1.1.1 Dietary fibre and complex carbohydrates

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1.1.1.1 Dietary fibre: not a simple defined category

Dietary fibre is a term which has several definitions, but the latest FAO/WHO analysis suggests that a chemical, physiological or botanical definition is preferred.[1] It is clear that FAO, WHO and many academics consider the specification of fibre should best be considered as the non-starch polysaccharides (NSPs) which are predominantly of plant cell wall origin. They favour this as an explicit chemical category within the carbohydrate group.[2] Other investigators have emphasised the specification of fibre as the residual components of plant cell wall which evade digestion in the small intestine.[3] This assessment, linked to the traditional focus on fibre's gastrointestinal effects, therefore includes the non-carbohydrate component lignin which is structurally intimately integrated with the NSPs in the plant cell wall. However, when these different definitions were being considered it was not recognised originally that some starches could be relatively resistant to digestion and indeed the process of cooking is important in determining how digestible the starches are. The granular structure of the starches, their processing and normal cooking all affect the digestibility. Any cooling of cooked food also alters the tertiary structure of starch by a process called retrogradation such that cooked starch after cooling, even when reheated, contains far more "resistant" starch i.e. starch which is likely to be poorly digested and pass into the colon where it is probably fermented. Often the impact of differential cooking, and whether or not the food has previously cooled before reheating, is not considered by those concerned with specifying the indigestible part of fibre. Yet the EFSA board concluded that the term dietary fibre should include all non-digestible carbohydrates.[4]

Thus, in general, two figures for fibre intake are now usually provided one specifying the non-starch component measured by the Englyst methods[5] which provides a lower number than the other "fibre" fraction which includes indigestible material measured by an in vitro assay originally developed by Asp and which attempts to simulate normal digestion.[6] This definition was accepted as the appropriate method for measuring dietary fibre by the Association of Official Analytical Chemists (AOAC) and is strongly supported by the food industry. It is also generally favoured in the US and has recently also been favoured by EFSA[7] but unfortunately it usually gives a higher value for fibre than that derived from measuring the NSP because it also includes for example coloured products involving the Maillard reactions of sugar-protein interactions induced by cooking. These products amplify the supposed fibre values of some processed foods, such as corn flakes, but there is no evidence that these products have discrete physiological effects on either the intestine or metabolism. In addition, there are modified starches which are used by the food industry to alter the physical properties of food and most of these modified starches, present in small amounts, are also not digestible so will be measured in standard in vitro tests.

Neither the Englyst nor the AOAC method measures the resistant oligosaccharides and inulin often used as supplements—so separate measurements needs to be made for these components. In Europe there has been a substantial emphasis by some companies on the potential probiotic properties of oligosaccharides and inulin has also been added to food to boost the claim for fibre-enriched products. Given all these uncertainties, and how best to define the different fibre fractions and their physiological roles, FAO and WHO have focused on the non-starch polysaccharides as a more robust definition and recommended its use to Codex for the purpose of international regulations.

1.1.1.2 The different measures for the fibre content of the diet

To complicate matters further there have been, historically, four main assays for the fibre content of foods. The first was Van Soest's assay of what one might term "crude" fibre based on measures then considered valuable by ruminant nutritionists.[8] These values were often used in USA reports dealing with fibre studies. In the US, food composition tables traditionally have no direct measure of carbohydrates in the foods listed in tables; carbohydrates are calculated as the weight difference once the fat, protein and ash in a dried sample of food had been measured. This, in practice, leads to substantially higher values for the energy content of food than those obtained by direct measurements.[9] Thus US and European measures of carbohydrate energy and fibre intake may differ markedly simply because of the methods used in their estimation.

Then the Southgate analysis was developed and involved an acetone extraction before a measure of enzymatic digestibility.[10] These values were those used traditionally in UK food composition tables before the Englyst assay superseded it.

Now only the Englyst and the AOAC assays are usually quoted when presenting results of fibre studies but care needs to be taken to assess which values were being chosen when particular studies are published dealing with the metabolic or other benefits of fibre.

1.1.1.3 Potential physiological effects and health benefits of fibre

As noted by Cummings and Stephen "the established epidemiological support for the health benefits of dietary fibre is based on diets that contain fruits, vegetables and whole grain cereals for which the intrinsic plant cell wall polysaccharides are a good marker."[11] What this means in practice is that some of the supposed effects of NSP do not relate to NSP as such but to frequently associated components in the diets which have a high NSP value. Thus fruit and vegetables contain NSP and some of these components have a distinct physiological and metabolic effects but fruits and vegetables are also rich in potassium (as are unrefined cereals in general) and the potassium may be one of the useful components which helps, for example, to lower blood pressure. Fruits and vegetables also contain varying amounts of complex molecules which have antioxidant and other properties which could impact on the blood vessel walls and reduce the inflammatory and endothelial thickening and thereby help to protect against cardiovascular diseases. (See section 1.3.5 for an outline of the potential mechanisms for the protective effect of fruit and vegetables.) However, when, for example, the Mediterranean type diet is highlighted as beneficial for the prevention of cardiovascular disease there are multiple components involved and the higher NSP values may then be more of a marker of the dietary pattern than intrinsically responsible for the diet's preventive role.

