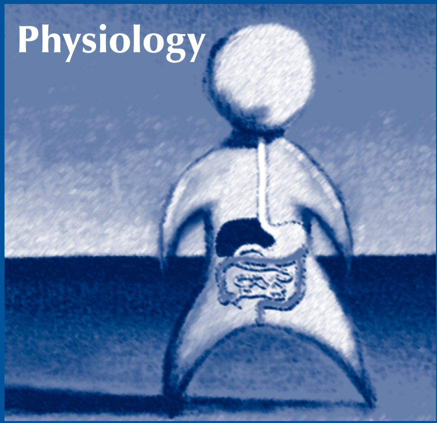
ILSI EUROPE CONCISE MONOGRAPH SERIES

DIETARY FIBRE



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DIETARY FIBRE

DEFINITION, ANALYSIS, PHYSIOLOGY & HEALTH

by Juliet Gray

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FOREWORD

The last decade has seen significant developments in our knowledge of dietary fibre and its role in preservation of health and disease risk reduction. The concept has broadened, and the quest for a universally recognised definition of dietary fibre continues. In defining fibre, the emphasis has shifted from analytical methodology to physiological impact, and it is no longer possible to apply a single analytical method to measure the quantity of dietary fibre in foods.

Although the underlying science remains complex, consumers now seem to be more aware of the fibre concept. Nevertheless, it has become clear that fibre consumption in most developed nations is suboptimal and strategies to encourage consumers to increase their fibre intake have achieved prominence.

ILSI Europe first summarised the then available evidence on dietary fibre in 1996 in its Concise Monograph entitled *Dietary Fibre*. The purpose of the present Concise Monograph, developed under the auspices of the ILSI Europe Dietary Carbohydrates Task Force, is to bring the subject up-to-date, highlighting the current status of deliberations concerning an appropriate definition of dietary fibre, the possible methods of analysis, and physiological and health aspects. It includes data on fibre intakes in a number of countries, as well as an overview of recommendations for intake.

In November 2005, the FAO/WHO Codex Committee on Nutrition and Foods for Special Dietary Uses reached consensus on a definition of dietary fibre. This, it is hoped, will pave the way for harmonisation of the definition of dietary fibre in food labelling legislation.

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SUMMARY

Definitions and composition

The concept of dietary fibre has changed considerably in recent years. It is now recognised that dietary fibre encompasses a much broader range of substances than was acknowledged previously and that it has greater physiological significance than previously thought. There is no generally accepted definition of dietary fibre in Europe or worldwide. However, there is a consensus that a physiologically based definition is necessary.

Non-digestibility in the small intestine is a key physiological characteristic of dietary fibre. Recent definitions of dietary fibre have therefore encompassed – in addition to non-starch polysaccharides – other non-digestible carbohydrates such as resistant starch and non-digestible oligosaccharides. Research over recent decades has identified the following main physiological effects of dietary fibre: improvements in large bowel function, lowering of blood cholesterol, and attenuation of post-prandial blood glucose and insulin levels. These physiological characteristics have been incorporated into recent definitions of dietary fibre.

According to the more recent definitions, dietary fibre consists of carbohydrate polymers and non-starch polysaccharides that are primarily components of plant cell walls. These include cellulose, hemicelluloses, hemiglucans and pectins, as well as other polysaccharides of plant and algal origin, such as gums and mucilages. Other components included are indigestible storage polysaccharides such as inulin and resistant starch. Recent definitions also encompass analogous non-digestible carbohydrates that pass through the small intestine unchanged. Examples of such are resistant starch, resistant maltodextrins, fructo-oligosaccharides and galacto-oligosaccharides, as well as modified celluloses and synthesised carbohydrate polymers such as polydextrose. They furthermore include associated substances such as lignin and other substances extracted with the polysaccharides and oligosaccharides in fibre analytical methods (e.g. waxes, cutin, polyphenols and phytosterols). The latest definition proposed by Codex Alimentarius includes carbohydrate polymers with a degree of polymerisation not lower than 3. They can be naturally present in or extracted from food raw material, or synthesised. The debate continues and some recent opinion has favoured a return to the original fibre definition along the lines that 'Dietary fibre consists of intrinsic plant cell wall polysaccharides'.

Analysis

The basis for both legal definitions and analysis of dietary fibre is, in many cases, the enzymatic, gravimetric methods approved by the *Association of the Official Analytical Chemists* (AOAC). However, dietary fibre as now defined cannot be measured by a single method of analysis because of the diversity of its constituents. For instance, the standard method or any other method for analysis of dietary fibre or non-starch polysaccharides does not measure oligosaccharides that are soluble in alcohol. Furthermore, in some cases, e.g. in the UK, food manufacturers tend to use AOAC whereas composition tables and dietary intake recommendations tend to be based on data produced with the Englyst method.

Consumption

Methods of data collection and analysis influence estimates of dietary fibre consumption. This limits comparison between different countries and populations. As yet there is even more limited information on the consumption of components of dietary fibre, such as resistant starch and non-digestible oligosaccharides.

Recommendations

There are also considerable differences between recommendations for dietary fibre consumption worldwide. These differences reflect variations in the way dietary reference values are defined, as well as the above-mentioned differences in analysis and definition of dietary fibre. Even with these reservations in mind, it is still clear that among adults in Western countries average dietary fibre intakes fall short of intakes recommended for maintenance of health and disease prevention. There is a paucity of data on the effects of dietary fibre in children. With the exception of the United Kingdom, The Netherlands and the USA, most countries have not made recommendations concerning dietary fibre intake during childhood.

Health benefits

The colonic microflora partially or completely ferments carbohydrates that resist digestion and absorption in the small intestine. The fermentation products, notably the short chain fatty acids, play a key physiological role both locally and systemically. Undigested carbohydrate that reaches the large intestine softens stool consistency and increases stool weight and frequency of defaecation. At higher dietary fibre intake stool weight tends to be higher and transit time longer. Both factors may contribute to the prevention of large bowel disorders such as constipation, diverticulitis and large bowel cancers. Most non-absorbed carbohydrates have laxative effects, both by increasing bacterial mass or osmotic effects, and by water binding to remaining unfermented fibre.

The aetiology of cancer involves both inherited and environmental (dietary) factors. Many large studies, mainly observational, have assessed the relationship between fibre intake and the risk of cancer in the colon or rectum. Intervention studies have addressed the effects of dietary fibre on the recurrence of adenoma, which are generally considered as an early marker for colorectal cancer. The overall evidence for an effect of total fibre intake on the risk of colorectal cancer is not considered sufficient to serve as a basis for guidelines on dietary fibre intake. However, individuals with (very) low fibre intakes may have an increased risk.

Recent observational studies consistently show an inverse association between dietary fibre intake and the risk of coronary heart disease. In intervention studies an increased dietary fibre intake decreased levels of coronary heart disease risk factors, e.g. circulating cholesterol and triglycerides. Several recent guidelines for fibre intake are therefore based on its effect on the risk of cardiovascular disease. Postulated mechanisms for lower levels of total and low density lipoprotein (LDL) cholesterol include alterations in cholesterol absorption and bile acid re-absorption, and alterations in hepatic metabolism and plasma clearance of lipoproteins. Highly viscous fibres (such as oat ß-glucans, pectins, guar gum) influence blood lipid levels, whereas non-viscous fibres, such as wheat fibre and cellulose, generally do not. In some countries the evidence for the cholesterol-lowering properties of certain viscous fibres, especially ß-glucans from oats, is considered sufficient for claims on the reduction of the risk of coronary heart disease.

Some cohort studies show an inverse association between dietary fibre intake and the risk of developing type 2 diabetes. Some dietary fibres reduce the glycaemic response. Viscous fibres have been shown to have such effect both in intact foods as well as in isolated supplement form. Paradoxically, prospective observational data show that the intake of non-viscous dietary fibre, e.g. like that in whole grain cereals, is a better predictor of the risk of insulin resistance and diabetes (risk being lower at higher intakes).

Dietary fibre consumption is inversely associated with body mass index. However, results of intervention studies on appetite, energy and total food intake are inconsistent. There are some indications that viscous fibres such as pectins and guar gum delay gastric emptying, and that slowly digested starch and resistant starch increase satiety.

Do isolated or synthetic, so-called functional components have similar effects when added to foods or taken separately as supplements, as when they are part of the intact structure of foods? There is evidence that the benefits of whole grains, fruits and vegetables outweigh those of the isolated components of these foods (used either as supplements or added to foods). Possibly other, as yet unidentified, substances in such foods can explain this; perhaps it is the overall combination of the dietary fibre, nutrients and bioactive substances, acting synergistically, that is critical to health. However, there are also isolated types of dietary fibre, such as resistant starch, non-digestible oligosaccharides and polydextrose, that help in the prevention and alleviation of bowel disorders, and decrease risk factors for coronary heart disease and type 2 diabetes.

