial energy loss) and to faeces. The following paper in these proceedings (van Es, 1991) deals with this approach

for sugar alcohols. A similar approach was adopted for the unavailable carbohydrates by the British Nutrition Foundation's (1990) Task Force on Complex Carbohydrates, but is simpler because unavailable carbohydrates by definition invariably reach the colon and losses to urine, if any, are considered negligible. Essentially, the equation for unavailable carbohydrates states that the NE value (for metabolic and physical work) is given as  $(1-A-B-C) \times D \times G \times H$ , in which A is the apparent efficiency of conversion of fermented carbohydrate to faecal energy (i.e. bacterial matter; unabsorbed volatile fatty acids, malabsorbed digesta), previously indicated to be about 0.3 times the carbohydrate fermented. B is the conversion to gaseous energy (methane and molecular H), about 0.05 times the carbohydrate thought to be fermented in man eating mixed diets (Livesey & Elia, 1987) as well as for sugar alcohols (van Es, 1987). C is the estimated heat of fermentation, about 0.05 times the carbohydrate fermented both theoretically in man (Livesey & Elia, 1987) and in ruminants (Hungate, 1966) and by experimentation in vitro (Arieli, 1986) and in vivo (Webster, 1978). D is the apparent digestibility, i.e. the proportion of unavailable carbohydrate fermented. G is the yield of ATP per kcal GE of volatile fatty acid compared with the yield from an equal kcal GE of glucose, it is about 0.85 under a variety of conditions (Livesey & Elia, 1985*b*). H is the heat of combustion of the unavailable carbohydrate, usually about 4.1 kcal GE/g. By far the largest variable is D, so much so that in general A B C G and H may be held constant and kcal NE for unavailable carbohydrate becomes approximately equal to 2.1D. This yields an NE value of approximately 1.5 kcal NE/g unavailable carbohydrate when D is 0.7 as is the usual case in man for mixed diets (Livesey, 1990*b*).

#### NE FOR METABOLIC AND PHYSICAL WORK ASSESSED BY MODIFIED EMPIRICAL EQUATIONS FOR CONVENTIONAL FOODS

Several empirical equations predicting energy available from whole diets have been proposed by others and reviewed (Livesey, 1988, 1990*b*). A variety of reasons have been advanced to suggest empirical equations would be preferable to the energy conversion factors (Livesey, 1988). A recently proposed equation is  $\text{kcal ME} = 0.96\text{GE} - 2\text{U} - 7\text{N}$  where U and N are intakes (g) of unavailable carbohydrate and N (Livesey, 1991, see also British Nutrition Foundation, 1990). This equation modifies to a NE system with the following equation:  $\text{kcal NE} = 0.96\text{GE} - 2.5\text{U} - 12\text{N}$ . This NE equation assumes that ATP per kcal DE, ME in fat is similar to that in available carbohydrate. The similarity is only approximate with NE from fat being slightly less than for available carbohydrate (Livesey, 1984) and possibly 12% less for physical activity than for metabolic work (Keys, 1943) but these tend to be balanced by a higher cost of storage (Flatt, 1978; Elia & Livesey, 1987). A second assumption is that urea synthesis and gluconeogenesis from protein cost 0.8 kcal GE, DE, ME/g protein (Livesey, 1984) equivalent to 5 kcal GE, DE, ME/g food N. A third assumption is that a further loss of 0.5 kcal GE, DE, ME/g U occurs which is the difference in the values 2 kcal DE, ME/g U and 1.5 kcal NE/g U already discussed. NE systems derived in this way require a reference substrate because of uncertainties in the stoichiometries of oxidative phosphorylation (Livesey, 1984, 1985, 1987). That is, NE is expressed relative to a reference substrate; here 3.75 kcal GE, DE, ME, NE/g glucose.

Variability in the conversion of ME to NE (ATP) in available carbohydrates and fats is small (Livesey, 1984) but variation in NE per g N for protein is appreciable in



conventional foods. The latter is of little consequence when 'value averaging' occurs as in conventional diets, but with artificial amino acid mixtures the range of 'protein' NE values per g N is wider than for conventional proteins and 'value averaging' may not occur (Livesey & Elia, 1985a).

#### USE OF ENERGY VALUES IN THE FOOD TABLES AND ON LABELS

The purpose usually mentioned for having calorie conversion factors is to calculate food energy intake from food intake values. Food intake measurement limits the accuracy of calculated energy intake so that for this purpose calorie conversion factors need not usually be very precise. A similar application is made when prescribing a diet aimed to meet an individual's energy requirement, again the estimate of requirement is likely to be less accurate than the calculated food energy value. However, for many people, the selection of low-energy foods in preference to high-energy foods is important. Once a decision to choose a low-energy food has been made neither food intake measurements nor estimates of requirement enter the selection process. Errors in the food energy values given on individual food labels arise both from variation in food composition, and from imprecision in the calorie conversion factors. Imprecise factors lead to bias, overestimating (Atwater (1910) system) or underestimating (British system) the energy value of diets with increasing unavailable carbohydrate content; with individual foods presumably the bias is larger than with the diet as a whole. For certain food ingredients the compositional variation is limited and accurate and precise energy values are needed. Examples of such ingredients are supplements rich in NSP (wheat bran, oat bran, and sugar-beet fibre etc.), sugar alcohols (van Es, 1991) and oligosaccharides (Polydextrose®, fructo oligo-saccharides). This need is twofold; one is to enable the food manufacturer (or consumer) to choose low-energy ingredients from a range of otherwise suitable alternatives, another is to enable the making of food-labelling regulations on calorie conversion factors. These needs are not of proven nutritional significance. For example, sugar alcohols usually contribute much less than 25 g to daily food intake (Ministry of Agriculture, Fisheries and Food, 1990) or equivalent to about 3% of GE or 1.5–3% of NE intake. However, anecdotes of much higher intakes of alternative carbohydrates (M. E. Lean and D. A. T. Southgate, personal communication) put possible intakes as high as 10% of GE intake. Such high intakes may influence energy balance.

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