Fibre and the other unavailable carbohydrates and their effects on the energy value of the diet

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The principles used in methods for the determination of crude fibre have a long history and for many years the empirical and generally unsatisfactory nature of the crude fibre method as an analytical technique *per se* has been recognised (Crampton & Maynard, 1938; Hallab & Epps, 1963). The development of more refined techniques (Van Soest, 1963; Van Soest & Wine, 1967) has led to the resolution of many of the problems associated with the older procedures and analytical values obtained have greater relevance in terms of the actual constituents of the plant cell wall.

However, in many respects these newer methods are of limited value in human nutrition, primarily because they were developed for nutritional studies with the ruminant. The majority of the structural polysaccharides of the plant cell wall are not available to man as sources of energy because he lacks a rumen or an enlarged caecum with their associated micro-organisms. He is, consequently, unable to make use of the hydrolytic activities of the intestinal microflora in the same way as the ruminant and non-ruminant herbivore. This means that crude fibre determinations or the determination of cellulose and lignin using more refined methods tend to over-estimate the proportion of the plant cell wall that can be digested by man.

Terminology

The current clinical interest in the 'fibre' content of the human diet (Painter & Burkitt, 1971) makes terminology in this field particularly important.

Table 1 lists some of the terms used to describe the carbohydrates in the diet. The limitations of the classical crude fibre determination have already been discussed.

Unavailable carbohydrate (McCance & Lawrence, 1929) as originally defined included all the polysaccharides not hydrolysed by the intestinal secretions of man. This includes pectic substances, hemicelluloses, cellulose and some reserve polysaccharides such as inulin. In the definition used by McCance & Lawrence (1929) the non-carbohydrate lignin was included and for this reason the term 'dietary fibre' has been used (Trowell, 1972) to distinguish it from 'crude fibre' and therefore avoid the use of 'carbohydrate.'

The available carbohydrates include all the free sugars and polysaccharides which are digested and absorbed by man and which are glucogenic. The use of carbohydrate 'by difference' values for estimating the energy value of foodstuffs

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Table 1. *Terminology used to describe the carbohydrates in the human diet*

Fraction	Chemical nature of fraction	Reference
Crude fibre	Cellulose and lignin together with variable amounts of other polysaccharides	Henneberg & Stohmann (1860); Association of Official Agricultural Chemists (1970)
Unavailable carbohydrate	All plant polysaccharides not hydrolysed by secretions of the human digestive tract	McCance, Widdowson & Shackleton (1936); Southgate (1969)
Dietary fibre	Unavailable carbohydrates and lignin	
Available carbohydrate	All sugars and polysaccharides which are digested and absorbed by man and which are glucogenic	McCance & Lawrence (1929)
Total carbohydrate	The residue after deduction of moisture, protein (N × factor), fat and ash from the total	Classical proximate procedure

for man may give misleading information (Southgate & Durnin, 1970), because it fails to distinguish between the available and unavailable carbohydrates.

Amounts of unavailable carbohydrates in the diet

The unavailable carbohydrates and lignin make up a relatively small proportion of man's total diet; consequently they have received little attention since the early years of this century, apart from a short burst of activity in the early 1930's, and methods for their estimation have not advanced to the extent of those for many other constituents of the diet. In the inter-war years Williams & Olmsted (1935) developed methods for estimating the amounts of hemicelluloses and cellulosic components in the diet and these were used by Macy and her colleagues in their extensive study of children (Macy, 1942). However, there have been few reports of experiments to estimate the quantitative significance of these constituents in the diet when eaten by populations as distinct from groups of subjects.

Robertson (1972) estimates that the average intake of crude fibre in the United Kingdom is 4–5 g/head per d which is equivalent to 10–15 g dietary fibre/head per d. The children studied by Macy (1942) had an average intake of 6–7 g dietary fibre/d varying from 0·33 g/kg body-weight per d in the younger children to 0·20 g/kg body-weight per d in the older ones. In these children the contribution of the dietary fibre to the gross energy intake was approximately 1%. In Southgate & Durnin's (1970) study, where the subjects were eating diets which were typical of those eaten in this country, the unavailable carbohydrates provided 1–4% of the gross energy intake. In these studies the various fractions of unavailable carbohydrate were estimated separately and approximately one-half of the total would have been measured in the crude-fibre fraction.