Adverse effects

Diets containing large quantities of dietary fibre may be bulky and of relatively low energy density. This may make them unsuitable for very young and very old people. Isolated or synthetic types of dietary fibre, such as non-digestible oligosaccharides or resistant starch have been reported to cause gastrointestinal symptoms such as flatulence. Generally such effects, if occurring at all, are only seen at high intake levels and may be transitory. There is also some evidence that high intakes of certain types of dietary fibre, particularly those associated with phytate, reduce the absorption in the small intestine of several minerals: iron, calcium, magnesium and zinc. On the other hand, dietary fibre may improve colonic mineral absorption during the fermentation process. However, the significance of this latter observation to overall mineral status and to physiological endpoints such as bone health is uncertain. The balance of calcium and magnesium is not adversely affected by large amounts of cereals, vegetables and fruits. Generally, consumption of foods naturally rich in fibre is self-limiting due to their bulking character. However, this applies to a lesser extent to foods enriched with fibre, and much less to supplements.

DEFINITIONS

History

The understanding of the physiological significance of substances defined as dietary fibre and thus the concept of dietary fibre has progressed considerably over the past ten years. It is now recognised that it encompasses a much broader range of substances than was originally acknowledged. As yet, there is no generally accepted definition of dietary fibre in Europe or beyond, but there has been considerable progress recently in the debate about how fibre should be defined. A precise, but sufficiently broad, definition of dietary fibre is of great importance globally. It is vital for food manufacturers and retailers and for regulatory authorities, in order to provide valid and accurate information for product labelling and in the development of a regulatory framework for nutrition and health claims. Such information is necessary for consumers who use the nutritional values declared on food labels and in associated material.

The term dietary fibre was first adopted in 1953 by Hipsley to describe the plant cell wall components of food. The physiological significance of dietary fibre came to the fore in 1971 when Burkitt recommended an increase in dietary fibre intake to improve bowel function, based on comparative observations of intakes and disease incidence in the UK and Africa. Since 1972, when Trowell first defined dietary fibre as *the remnants of the plant cell wall that are not hydrolysed by the alimentary enzymes of man*, many definitions have been proposed by different national, international and industrial organisations. Many of these definitions have been based primarily on analytical criteria and have been developed with nutrition labelling in mind. In most countries, fibre has been defined for labelling purposes by various analytical methods accepted by the *Association of Official Analytical Chemists International* (initially the AOAC method 985.29, see also Box 1). The principal methods of dietary fibre analysis currently in use are summarised in Table 1.

In the UK, a chemical definition of dietary fibre as *non-starch polysaccharides plus lignin*, based on the analytical methodology of Englyst, Cummings and colleagues, has been in use since 1991 in tables of food composition. However, this has been superseded by AOAC methods for labelling purposes.

Non-starch polysaccharides (defined as polysaccharides with a degree of polymerisation ≥10) are often considered specific for the intrinsic cell wall components of dietary fibre, but methods also include naturally occurring or added extrinsic products such as gums and pectins and modified or synthetic fibre types such as modified cellulose. However, as with other current methods, components such as oligosaccharides and polydextrose are not measured due to their solubility in the aqueous alcohol used to precipitate water-soluble components. Its major disadvantage is that it is based on a narrow definition that excludes lignin, resistant starch and non-digestible oligosaccharides but potentially includes non-plant (bacterial and fungal) polysaccharides.

Physiological definition

Physiological properties of dietary fibre determine its importance in the human body and its requirement in the human diet. Therefore, most scientists now agree that the definition of dietary fibre should be physiologically based. However, historically and for labelling purposes, physicochemical characteristics distinguish types of dietary fibre. The specification of

BOX 1

Analysis of dietary fibre

Since 1985, the main official method for measurement of total fibre has been the enzymatic-gravimetric method of the *Association of Official Analytical Chemists* (AOAC 985.29). It is based on the concept of resistance to digestion. It uses enzymatic digestion to eliminate non-fibre components and quantification of the residues by weighing (hence the term 'gravimetric'). The methods and enzymes used have strict criteria of performance and purity. Its use has been advocated in part because of its purported reproducibility, but this was not confirmed by a European Commission certification study in 1996.

In the UK, whereas the AOAC method is used for labelling purposes, the amount of dietary fibre is measured as non-starch polysaccharides by the Englyst method for the purposes of food composition tables. This uses an enzymatic and chemical (solvent) extraction and separation of fibre components from digestible carbohydrates, and subsequent quantification by colorimetry, GLC, or HPLC. Resistant starch can be quantified separately by other methods (see Table 1). The Englyst method has the advantage of clearly identifying components classified as non-starch polysaccharides and separate quantification of resistant starch and non-digestible oligosaccharides without major interference between the various methods. Its major disadvantage is its questionable reproducibility.

A range of other AOAC and the *American Association of Cereal Chemists* (AACC) approved methods have been developed to measure the broad range of components of dietary fibre, including resistant starch, non-digestible oligosaccharides and non-digestible synthesised carbohydrate polymers. These methods must also conform to specified, strict performance criteria.

If there is agreement that a) dietary fibre is the sum of non-starch polysaccharides, resistant starch and non-digestible oligosaccharides and that b) three (or possibly more) methods are required for complete analysis of these components, then it is important to ensure that there is no overlap in quantification among these methods. Internationally, the originally accepted method for measurement of dietary fibre was AOAC method 985.29. It has now become clear that a variety of methods may be necessary for different dietary fibres (Table 1). In order to validate labelling declarations and claims, it may be necessary to specify different methods for measurement of the dietary fibre content in different foods. It may depend on, for example, the presence of non-digestible carbohydrates not properly quantified by AOAC 985.29 or 991.43, such as resistant starch or polydextrose.

The proposed Codex Alimentarius Commission definition of dietary fibre (Box 2) includes a specified list of AOAC analytical methods on the basis that this methodology is used worldwide for routine analysis. In addition to methods AOAC 985.29 and 991.43 for total dietary fibre in most foods, methods AOAC 995.16, 2002.02, 999.03, 997.08, 2001.02, 2001.03 and 2000.11 can be used for complementary measurement of the other components within the definition. Codex also notes that the Englyst method or similar methods may be necessary for food products that are difficult to analyse with the above routine methods, for example infant formulas.

TABLE 1

Principal methods of dietary fibre analysis

Name	Type	Components measured	Comments
Total dietary fibre;	Enzymatic-gravimetric AOAC 985.29 AOAC 991.43	Soluble + insoluble polysaccharides (including RS3) + lignin	Quantifies only part of the RS3 fraction of total resistant starch, Inulin, polydextrose fructooligosaccharides and resistant maltodextrins
Englyst method for NSP	Enzymatic-chemical or GLC or HPLC	Non-starch polysaccharides	Consistent with *in vivo* data; Reproducibility may be low
Uppsala method AOAC 994.13	Enzymatic-chemical	Soluble + insoluble polysaccharides (including RS3) + lignin	Few users
AOAC 995.16; AACC32-33	Enzymatic	Beta-glucans	
Englyst method for resistant starch	Enzymatic	Resistant starch	Consistent with *in vivo* data; Reproducibility may be low
AOAC 2002-02; AACC 37.42	Enzymatic	Resistant starch and algal fibre	Consistent with *in vivo* data
AOAC 999.03	Enzymatic and colorimetric	Fructans (oligofructans, inulin derivatives, fructo-oligosaccharides)	
AOAC 997.08	Enzymatic and ion-exchange chromatography	Fructans (oligofructans, inulin derivatives, fructo-oligosaccharides)	
	Chromatography Ion exchanger	Fructans (oligofructans, inulin derivatives, fructo-oligosaccharides)	
AOAC 2000.11	HPAEC	Polydextrose	
AOAC 2001.02	HPAEC-PAD	Trans-galacto-oligosaccharides	
AOAC 2001.03	Enzymatic, gravimetric and liquid chromatography	Total dietary fibre in foods containing resistant maltodextrins	

Adapted from AFSSA, 2002

the beneficial health effects of dietary fibre within the definition eliminates substances which might be added to foods because of techno-functional properties but which do not have positive health benefits.

Before considering these physiological properties, it is important to emphasise that dietary fibre comprises different components in variable proportions in different foods. Dietary fibres from different sources may not all produce the full range of positive physiological effects that research has shown dietary fibre to have. Some effects are specific to certain fibres.