Cummings and Stephen have summarised the physiological effects as set out in Table 2 for all the components of dietary carbohydrates. This approach, of course, differs from an approach which attempts to assess the health benefits of NSPs or the dietary fractions conventionally included in the term dietary fibre. If the term fibre or NSP is considered in epidemiological or intervention studies then the potential benefits (and hazards) of these physiological effects need to be considered.

Table 1 The principal physiological effects of carbohydrates including the non-starch polysaccharides as set out by Cummings and Stephen[11]

	Provide energy	Increase satiety	Glycaemic[a]	Cholesterol lowering	Increase calcium absorption	Source of SCFA[b]	Alter balance of microflora (prebiotic)	Increase stool output	Immunomodulatory
Monosaccharides	✓		✓						
Disaccharides	✓		✓		✓				
Polyols	✓					✓[c]		✓	
Maltodextrins	✓		✓						
Oligosaccharides (non-α-glucan)	✓				✓	✓	✓		✓
Starch	✓		✓			✓[d]		✓[d]	
NSP	✓	✓		✓[e]		✓		✓	

[a]Provides carbohydrate for metabolism (FAO, 1998).
[b]Short chain fatty acids.
[c]Except erythritol.
[d]Resistant starch.
[e]Some forms of non-starch polysaccharide (NSP) only.

1.1.1.3.1 Gastrointestinal effects of fibre

Perhaps the greatest series of meticulous studies on fibre's effects relate to the effect of NSP on total daily faecal output which conventionally is not considered a major disease, albeit that in adults and children on "western" processed or refined diets constipation is a major problem for an appreciable proportion of the general population. It is clear that in deriving goals for fibre often this laxation effect of NSPs has been taken as a simple index, or marker, which is expected to correlate with other effects. This approach was adopted in WHO's 1990 report on diet and the prevention of chronic diseases[12] and has been used again by EFSA in its 2010 specification of Dietary Reference values.[7] This report estimated that an average goal of 16g NSP (for adults) would limit constipation and took account of the observed variation in faecal output between volunteers on defined diets and fibre intakes and the volume needed for volunteers to consider that they did not have constipation or difficulties associated with defaecation. An upper limit of 24 g/d was also set, based on the concern that as whole grain cereal intakes rose then the potentially greater intakes of phytates associated with the whole grain might inhibit the absorption of important minerals such as iron and zinc, and these mineral deficiencies were known to be globally important.

Two further features were already evident 20 years ago. First, that, given the substantial differences between the energy needs of different populations based on their different levels of physical activity and their different average body weights, the NSP values could be expressed as 2.2–3.2 g NSP/MJ dietary energy. This actually also had the implicit value of allowing for the different energy requirements of women and men and of different groups within the population. The second issue related to the broader definition of dietary fibre. On this basis the 16 g and 24 g NSP values were estimated to be equivalent to 27 g and 40 g dietary fibre as measured at that time by a combination of studies using the Southgate and Asp methods.

1.1.1.3.2 Non-gastroenterological effects of fibre

In the WHO 1990 report it was also recognised that the use of faecal bulking was just a simple marker and that there could well be parallel benefits on other metabolic systems and in disease prevention which were far less easy to define in a precise way. Thus it was estimated that the 16 g NSP would be a reasonable figure capable of normally including the 400 g/day of fruit and vegetables which was also being set out as a suitable goal. It was known that the faecal bulking effect of whole grain cereal derived NSPs was greater than the NSPs derived from fruit and vegetables but the whole grain cereal component of the improved diet could also be accommodated within the 16 g/d figure.

At that time it was also known that the whole grain cereals included in the NSP estimation would contribute substantially to lowering the speed of digestibility and would limit the sudden rise in glucose and insulin levels. It was also recognised that there was a poorly quantified potential effect of dietary bulking on satiety. The impact of pectins and guar gums in the NSPs of whole grain cereals, fruit and vegetables in lowering blood cholesterol levels was known but was difficult to quantify. Therefore, no detailed examination of data in relation to blood sugar and insulin fluctuations and blood cholesterol lowering or the prevention of obesity, type 2 diabetes or cardiovascular disease was used in deriving the preliminary WHO NSP goal in 1990.

The updating of the original WHO report was undertaken a decade later and this joint FAO/WHO Consultation found that high intakes of dietary fibre was convincingly important in preventing obesity and probably important in preventing type 2 diabetes and cardiovascular disease.[13] Only a possible preventive role was assigned to fibre for cancer prevention but the more recent WCRF/AICR report,[14] which undertook an enormously exhaustive analysis of epidemiological data relating diet to the development of cancer, concluded that dietary fibre was probably protective against colorectal cancer. In the later WCRF/AICR policy report[15] it was proposed on the basis not only of cancer but to engage other preventive principles that NSP intakes should be at least 25 g/d as a population average.