Some of the problems associated with the measurement of lignin have been described in the previous paper (Van Soest, 1973) and these are accentuated when one is concerned with the diet eaten in this country and most developed countries. In

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these countries highly lignified plant tissues are rarely eaten and the amounts in the diet are extremely small. The diets used by Southgate & Durnin (1970) had very low lignin contents and recent analyses of a homogenate of the average diet eaten in the United States of America showed a similarly low intake.

Apparent digestibility of the unavailable carbohydrates

Although the human digestive tract does not secrete enzymes which can hydrolyse the unavailable carbohydrates, estimation of their apparent digestibility shows that appreciable amounts of unavailable carbohydrates disappear during their passage through the gastrointestinal tract. The values reported for the apparent digestibility of cellulose show a very large range. In part, this is the result of analytical problems and it is difficult to compare the absolute values obtained by different workers. However, the same variation is also observed between subjects studied using the same methods. The mean values obtained for the apparent digestibility ratios together with the ranges observed by Southgate & Durnin (1970) are given in Table 2; these values show the typical variation observed. One reason for the great individual variation is that one is not looking at differences between two individuals but at differences between their intestinal flora. There is also an additional factor involved, the transit time. As the micro-organisms in the large intestine are responsible for the degradation of cellulose, a longer period of incubation would be expected to increase the extent of degradation. In our study the subjects with the longest transit time tended to show the greatest apparent digestibility of cellulose.

Table 2. *Apparent digestibility ratios for cellulose* (*Southgate* & *Durnin*, 1970)

(Mean values for each group. No. of subjects in parentheses.)

	Diet 1*		Diet 2*	
	Mean	Range	Mean	Range
Young men (12)	0·15	0·13–0·36	0·16	−0·07–0·29
Young women (14)	0·26	0·02–0·48	0·26	0·07–0·40
Elderly men (11)	0·55	0·24–0·84	0·44	0·21–0·60
Elderly women (12)	0·35	−0·20–0·65	0·26	0·09–0·51

*Diet 1 was low in unavailable carbohydrate; diet 2 contained increased amounts of unavailable carbohydrate.

Early German workers (Rubner, 1918; Rubner & Thomas, 1918) reported that the very delicate walls of young plants were more readily digested than thicker walls. This appears perfectly reasonable because the microflora are acting on an insoluble substrate and the cellulases must be secreted into the medium. Therefore there would be a greater degradation of a thin wall with a high surface: volume ratio. A large number of these observations were based on microscopical examination of the faeces and these fine membranes would be the most difficult to distinguish, therefore these findings must be accepted with caution.

A similar situation exists for the apparent digestibility of the hemicelluloses

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although generally the variation between individuals is not apparently as great. This may be because these substances are more readily soluble than cellulose.

The amounts of cellulose and hemicellulose that are degraded during transit through the gastrointestinal tract may be quite considerable as shown in Table 3, which shows the amounts of cellulose and pentosans which were apparently digested by the subjects studied by Southgate & Durnin (1970). The amounts degraded, although appreciable, are still small relative to the total intake of organic matter.

Table 3. *Amounts of unavailable carbohydrates (g/7 d) disappearing during transit through the gastrointestinal tract (Southgate & Durnin, 1970)*

(Mean values for each group)

	Pentosans		Cellulose	
	Diet 1*	Diet 2*	Diet 1	Diet 2
Young men	46·6	68·2	2·5	8·7
Young women	32·2	59·2	2·3	9·4
Elderly men	55·7	120·9	5·4	24·6
Elderly women	44·0	88·9	2·3	10·4

*Diet 1 was low in unavailable carbohydrate; diet 2 contained increased amounts of unavailable carbohydrate.

In man, the products of the bacterial and fungal enzyme activity on the cellulose and hemicellulose fractions are to some extent uncertain but in vitro studies (Halliwell, 1959) indicate that initial products may include cellobiose from cellulose and either monosaccharides or disaccharides from the hemicelluloses. Faeces normally contain only minute amounts of free sugars (Southgate, 1964; Southgate & Durnin, 1970), but this is probably a consequence of the rapid utilization of simple sugars by the intestinal microflora which prevents the accumulation of the initial products of hydrolysis. McCance & Lawrence (1929) thought that short-chain fatty acids would be the most likely end product of the activity of the intestinal organisms. Macy (1942) found that although there was a correlation between the free fatty acids in the stools and the faecal excretion of complex carbohydrates, there was no correlation between the free fatty acids and the amounts of these substances which had been apparently digested. Olmsted, Curtis & Timm (1935) could find no evidence of an increased production of fatty acids in the faeces of men given a diet rich in pentosans derived from wheat and they assumed that the products of bacterial decomposition were pentoses which were absorbed as pentoses. There is a small urinary excretion of pentoses in man which may well be derived from this source.