Non-digestibility is the key characteristic of dietary fibre, and thus key in its definition. It means that it is neither digested nor absorbed in the human small intestine and it will pass into the large intestine, where it will induce a range of effects. Therefore, recent definitions have been extended to include non-digestible carbohydrates such as resistant starch and non-digestible oligosaccharides. In this context, it is essential to define the concept of digestibility as small intestinal or ileal digestibility, that is digestion occurring in the upper part of the digestive tract. However, it must be understood that the criterion of 'non-digestibility' is absolute only for non-starch polysaccharides and other dietary fibre components for which digestive enzymes are not produced in the human upper gastrointestinal tract. For resistant starch it is relatively imprecise, because upper intestinal digestibility may vary between subjects and may depend on factors such as chewing efficiency and gastrointestinal transit time. The term *unavailable carbohydrate* is sometimes used as an alternative to non-digestible carbohydrates, as distinct from *available* or *glycaemic* carbohydrate, i.e. carbohydrate that is digested and absorbed and becomes available for the body.

A large proportion of the non-digestible carbohydrates and related compounds that escape digestion in the small intestine are partially or completely fermented by the microflora of the large intestine. The process of fermentation is essential to large bowel function but it also has more far-reaching physiological consequences. Therefore, the stimulation of fermentation in the large bowel is a further key, although not universal, physiological characteristic that is agreed should be embraced within the definition of dietary fibre. Non-digestible food components that selectively stimulate the growth and/or activity of one or a limited number of beneficial bacteria (mostly lactic bacteria such as bifido-bacteria) in the colon are termed *prebiotics*. Prebiotics may also be fibres and fibres may also have prebiotic effects, but the two terms are not interchangeable.

Research over the past five decades has identified the following key effects of dietary fibre: improvements in large bowel function (stool bulking, laxation, fermentation), lowering of blood cholesterol levels and lowering of post-prandial blood glucose and insulin levels. Recent definitions have encompassed these physiological characteristics. Definitions will undoubtedly evolve as further scientific evidence on the effects of dietary fibre becomes available.

Most recent definitions

The most recent definitions of dietary fibre emanate from the *American Association of Cereal Chemists*, the US *Institute of Medicine*, the *Agence Française de Sécurité Sanitaire des Aliments*, the *Codex Alimentarius Commission* and the *Health Council of The Netherlands* (Box 2). These definitions all take into account the physiological characteristics of dietary fibre, but with a varying emphasis.

BOX 2

Recent definitions of dietary fibre

American Association of Cereal Chemists (AACC, 2001)
The edible parts of plants or analogous carbohydrates that are resistant to digestion and absorption in the human small intestine, with complete or partial fermentation in the large intestine. Dietary fibre includes polysaccharides, oligosaccharides, lignin and associated plant substances. Dietary fibres promote beneficial physiological effects including laxation, and/or blood cholesterol attenuation, and/or blood glucose attenuation.

Dietary Reference Intakes for Energy, Carbohydrates, Fibre, Fat, Protein and Amino Acids (Macronutrients), Institute of Medicine (2002)
Dietary Fibre consists of non-digestible carbohydrates and lignin that are intrinsic and intact in plants.
Functional Fibre consists of isolated, non-digestible carbohydrates that have beneficial physiological effects in humans.
Total Fibre is the sum of *Dietary Fibre* and *Functional Fibre*.

Agence Française de Sécurité Sanitaire des Aliments (AFSSA, 2002)
Dietary fibre consists of:
- Carbohydrate polymers (Degree of polymerisation ≥3) of plant origin with lignin or other non-carbohydrate components (e.g. polyphenols, waxes, saponins, cutin, phytates, phytosterols). AND
- Carbohydrate polymers (Degree of polymerisation ≥3), processed (by physical, enzymatic or chemical means) or synthetic.
- IN ADDITION dietary fibre is neither digested nor absorbed in the small intestine. It has at least one of the following properties:
  - Stimulates colonic fermentation
  - Reduces preprandial cholesterol levels
  - Reduces post-prandial blood sugar and/or insulin levels.

Codex Alimentarius Commission (CAC, 2006)
Dietary fibre means carbohydrate polymers* with a degree of polymerisation not lower than 3, which are neither digested nor absorbed in the small intestine. A degree of polymerisation not lower than 3 is intended to exclude mono- and disaccharides.
It is not intended to reflect the average degree of polymerisation of a mixture. Dietary fibre consists of one or more of:
- edible carbohydrate polymers naturally occurring in the food as consumed,
- carbohydrate polymers, which have been obtained from food raw material by physical, enzymatic, or chemical means,
- synthetic carbohydrate polymers

Dietary fibre generally has properties such as:
- Decrease intestinal transit time and increase stool bulk
- Fermentable by colonic microflora
- Reduce blood total and/or LDL cholesterol levels
- Reduce post-prandial blood glucose and/or insulin levels.

Health Council of The Netherlands (2006)
Dietary fibre is the collective term for substances that are not digested or absorbed in the human small intestine, and which have the chemical structure of carbohydrates, compounds analogous to carbohydrates, and lignin and related substances.

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* When from plant origin, dietary fibre may include fractions of lignin and/or other compounds when associated with polysaccharides in plant cell walls and if these compounds are quantified by the AOAC gravimetric analytical method for dietary fibre analysis. Fractions of lignin and/or other compounds (e.g. proteic fractions, phenolic compounds, waxes, saponins, phytates, cutin, phytosterols) intimately associated with plant polysaccharides are often extracted with the polysaccharides in the AOAC 991.43 method. These substances are included in the definition of fibre insofar as they are actually associated with the poly- or oligo-saccharidic fraction of fibre. However, when extracted or even re-introduced into a food containing non-digestible polysaccharides, they cannot be defined as dietary fibre. When combined with polysaccharides, these associated substances may provide additional beneficial effects.

TABLE 2

Elements of definitions of dietary fibre

- Biological or synthetic origin of the fibre.
- Chemical nature of the substances included.
- Minimum degree of polymerisation of the carbohydrate polymers.
- Resistance to hydrolysis (digestion) by the enzymes of the gastrointestinal tract.
- Reference to a method of analysis.
- Reference to fermentability in the colon, including short chain fatty acid production and associated physiological effects, such as reduction of toxic stool components, mineral absorption, prebiotic properties.
- Reference to other measurable physiological properties, such as laxative or metabolic effects (e.g. reduction in blood cholesterol or blood glucose or insulin levels).

Adapted from AFSSA, 2002

In 1999, the *American Association of Cereal Chemists* proposed a definition that was restricted to plant sources and did not include physiological aspects. This was updated in 2001 and has the major advantage of being simple and straightforward. It does not refer to the origin of the dietary fibre and encompasses the various physiological characteristics of different fibres. It is more precise than earlier definitions that referred only in very general terms to the physiological properties of dietary fibre.

The US *Institute of Medicine* (2001) used a novel approach in distinguishing between intrinsic, intact components of plant foods, *dietary fibre*, and *added fibre*, summed as *total fibre*. This definition was modified later on (2002), as part of the development of dietary reference intakes. *Added fibre* was reclassified as *functional fibre*, to indicate the requirement for physiological benefits and functionality of the isolated non-digestible carbohydrates added to foods. However, the definition does not include any precise description of the physiological characteristics of fibre. It also creates an artificial, analytically impossible and therefore in practice non-existing distinction between fibres naturally present in plant cells and those extracted from plant sources or synthetically produced. The term *functional fibre* may also imply that fibres other than *functional fibre* are not or at least less functional, which is not the case. The term *functional foods* has a similar drawback.

Most recently, the *Agence Française de Sécurité Sanitaire des Aliments* (2002) reviewed existing definitions of dietary fibre and usefully identified the criteria covered by these definitions (Table 2). It observed that no definition before 2002 had been sufficiently comprehensive to encompass all of these criteria and proposed a broader but much more complex definition, although it is mostly confined to fibres of plant origin or synthetic fibres, excluding fibres of animal or microbial origins.