The new analysis by EFSA sets out their basis for recommending diets with a reasonable content of dietary fibre. They suggest 25 g/d dietary fibre or 2 g fibre/MJ energy intake as the Dietary Reference Value on the basis of analyses relating to gastrointestinal function. On this basis this might be considered using their current methods of analysis as about equivalent to 20 g/d NSP.

The WCRF/AICR report, however, considered that the desirable long-term goal should be >600 g/d of vegetables and fruit which would then be accommodated by a mixed Mediterranean diet containing >25 g/d NSP. This implies an energy adjusted value of >2.25 g NSP/MJ or an AOAC fibre value of say >35 g/d or >3 g fibre/MJ.

1.1.1.4 Dietary fibre intake and cardiovascular disease

The analysis of appropriate fruit and vegetable intakes set out in Section 1.3.5 presents a case for considering fruits and vegetables as important in cardiovascular prevention. If one then takes the WHO/FAO 916 report where it specified the NSP goal as >20 g/d with total fibre intakes of >25 g/d fibre this was accepted as accommodating the ≥ 400 g/d of vegetables and fruits which was retained as a reasonable goal.

The FAO/WHO 916 report had a series of background papers on different aspects of diet and prevention of cardiovascular disease and noted, not only the cholesterol-lowering effects of some of the NSPs, but also quoted three cohort studies which had shown the benefits of intakes of whole grain consumption in preventing coronary heart disease

The Population Health Research Institute in Canada[16] undertook a detailed systematic review of the evidence from cohort and randomised intervention studies to assess the potential role of different dietary factors in relation to CHD. They used the Bradford Hill guidelines to generate a causation score based on the four criteria of strength, consistency, temporality, and coherence for each dietary exposure in cohort studies and then examined the results for consistency with the findings of randomised trials. Strong evidence with all four criteria satisfied suggested protective factors including intakes of vegetables, nuts, and "Mediterranean" and high-quality dietary patterns in preventing coronary heart disease. Harmful associations included intakes of *trans* fatty acids and foods with a high glycaemic index or load. Moderate evidence with three of the Bradford Hill criteria satisfied included, apart from fish, marine omega-3 fatty acids, alcohol and folate, whole grains, dietary sources of vitamins E and C, beta carotene, fruit, and fibre. Among the dietary exposures with strong evidence of causation from cohort studies, only a Mediterranean dietary pattern related to CHD in randomised trials.

In this analysis there were 15 cohort studies trials dealing with dietary fibre and the pooled analysis of these cohorts showed a relative risk of 0.78 (0.72-0.85) for coronary events and secondary outcomes associated with a high fibre diet. There was, however, only one randomised trial that selectively dealt with fibre. Nevertheless, the Mediterranean diet was specified as one which contained a higher intake of vegetables, legumes, fruits, nuts, whole grains, cheese or yogurt, fish, and monounsaturated relative to saturated fatty acids.

Given this perspective the issue then is the sources and amount of fibre which could be considered reasonable from a cardiovascular, as distinct from a gastrointestinal, point of view. Recently the EPIC consortium relating diet to disease has evaluated the carbohydrates and fibre intakes across Europe.[17] Unfortunately, the basis for the assessment was the AOAC figures for fibre and on this basis the fully adjusted high intakes of fibre for health conscious, moderately active, normal weight UK men seems to be about >35 g/d and for UK women > 27 g/d. Figures are not yet available to characterise the fibre or NSP content of a Mediterranean diet from this data set but recent Spanish analyses[18] of fibre intakes in relation to carotid intimal thickening—taken as an important biological index of important atherosclerosis—showed an inverse relationship between fibre intakes and intimal thickening with the higher fibre intakes set at >35 g/d in adults. In other words, the levels are similar to that inferred for men from the EPIC data set.

1.1.1.5 Conclusions

The different suggested goals are set out in Table 3.

Table 2 Suggested population goals for fibre intakes

Study	**Intermediate target g/dNSP; (g/d fibre)**	**Intermediate target g/dNSP/MJ; (g/d fibre/MJ)**	**Longer term goal g/dNSP; (g/d fibre)**	**Longer term goal g/d NSP/MJ; (g/d fibre/MJ)**
WHO 797 1990	16 g NSP			
WHO 916 2003	20 g NSP			
WCRF/AICR 2009			>25 g NSP	
EFSA 2010	(>25 g fibre)	(2 g fibre/MJ)		
This report: EHN 2010	**>20 g NSP (>27 g fibre)**	**1.6 g NSP/MJ (>2.2 g fibre/MJ)**	**>25 g NSP (>35 g fibre)**	**>2.gNSP/MJ (>2.8 g fibre/MJ)**

On the basis of current evidence in relation to cardiovascular disease it seems reasonable to conclude that fibre intakes should be consumed as whole foods with a mix of whole grain cereals, legumes, vegetables and fruit and that the intermediate target for average population intakes should be >20 g NSP (> 1.6 g/d NSP/MJ) or 27 g AOAC fibre with an optimum goal of a population average intake of >25 g NSP (>2 g NSP/MJ) or >35 g AOAC fibre (2.8 g fibre/MJ).

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