Contribution to the metabolizable energy of the diet

If the products of the microbial digestion of these complex carbohydrates are fatty acids then there would be a loss of 20–25% of the gross energy during fermentation (Marston, 1948). Also, if these free fatty acids are absorbed in the large intestine the amounts of metabolizable energy they would provide, as a proportion of the

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total metabolizable energy intake, would be quite small. Calculations based on the results obtained with the four groups of subjects in our study (Southgate & Durnin, 1970) show that the maximum contribution to the metabolizable energy from pentosans range from 0·6 to 2·1% and from cellulose from 0·03 to 0·38%. Their contribution to the metabolizable energy intake of man can, therefore, for practical purposes be ignored and the use of the term 'unavailable' is fully justified.

Effects on the apparent digestibility of other constituents

Although the positive contribution of unavailable carbohydrates can be ignored, their negative effect on metabolizable energy cannot.

As the intake of unavailable carbohydrate is increased the apparent digestibility of the other constituents in the diet is reduced. This effect was noted by Rubner (1918) and the changes produced by increasing the intake of unavailable carbohydrate are shown in Table 4, which gives values for two of the groups studied by Southgate & Durnin (1970). The differences in the apparent digestibility ratios between diets

Table 4. *Effects of unavailable carbohydrate intake on the apparent digestibility of protein, fat and energy (Southgate & Durnin,* 1970)

(Mean values for each group)

Subjects	Intake of unavailable carbohydrate (g/d)	Apparent digestibility ratios		
		Protein	Fat	Energy
Young men	9·7	0·90	0·96	0·97
	21·5	0·87	0·95	0·94
Young women	6·2	0·92	0·97*	0·97
	15·2	0·91	0·96*	0·95
	31·9	0·85	0·93	0·93

*Not significantly different but all other values differed significantly ($P<0·05$).

providing different amounts of unavailable carbohydrate was significant ($P<0·05$) in all cases except for fat in the first two diets eaten by the young women.

The effect of increasing the intake of unavailable carbohydrate is probably the result of a combination of factors. First, as a *caveat*, there are usually qualitative changes in the diet as a whole when its unavailable carbohydrate content is increased. Many of the diets eaten in different parts of the world which appear to differ primarily in the amounts of 'dietary fibre' they contain, also differ qualitatively in other respects. It is important to consider the possible effects of these qualitative changes before one ascribes all the observed differences to changes in the intake of 'dietary fibre'.

Secondly, the increased bulk of non-assimilable material in the large intestine and possibly in the small intestine has an effect on transit time so that there is less time for the processes of digestion and absorption.

Thirdly, there may be physico-chemical effects resulting from the increased bulk and other properties, such as water-binding of the unavailable carbohydrates which reduces the rate of diffusion of the products of digestion towards the absorptive mucosal surfaces.

Another effect which is often quoted but difficult to quantify is the mechanical erosion of the mucosal surface leading to increased losses of endogenous material.

This effect of the unavailable carbohydrates on the apparent digestibility of the other energy-yielding constituents of the diet implies that the use of a single series of energy conversion factors for calculating the metabolizable energy of a diet from its composition may lead to an over-estimation if the diet is rich in unavailable carbohydrates.

For the majority of diets eaten in this country the errors involved are quite small especially when compared with the intrinsic errors involved in the use of such a system of calculation. However, for many diets eaten in the developing countries these errors may be significant and important, particularly where energy intake itself is restricted.

Conclusions

The contribution of 'fibre' and the other 'unavailable' carbohydrates to the metabolizable energy intake of man can be neglected for practical purposes for diets eaten in the United Kingdom. The effects of the 'unavailable' carbohydrates on the apparent digestibility of the other energy-yielding constituents of the diet is not negligible and may become very important for diets containing large amounts of plant foods.

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