The definition of the *Agence Française de Sécurité Sanitaire des Aliments* is one of the most comprehensive definitions to date. In common with the definition of the *American Association of Cereal Chemists*, it encompasses fibres that are carbohydrate polymers naturally present in plant foods (but not animal foods), as well as non-carbohydrate associated materials (for example, lignin, polyphenols and waxes). In common with the US *Institute of Medicine* definitions, the *Agence Française de Sécurité Sanitaire des Aliments* also includes processed and synthetic fibres, because of the important physiological properties of these materials. It is, however, more specific in including, as an annex, a positive list of these compounds for labelling purposes (Table 3). It is stipulated that compounds can be

TABLE 3

Carbohydrate polymers either processed (by physical, enzymatic or chemical means), or synthetic, likely to be accepted within the definition of dietary fibre

Substance	Mode of obtaining	Recognised physiological properties	Validation(s) by public bodies
OLIGOSACCHARIDES			
Fructo-oligosaccharides*	Enzymatic synthesis from saccharose*	Inclusion in the category of dietary fibre Bifidogenic ingredient	CEDAP (13/09/95 Scientific Committee for Food (DGXXIV, Brussels) (July 1997)
Oligofructose*	Enzymatic hydrolysis of inulin in chicory root*	Idem	Idem
ß-galacto-oligosaccharides or transgalacto-oligosaccharides (TOS)	Enzymatic transgalactosylation of lactose	Prebiotic effect	
Gluco-oligosaccharides	Enzymatic trans-glucosidation of glucose	Prebiotic effect (few trials, none in humans)	
Xylo-oligosaccharides (XOS)	Enzymatic hydrolysis of polyxylan of *Trichoderma* sp.		
ßeta-cyclodextrins		Very few studies	
Resistant maltodextrins	Heat and enzyme treatment applied to maize starch	Prebiotic effect	
Other dextrins	Dextrinisation followed by a chromatographic step		
POLYSACCHARIDES			
Resistant starch	Hydrothermal treatment of tapioca maltodextrins and enzymatic debranching	Stimulates colonic fermentation	Source of butyrate C*ActiStar® should be deemed to be an ingredient by the European Union
Polydextrose (E1200)*	Heat polymerisation of glucose in the presence of sorbitol and acid (permitted) as catalyst	Stimulates colonic fermentation	Endorsed as fibre by AFSSA

* Proposed by AFSSA for immediate inclusion – the others require further examination by AFSSA.
** Requires further substantiation
Adapted from AFSSA 2002

accepted into this category only on the basis of evidence. Finally, the *Agence Française de Sécurité Sanitaire des Aliments* includes a physiological definition of dietary fibre – namely that it is *neither digested nor absorbed in the small intestine*. Unlike previous definitions, it also specifies that to be defined as dietary fibre, a substance should have at least one other physiological property, to increase stool production, to stimulate colonic fermentation, to reduce fasting blood cholesterol levels, or to reduce blood glucose or insulin levels.

The Codex Alimentarius Commission has developed this definition further in 2006. It specifies that dietary fibre means *carbohydrate polymers with a degree of polymerisation not lower than 3 which are neither digested nor absorbed in the small intestine*. It includes edible polymers naturally occurring in food (of either plant or animal origin) and carbohydrate polymers that are either extracted from food raw material or are synthesised. It notes that fibres of plant origin may include associated materials such as lignin or other compounds, if these compounds are quantified by the AOAC method for total dietary fibre.

The proposed Codex definition includes the important criterion of non-digestibility in the human small intestine and specifies a range of physiological benefits of different fibre components. Its main advantage over earlier analytically based definitions is that it allows for the fact that there are greater similarities in terms of physico-chemical or physiological characteristics between, for example, resistant starch, non-digestible oligosaccharides and fermentable non-starch polysaccharides, than between the category of non-starch polysaccharides as a whole. It is therefore more meaningful in physiological terms.

The *Health Council of The Netherlands* (2006) defined dietary fibre as *substances that are not digested or absorbed in the human small intestine, and which have the chemical structure of carbohydrates, compounds analogous to carbohydrates, and lignin and related substances.* The debate continues and some recent opinion has favoured a return to the original fibre definition along the lines that 'Dietary fibre consists of intrinsic plant cell wall polysaccharides'.

Soluble and insoluble dietary fibre

Early chemistry of non-starch polysaccharides extracted different fibre fractions by controlling the pH of solutions; in this context the terms *soluble* and *insoluble* fibre evolved. They provided a useful simple categorisation of dietary fibre with different physiological properties, as understood at the time. On the one hand, there are fibres that principally affect glucose and fat absorption. Historically, these were referred to as *soluble* because many of them were viscous and formed gels in the small intestine (e.g. pectins and ß-glucans). In contrast, types of dietary fibre with a greater influence on bowel function were referred to as *insoluble* (including cellulose and lignin). It is now apparent that this simple physiological distinction is inappropriate because some *insoluble* fibre is rapidly fermented and some *soluble* fibre does not affect glucose and fat absorption. As the terms *soluble* and *insoluble* may be misleading, the *World Health Organization* and the *Food and Agricultural Organisation* recommended already in 1998 that they should no longer be used.

COMPOSITION AND TYPES OF DIETARY FIBRE

Introduction

Although the concept of dietary fibre has been debated for decades, the constituents now considered part of it are not very different today from those discussed several decades ago (Table 4). They consist primarily of carbohydrate polymers (non-starch polysaccharides) that are components of plant cell walls, including cellulose, hemicelluloses and pectins, as well as other polysaccharides of plant or algal origin, such as gums and mucilages and oligosaccharides such as inulin. Analogous non-digestible carbohydrates that pass through the small intestine unchanged but are fermented in the large intestine should also be included, for example resistant starch, fructo-oligosaccharides, galacto-oligosaccharides, modified celluloses and synthesised carbohydrate polymers, such as polydextrose. Associated substances, principally lignin, and minor compounds including waxes, cutin, saponins, polyphenols, phytates and phytosterols, are also included, insofar as they are extracted with the polysaccharides and oligosaccharides in various fibre analytical methods. However, with the exception of lignin, these associated substances when isolated, could not be described as dietary fibre. The *Agence Française de Sécurité Sanitaire des Aliments* and *Codex Alimentarius* definitions exclude carbohydrate polymers with a degree of polymerisation lower than 3. Listed here is a brief description of the most important, commonly occurring components of dietary fibre that occur naturally or are used as food ingredients.

Cellulose

Cellulose is an unbranched and linear polysaccharide consisting only of glucose units, up to 10,000 glucose units per molecule. The linear molecules are packed closely together as long fibres in a structure that is very insoluble and resistant to digestion by human enzymes. Cellulose is a principal component of the cell wall of most plants (Figure 1) and is therefore present in fruits, vegetables and cereals. Much of the fibre in cereal bran is cellulose. Cellulose forms about one quarter of the dietary fibre in grains and fruit and one third in vegetables and nuts.

Hemicelluloses

Hemicelluloses are polysaccharides that contain sugars other than glucose, and are associated with cellulose in plant cell walls. They include both linear and branched molecules, smaller than cellulose, typically containing 50-200 pentose units (xylose and arabinose) and hexose units (glucose, galactose, mannose, rhamnose, glucuronic and galacturonic acids). The name hemicellulose therefore describes a heterogeneous group of chemical structures that are present in plant foods in water soluble and insoluble forms. Approximately one third of the dietary fibre in vegetables, fruits, legumes and nuts consists of hemicelluloses.

Pectins

Pectins are polysaccharides that are soluble in hot water and then form gels on cooling. They are composed mainly of chains of galacturonic acid interspersed with units of rhamnose and are branched with chains of pentose and hexose units. They are present in the cell walls and intracellular tissues of fruit and vegetables and are used as gelling and thickening agents in various food products. Although fruits contain the most pectins, they also represent 15-20% of the dietary fibre in vegetables, legumes and nuts.

ß-Glucans

ß-glucans are glucose polymers. Unlike in cellulose, the linkages between the units are variable, they have a branched structure and are of smaller size. These

TABLE 4

Proposed constituents of dietary fibre (AACC, 2001)

Non-starch polysaccharides and non-digestible oligosaccharides

- Cellulose
- Hemicelluloses
- Pectins
- Beta-glucans
- Gums
- Mucilages
- Fructans
- Inulin
- Oligofructoses/Fructo-oligosaccharides

Analogous carbohydrates

- Resistant starches
- Fructo-oligosaccharides
- Galacto-oligosaccharides
- Indigestible dextrins
- Modified or synthesised carbohydrate compounds
- Modified celluloses (methyl cellulose, hydroxypropylmethyl cellulose)
- Polydextrose

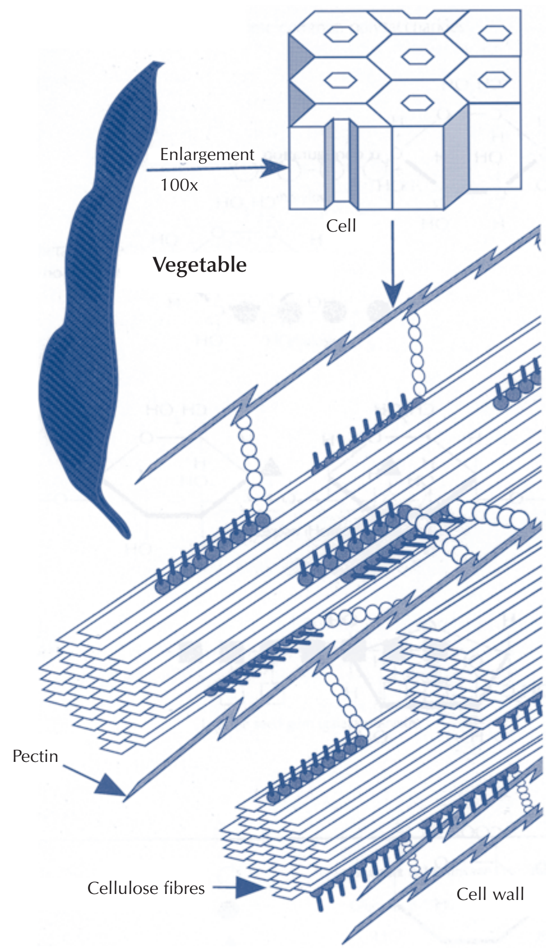
Lignin and other associated substances

- Lignins
- Waxes
- Phytate
- Cutin
- Tannins

properties influence their solubility, enabling them to form viscous solutions. ß-glucans are a major component of the cell wall material in oats and barley grains but are present in only small quantities in wheat. They have generated interest as a source of soluble fibre. Oat bran has been added to some food products as a source of these ß-glucans.

FIGURE 1

Model of the plant cell wall



The fibres of food are mostly the elements that give the structure for the cell wall and the connective tissue of the plants

TABLE 5

Starch content in selected foods

Food	Total Starch g/100 g dry matter	Resistant Starch g/100 g total starch
White bread	77	1.2
Wholemeal bread	60	1.7
Shredded wheat	71	0
Corn flakes	78	3.8
Porridge oats	65	3.1
Rye crisp bread	61	4.9
Potato, boiled, hot	74	6.8
Potato, boiled, cold	75	13.3
Spaghetti, freshly cooked	79	6.3
Peas, cooked	20	25
Haricot beans, cooked	45	40

Source: Englyst *et al.*, 1992

Resistant starch

Starch and starch degradation products that are not absorbed in the small intestine of healthy humans are referred to as *resistant starch*. It is present in a wide range of carbohydrate-containing foods in varying proportions (Table 5). Four classes of resistant starch have been identified: physically inaccessible starch (RS1), native starch granules (RS2), retrograded starch (RS3) and chemically modified starch (RS4) (Box 3). Legumes are one of the main sources of RS1 as they have thick cell walls that make the starch inaccessible to enzymes. The cooking and processing of foods can disrupt cell walls, making the starch more available for digestion. Certain types of starch, such as in raw potatoes and under-ripe bananas, are very resistant to enzymic hydrolysis (RS2). However, unlike bananas, potatoes are eaten in a cooked form, and most cooking processes allow the gelatinisation of starch. Therefore, banana is the major source of RS2 in the human diet. The amount of RS2 in a banana depends on its ripeness. Another category of RS2 is high amylose starches that are frequent sources of industrial resistant starch. Cooking, cooling and storage of foods without prior drying causes retrogradation (recrystallisation) of gelatinised starch: RS3. Reheating of, for example, cooled potatoes, can reduce the RS3 content. However, repeated cycles of heating and cooling increase RS3 levels in potatoes.

Chemically modified starch (RS4) includes starch ethers and esters, cross-bonded starches and pyrodextrinated starches. The chemical modifications are the reasons for a reduced starch digestibility in the small intestine and thus formation of RS4. Some chemically modified starches that are not subject to alteration of starch digestibility are used as ingredients in products such as baby foods.

BOX 3

Resistant starch (RS)

RS1 – starch that is physically inaccessible e.g. enclosed within intact cell structures in foods such as leguminous seeds and partly milled cereal grains and seeds.

RS2 – native starch granules (of B-type X-ray spectrum), e.g. in maize rich in amylose, raw potatoes, green bananas.

RS3 – retrograded amylose (and to a lesser extent, amylopectin) in processed foods. Food starches may be rendered partially indigestible by physical or chemical processes and by cooling, e.g. in bread, cornflakes and cooled cooked potato or rice.

RS4 – chemically modified starch (including pyrolised, pyrodextrinated starch).

The resistant starch content of a food may change during storage, depending on temperature and water content, and during food preparation. Consequently, an exact quantification of resistant starch in a food item at the time of consumption is impossible. One person may digest a greater proportion of starch in the small intestine, while in another individual this would behave as resistant starch.

Non-digestible oligosaccharides

Non-digestible oligosaccharides with degree of polymerisation ranging from 3-10 occur naturally in plant foods, mainly vegetables, cereals and fruits. They can also be synthesised either chemically or enzymatically from monosaccharides and disaccharides, or by enzymatic hydrolysis of polysaccharides. They are included in the definition of dietary fibre because, as a result of their non-digestibility, they exhibit similar physiological effects as their larger polysaccharide counterparts. They are generally highly fermentable and some have so-called prebiotic properties. The most well known prebiotics are the fructans, which include the fructo-oligosaccharides or oligofructoses, obtained from the enzymatic hydrolysis of naturally occurring inulins (with degree of polymerisation 3-60) and their synthetic analogues obtained through enzymatic synthesis from sucrose. Onions, chicory and Jerusalem artichokes are the major dietary sources of naturally occurring fructans, from which inulin and fructo-oligosaccharides are obtained.

Large numbers of processed and synthetic non-digestible oligosaccharides have been described. Physiological properties have been confirmed for some of these. Primarily these are effects mediated by changes in the activity and/or composition of the human colonic microflora. Therefore, these may be seen to represent new sources of dietary fibre in that they conform to the criteria laid down by recent definitions of dietary fibre. However, not all non-digestible oligosaccharides are universally permitted for food use. Currently, fructo-oligosaccharides and certain galacto-oligosaccharides are permitted within most European countries, USA and Canada. Japan permits a wider range of non-digestible oligosaccharides for food use.

Other synthetic carbohydrate compounds

Like cellulose itself, synthetic derivatives of cellulose, such as methylcellulose and hydroxypropylmethylcellulose, are non-digestible. Unlike their parent molecule they are soluble, but are hardly fermented by the colonic microflora.

Polydextrose is a non-digestible carbohydrate polymer, with an average degree of polymerisation of 12, synthesised from glucose and sorbitol, using an organic acid, such as citric acid, as a catalyst. The result is a complex structure, resistant to hydrolysis by human digestive enzymes. It is partially fermented in the colon – about 50% in humans – and has bulking and prebiotic properties.

Resistant dextrins are produced by heat at alkaline pH and enzymatic treatment of starches, such as maize and potato, resulting in a material of degree of polymerisation approximately equal to 15. They are partially indigestible by human digestive enzymes and partially fermented in the colon. Consequently, they behave physiologically as dietary fibre. The prebiotic effects of these dextrins are yet to be confirmed.

Gums and mucilages

The hydrocolloids comprise a wide range of mixed viscous polysaccharides. They are derived from plant exudates (gum arabic and tragacanth), seeds (guar and locust gums) and seaweed extracts (agar, carrageenans and alginates). Mucilages are present in cells of the outer layers of seeds of the plantain family e.g. ispaghula (psyllium). These hydrocolloids are used in small amounts as gelling, thickening, stabilising and emulsifying agents in certain foods. Some, for example guar gum and ispaghula, are also being investigated and/or used as functional ingredients in foods.

Lignin

Lignin is not a polysaccharide but is chemically bound to hemicellulose in the plant cell wall and therefore it is intimately associated with plant cell wall polysaccharides. It also influences gastrointestinal physiology. It is present in foods with a ‘woody’ component such as celery and in the outer layers of cereal grains.

Other minor associated components

Phytic acid (inositol hexaphosphate) is associated with fibre in some foods, especially cereal grains. Its phosphate groups bind very strongly with positively charged ions such as iron, zinc, calcium and magnesium and may influence mineral absorption from the gastrointestinal tract. Other plant constituents associated with dietary fibre, for example polyphenols (tannins), cutins, and phytosterols, can also have physiological effects.

FOOD SOURCES

The major food sources of dietary fibre and indigestible carbohydrates are plant foods such as cereal grains, legumes, vegetables, fruits and seeds, as shown in Table 6. The term *whole grain* is frequently used in connection with cereals and has recently been redefined by the AACC. In terms of consumption, the major cereal grains are wheat, rice, maize, oats and rye. Minor ones are barley, triticale, millet and sorghum. Buckwheat, wild rice, amaranth and quinoa are not classified as grains botanically, but are associated with them in a dietary context because of their similar composition. The whole grain consists of a protective hull, beneath which are the bran layer, the protein-rich aleurone layer, the endosperm of which 50-75% is starch, and the germ (Figure 2).

Whole grains have a high content of dietary fibre, including resistant starch and non-digestible oligosaccharides, but are also rich in nutrients and potentially beneficial phytochemicals (including phenolic compounds, phytoestrogens and plant sterols). Most of these are located in the aleurone and germ fractions of the grain.

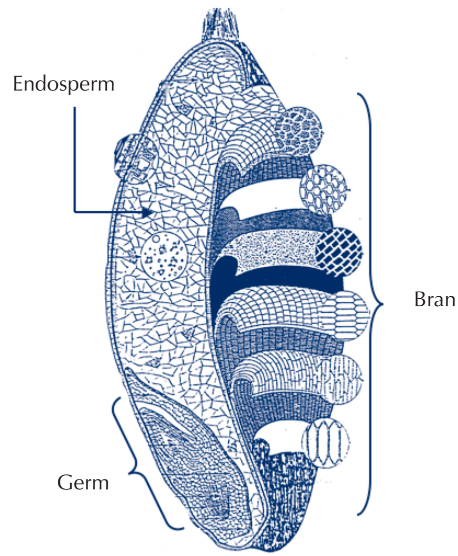
TABLE 6

Natural sources of various components of dietary fibre

Fibre component	Main food source
Cellulose	Vegetables, woody plants, cereal brans
Hemicellulose	Cereal grains
Lignin	Cereal brans, rice and legume hulls, woody plants
ß-glucans	Grains (oats, barley, rye, wheat)
Pectins	Fruits, vegetables, legumes, sugar beet, potato
Gums	Legumes, seaweed, micro-organisms (guar, locust bean, carrageenan, xanthan, gum arabic)
Inulin and oligofructoses/fructo-oligosaccharides	Chicory, Jerusalem artichoke, onions
Oligosaccharides	Human milk, grain legumes
Resistant starches (types RS1 and RS2)	See Box 3

FIGURE 2

Structure of a whole grain



Source: Slavin J. Whole grains and human health. *Nutrition Research Reviews* 2004;17:99-110. Reprinted with permission

A variable proportion of dietary fibre will be derived from isolated or synthetic indigestible carbohydrates, incorporated into food products, for example, non-digestible oligosaccharides (fructo-oligosaccharides, galacto-oligosaccharides), resistant starch, resistant maltodextrins and polydextrose (Table 7).

TABLE 7

Some synthetic and modified fibres

Fibre component	Production process
Fructo-oligosaccharides	Transfructosylation of sucrose with a ß-fructosidase of *Aspergillus niger*
Oligofructose	Partial enzymatic degradation of native plant inulin
Galacto-oligosaccharides	Enzymatic transgalactosylation of lactose
Gluco-oligosaccharides	Transglycosylation using dextransucrase from *Leuconostoc mesenteroides*
Xylo-oligosaccharides	Partial enzymatic hydrolysis of xylan by xylanase from *Trichoderma* sp.
Polydextrose	Thermal polymerisation of glucose with sorbitol and acid (as a catalyst)
Resistant maltodextrins	Alkaline heat treatment of starch
Resistant starches	Retrogradation of high amylose starch

ANALYSIS

As noted above, no single analytical method is able to measure all fibre components in foods. There is a need for analytical methods that quantify the components in the dietary fibre definition, and at the same time excludes other food components. Box 1 and Table 1 describe the principal methods of analysis for dietary fibre currently in use.

Since 1985, the main accepted official method for measurement of total fibre has been the enzymatic-gravimetric method of the AOAC (no. 985.29). However, as the definition of dietary fibre has evolved and a range of other AOAC and AACC approved methods have been adopted, total dietary fibre methods do not quantify the wider range of components now considered as dietary fibre.

In the UK, for the purposes of food composition tables, dietary fibre is measured as non-starch polysaccharides by the Englyst method (Box 1). However, the AOAC method (985.29) generates significantly higher values for dietary fibre than the Englyst method, particularly for foods rich in starch such as potato, bread, beans and cornflakes. This results from the recovery of some of the RS3 fraction of resistant starch as dietary fibre. In foods containing lignin, such as whole grain cereals, the fact that lignin is not included in the non-starch polysaccharides analysis contributes further to the lower values for this method. Therefore it is important to recognise that where the Englyst values are used in food tables and as the basis for dietary recommendations, as in the UK, values will not always coincide with the declared values on food product labels, which are based on the enzymatic-gravimetric AOAC method.

The analysis of the resistant starch fractions of food products is somewhat problematical. There are a number of validated methods available for measuring the average resistant starch content of foods on which product labelling can be based (Box 1, Table 1). However, because of the recognised increases and decreases in the resistant starch content of food during ripening, cooking and cooling, it is difficult for food manufacturers and retailers to declare accurate, representative values on labels. There is an ongoing debate as to whether declarations should be based on the product either 'as packaged' or 'as prepared'; the latter is supported in Europe. An alternative approach is that adopted in the US, where the declaration must relate to the product 'as sold', but where optional information for the product 'as prepared' may also be declared. The latter option would seem desirable in products in which the resistant starch content can decrease or increase during processing.

Debate concerning appropriate methodologies for quantification of dietary fibre continues and is at least partly dependent on the discussion about the definition of the concept itself. None of the existing methods are optimal for measuring the wide range of components now generally accepted as being dietary fibre. Therefore, current methodology for measurement of quantities of total dietary fibre almost certainly underestimates the dietary fibre content in many food products.

CONSUMPTION

Estimates of total dietary fibre consumption (Table 8) are derived using differing methods of data collection, with varying degrees of accuracy. The populations studied are not necessarily nationally representative for the individual countries listed. These estimates are also influenced by the analytical methodology for measurement of quantities of dietary fibre used by the various government bodies and research groups. For these reasons, current figures are inaccurate and comparison of dietary fibre consumption between different countries is not straightforward.

The average consumption of total dietary fibre ranges, across countries, from 12 to 29 g per day. Because of the explained deficiencies in the data, the only clear observation that can be made is that there are distinct gender differences in dietary fibre consumption. Estimates for women are consistently lower than those for men, but this is mainly explained by the generally lower total food and energy intake of women compared to men.

With regard to specific fibre components, some data exist for resistant starch. A variety of methods have been used to estimate the resistant starch content of foods, and the actual resistant starch content of processed foods varies greatly. It has been estimated that resistant starch represents about 5% of total starch consumption. The main sources of resistant starch intake are cereal-based food items (mainly bread, pasta and rice), legumes and potatoes. In Europe, the average value is estimated to be 4 g/day. In Italy, the average resistant starch intake ranges from 7 g/day in the North West to 9 g/day in the South, reflecting the high consumption of pasta and

TABLE 8

Estimates of dietary fibre consumption

Country	Type of Study/Source	Quantity g/day
Belgium (Cho *et al.*, 1999)	24-hour recall*	21 men 19 women
Denmark (Bingham *et al.*, 2003)	EPIC Dietary questionnaire/24-hour recall***	21 men 20 women
France (Lairon *et al.*, 2003)	SU.VI.MAX Computerised dietary questionnaires (every 2 months)***	21 men 17 women
Germany (Bingham *et al.*, 2003)	EPIC Dietary questionnaire/24-hour recall***	24 men 21 women
Italy (Bingham *et al.*, 2003)	EPIC Dietary questionnaire/24-hour recall***	25 men 22 women
Japan (Miller-Jones *et al.*, 2004)	23 prefectures, multiple nutrition surveys***	17
Netherlands (Bingham *et al.*, 2002)	EPIC Dietary questionnaire/24-hour recall***	27 men 23 women
Spain (Bingham *et al.*, 2003)	EPIC Dietary questionnaire/24-hour recall***	29 men 23 women
Sweden (Bingham *et al.*, 2003)	EPIC Dietary questionnaire/24-hour recall***	21 men 19 women
United Kingdom (Hoare *et al.*, 2004, Bingham *et al.*, 2003)	7 day weighed intake National Diet and Nutrition Survey, 2003** EPIC Dietary questionnaire/24-hour recall***	15.2 men 12.6 women 20 men 20 women
United States (USDA 2005)	NHANES 2001-2002***	18 men (19-70 years) 14 women (19-70 years)

* Total dietary fibre
** Non-starch polysaccharides
*** Dietary fibre, non-specific method

bread. Reported intakes in Australia and New Zealand are about 5 g/day, similar to the average European intakes. Estimates for less developed countries, many of which have high intakes of unprocessed starch, grain and legumes, range from 10 to 40 g/day.

There are only very limited intake data for other specific components of dietary fibre. But, one example is that the consumption of naturally occurring inulins from wheat, onions, leeks and other vegetables is estimated to be 3-10 g/day.

RECOMMENDATIONS FOR INTAKE

The substances considered as dietary fibre form a rather heterogeneous group. One could therefore argue that a recommended total fibre intake makes as much – or as little – sense as a recommended total vitamin intake. However, many agree that the group of substances that meet the definition of dietary fibre have enough in common that it makes sense to define a recommendation for their total intake.

Adults

Worldwide recommendations for consumption of dietary fibre, for adults, are summarised in Table 9. The differences in the values are due to differences in the way in which dietary reference intakes are derived and also to the differences in analytical methods and accepted definitions of dietary fibre in different countries.

In some cases they are expressed as total dietary fibre (AOAC 985.29), in others as non-starch polysaccharides or just as dietary fibre without specifying the method of analysis. This is a source of confusion for consumers, health professionals and others who need to use these recommendations. Despite these reservations, the data in Tables 8 and 9 may be used to compare intake against recommendations within individual countries. From this it is clear that in Western countries, average intakes of dietary fibre fall short of recommendations.

Children

There is a lack of data on the effects of dietary fibre in children, and only few countries have set recommended dietary fibre intakes during childhood. In the UK, it is recommended that children under two years of age do not consume fibre-rich foods at the expense of energy dense foods required for growth. It is further advised that children under the age of five should not consume a diet based on recommendations for adults.

In 2002 the US *Institute of Medicine* also established dietary fibre recommendations for children and adolescents. These are based on prospective studies, in which the risk of coronary heart disease was found to be lowest among those in the highest quintile of total dietary fibre intake – with a mean of 3.4 g/MJ or 14 g/1000 kcal in the highest quintile. Extrapolating this for different age groups on the basis of energy intakes, recommendations for dietary fibre consumption range from 19 g per day for young children (1-3 years) to 26 g and 38 g per day for adolescent girls and boys (14-18 years) respectively.

In 2006, the *Health Council of The Netherlands* issued its guidelines for fibre intake. It advised not to apply the guideline of 3.4 g dietary fibre per MJ, based on associations with coronary heart disease risk and gastro-intestinal transit speed in adults, to – young – children. In the Netherlands, fewer than 5% of children consume that much fibre. This level, particularly in the 1-3 year old, may jeopardise energy intake. Therefore, the new Dutch guidelines for dietary fibre intake in 1-3, 4-8, 9-13 and 14-18 year old children are, respectively, 2.8, 3.0, 3.2 and 3.4 g/MJ (12, 13, 13 and 14 g/1000 kcal).

TABLE 9

Selection of worldwide recommendations for dietary fibre intake by adults

Country	Recommendation	Source of recommendation
Worldwide	>25 g * >20 g **	WHO/FAO, 2003
France	25-30 g ***	Agence Française de Sécurité Sanitaire des Aliments, 2001
Germany, Austria, Switzerland	30 g ***	German Nutrition Society, 2000
Netherlands	30-40 g: 3.4 g/MJ ***	Health Council of The Netherlands, 2006
Nordic countries	25-35 g ***	Nordic Nutrition Recommendations 2004
Spain	30 g *	No official figure
UK	18 g **	Department of Health, 1991
USA	38 g men, 19-50 years, 31 g men 50+ years; * 25 g women 19-50 years, 21 g women 50+ years *	Institute of Medicine, 2002
Colombia	15-20 g **	Health Ministry, 1992
Japan	20-30 g *	Ministry of Health
South Africa	30-40 g *	Heart Foundation; Cancer Association; Department of Health

* Total dietary fibre (AOAC, 1995)
** Non-starch polysaccharides (Englyst *et al*, 1982)
*** Dietary fibre, non-specific method

HEALTH BENEFITS

Introduction

Since the concept of dietary fibre was established three to five decades ago, it has been suggested that an insufficient consumption of dietary fibre contributes to a plethora of chronic disorders such as constipation, diverticulitis, haemorrhoids, appendicitis, varicose veins, diabetes, obesity, cardiovascular disease and cancer of the large bowel and various other cancers. These hypotheses have been developed largely from early observational studies. All these disorders have a multifactorial aetiology and over time experimental research has helped to refine our understanding of their relationships with dietary fibre. This has shown that only some of the proposed effects actually exist, but also suggested that dietary fibre influences other processes of significance for disease risk.

It is now evident that the individual components of dietary fibre have different physiological effects and therefore differing potential for disease risk reduction. More recently claimed properties of potential physiological significance are butyrate formation, prebiotic properties and enhanced mineral absorption.

It is important to note that the use of dietary fibre as a generic term and the use of different methodologies for its measurement, notably the Englyst method for non-starch polysaccharides and the AOAC methods for total dietary fibre, has complicated the interpretation of observational studies in this area. In many cases it has been impossible to disentangle whether the specific components of dietary fibre have the postulated physiological effects and health benefits, or whether it is the total dietary pattern that is responsible. Furthermore, evidence from well-controlled recent studies suggests that the beneficial effects of dietary fibre may not be due only to dietary fibre per se, and that other components or properties of the dietary fibre-containing food also contribute.

Short chain fatty acids

Fermentation and physiological functions

Many dietary fibre components are partially or completely fermented by the colonic microflora. This adds to the body's digestive capacity. The colon is estimated to contain typically at least 400 different anaerobic species of bacteria with total numbers of the order of 10^{12} per gram of colon contents. There is considerable variation in bacterial species between and within individuals, depending on factors such as age and diet. Most of the bacteria in the human colon use carbohydrates as an energy source, but not all species can degrade the polysaccharides and some rely for their substrate on the initial degradation products of other species. The main fermentation pathway generates pyruvate from hexose sugars in the undigested carbohydrate. The colonic bacteria produce a wide range of enzymes subsequently producing hydrogen, methane, carbon dioxide, short chain fatty acids (mainly acetate, propionate and butyrate) and lactate. The bacteria generate energy and carbon from the fermentation products. Therefore, dietary components that stimulate fermentation lead to an increase in the bacterial mass (biomass) and consequently in faecal mass, that is, they have a stool bulking effect. It is estimated that about 30 g of bacteria are produced for every 100 g of carbohydrate that is fermented.

At both the local (colonic) and systemic levels, fermentation has important physiological effects in which the short chain fatty acids play a central role (Box 4). Colonic epithelial cells demonstrate essential metabolic activities. Butyrate is used preferentially as an

BOX 4

Physiological effects of colonic microflora and their fermentation products (short chain fatty acids)

- Act as immunomodulators, e.g. absorb procarcinogens, promote attack on malignant cells
- Inhibit growth of many harmful yeasts and (peptolytic) bacteria
- Improve mineral absorption
- Reduce food intolerances and allergies
- Stimulate growth of healthy intestinal flora
- Reduce undesirable compounds (e.g. amines and ammonia, phenols, secondary bile acids)
- Produce nutrients (B group vitamins) and digestive enzymes

Source: Modified from Meyer PD, 2004

energy source by the colonocytes, even when competing substrates such as glucose and glutamine are available. Butyrate is considered to be the key nutrient determining the metabolic activity and growth of these cells and therefore may be a primary protective factor for colonic disorders.

Fermentation and short chain fatty acids production decrease colonic and faecal pH, and thereby inhibit the growth of pathogenic organisms. The low pH reduces peptide degradation and formation of toxic compounds such as ammonia, phenolic compounds and secondary bile acids, and decreases the activity of undesirable bacterial enzymes. The short chain fatty acids are absorbed into the bloodstream, with resultant systemic effects, including beneficial changes in glucose and lipid metabolism, and they also provide some metabolic fuel. Up to 13 kJ of energy can become available per gram of a completely fermentable component. The average value for energy from fibre in foods not enriched with isolated or synthesised dietary fibre or analogous carbohydrates is estimated to be 6 kJ/g fibre. However, energy values applied to fermentable dietary fibre vary on a worldwide basis from zero to 17 kJ/g with a tendency towards acceptance of 8 kJ/g as an average.

Most resistant starch appears to be readily fermented in the human colon. The fermentation of non-digestible oligosaccharides by the colonic microflora is also the basis for the physiological characteristics and potential health benefits of these carbohydrates. Several non-digestible oligosaccharides and other carbohydrates such as inulin, fructo-oligosaccharides and polydextrose have been shown to exhibit prebiotic properties, i.e. they stimulate beneficial gut bacteria, namely bifidobacteria and lactic acid bacteria, but may also favour the growth of butyrogenic bacteria (Table 10). The ratio of short chain fatty acids will vary according to specific microflora composition and other factors.

Gut barrier function and immunity

Pro-inflammatory macromolecules may permeate the epithelium mainly via paracellular tight junctions, which is of potential pathogenic significance. The colonic epithelium can prevent such macromolecules from reaching the internal milieu. Both fermentable and non-fermentable dietary fibre has been shown to impact on paracellular permeability. This indicates that there are distinctly different mechanisms involved, one of which is independent of short chain fatty acids production. The gut immune system consists of organised aggregates of lymphoid tissue, including Peyer’s patches, the appendix and mesenteric lymph nodes.

TABLE 10

Variable patterns of short chain fatty acid production from various substrates

Substrates	Acetate	Propionate	Butyrate
Resistant starch	41	21	38
Starch	50	22	29
Oat bran	57	21	23
Wheat bran	57	15	19
Cellulose	61	20	19
Guar gum	59	26	11
Ispaghula (psyllium)	56	26	10
Pectin	75	14	9

Source: Champ *et al.*, 2003

In experiments with specific cell lines, butyrate down-regulated the expression of specific receptors in gut immune cells and epithelial cells. Short chain fatty acids, especially butyrate, may also inhibit effects of the pro-inflammatory cytokines. Butyrate seems to influence lymphocyte activation and to inhibit cell proliferation. This may represent a mechanism whereby the colonic microflora regulates the host immune response. However, an abnormal response to butyrate may upset the homeostasis between the gut immune system and the colonising bacteria, resulting in epithelial unrest and inflammation.

Human breast milk contains complex oligosaccharides that are partially fermented by the resident gut bacteria to produce short chain fatty acids. These oligosaccharides are probably responsible for the proliferation of bifido bacteria and lactobacilli in the gut of the breast-fed infant. These bacteria appear to be important in the development and maintenance of intestinal defences against pathogenic microbial invasion.

Bowel habit

Stool consistency, stool weight and frequency of defaecation are indicators of gut and specifically of colonic function. Transit time, the time a substance takes to pass through the gut, has a wide inter-individual variation (24-72 hours). The larger part (16-64 hours) of this time is spent in the large intestine. Dietary fibre intake is the main determinant of stool weight, which it increases, and transit time, which it reduces. Both are important aspects of bowel habit, and seem to play a role in the prevention of diseases of the large bowel.

As described above fermentable fibres, non-digestible oligosaccharides and polysaccharides in the colon increase faecal mass. The short chain fatty acids generated by fermentation decrease pH within the colon and, together with the gas produced, encourage peristalsis. Most studies of the effects of resistant starch show increases in stool output or bulk. In part, this is believed to be because the easily fermentable resistant starch appears to influence the fermentation of other less well fermentable substrates in the large bowel.

Accordingly, resistant starch increases faecal excretion of non-starch polysaccharides. Most studies have also shown that resistant starch consumption increases faecal butyrate and acetate concentration, and thus decreases faecal pH. However, resistant starch does not appear to influence gut transit time in humans.

Constipation

Traditionally considered as being the need to strain on defaecation, constipation is defined variously in terms of regularity of bowel movements, stool consistency and stool weight. Various types of dietary fibre seem to prevent and relieve this disorder. Increases in faecal bulking and stool weight are important, but not the only factors involved. Wheat bran has been shown to be most effective in increasing faecal bulk, although isolated cellulose is also effective and increases faecal bulk to a greater extent than isolated fermentable fibres such as pectin. However, all non-absorbed carbohydrates may increase laxation through water binding, osmotic effects of degradation products and increasing bacterial mass. It has been estimated that fibre intake should amount to 32-45 g/day in order to reach a 'critical ' faecal mass of 160-200 g/day needed to minimise the risk of constipation.

Diverticulosis

Diverticulosis of the colon is characterised by herniations in the colonic wall, which are normally asymptomatic. They may cause pain when inflamed as a result of bacterial action, a condition referred to as diverticulitis. There is evidence from both observational and intervention studies that dietary fibre intake protects against the disorder and relieves symptoms. Non-viscous fibres such as cellulose are particularly effective in this respect, as are bran-containing cereal foods. These protective effects may involve increased stool weight, decreased transit time and decreased intra-colonic pressure.

Inflammatory bowel disease

Butyrate is formed and used more in the proximal colon than in the distal colon. There is some evidence that a lack of butyrate availability or oxidation is involved in the pathogenesis of inflammatory bowel disorder, e.g. ulcerative colitis in the distal colon. In some patients, treatment with butyrate reduced inflammation. In animal studies butyrogenic carbohydrates such as RS3 accelerate the resolution of inflammation. *In vitro* and animal studies have shown that polydextrose is fermented slowly throughout the colon and generates butyrate in both the proximal and distal colon. However, it is still uncertain whether consumption of fibre that generates large amounts of butyrate is efficacious in patients with ulcerative colitis.

Colorectal cancer and related factors

The effect of dietary fibre on cancer of the colon and rectum has been the subject of controversy. Carcinogenesis is a complex biological process that in some cases results from inherited genetic mutations but is also influenced by external factors including diet. Dietary fibre has effects that could contribute to a reduction of the risk of colorectal cancer. These effects include the dilution and binding of carcinogens, changes in the profile of bile salts within the colon, increased speed of gut transit and effects of end products of fermentation of non-digestible carbohydrates and analogous substances (inulin, fructo-oligosaccharides, resistant starch, aleurone fibre and wheat bran). Short chain fatty acids may modulate expression of cell cycle-regulating proteins and induce self-destruction of colon cancer cells. They also increase the susceptibility of colon cancer cells to cell injury. Other relevant effects include reduced activity of harmful bacterial enzymes, lower levels of phenol and peptide degradation products and the formation of cellular antioxidants and radical scavengers.

Although most adenoma do not evolve into carcinoma as such, their presence is generally considered to be indicative of the risk of developing colorectal cancer. In a large case-control study dietary fibre intake was lower among patients with adenoma than in controls. In intervention studies, however, fibre supplements did not influence their onset or recurrence.

An important advantage of observational prospective studies is that they can address the eventual outcome of interest, i.e. the actual onset of colorectal cancer. The *European Prospective Investigation into Cancer and Nutrition* (EPIC) is such a study. It comprised 519 978 subjects from across Europe among which, after six years of follow-up, 1 721 persons had developed colorectal cancer. Over the four lowest quintiles of fibre intake there was an inverse association with the risk of developing colorectal cancer. In the one-but highest and highest quintiles the risk was 21% lower than in the lowest quintile.

The association between dietary fibre intake and risk of colorectal cancer has also been analysed in five other large cohort studies: the *Nurses' Health Study* (88 757 subjects, 16 years of follow-up, 787 incident cases), the *Health Professionals Follow-Up Study* (47 949 subjects, 6 years of follow-up, 251 cases), a Finnish cohort (21 930 subjects, 8 years of follow-up, 185 cases), the *Breast Cancer Detection Demonstration Project* (61 429 subjects, 8.5 years of follow-up, 487 cases) and the *Cancer Prevention Study II Nutrition Cohort* (133 163 subjects, 4.5 years of follow-up, 508 cases). The relative risk for developing colorectal cancer, in the highest versus the lowest quintile of dietary fibre intake, varied between 0.86 and 1.08. It was not statistically significant in any of the five cohorts.

The data of 13 European and American cohort studies have been merged into one dataset comprising 725 628 participants, 6 to 20 years of follow-up and 8 081 new cases. It did not include EPIC, but did include the above-mentioned five other cohorts. Analysis of these pooled data revealed a higher risk of colorectal cancer in the lowest quintile intake as compared to the one-but-lowest and middle quintiles, but not as compared to the one-but-highest and highest. In other words: across the larger part of the range of dietary fibre intake, i.e. the whole population distribution minus the lowest 20%, the risk of developing colorectal cancer was not associated with dietary fibre intake.

According to the US *Institute of Medicine*, and more recently also according to the *Health Council of The Netherlands*, the overall evidence for an effect of total fibre intake on the risk of colorectal cancer is not sufficient to serve as a basis for guidelines on dietary fibre intake. The *Health Council* also commented that if dietary fibre does play a role, it is more likely to be fibre from fruits rather than the whole spectrum of dietary fibre.

Cancers other than colorectal cancer

Observational data on the relationship between dietary fibre and the onset of other types of cancer are inconsistent. Although many case-control studies have demonstrated a reduced risk of breast cancer among post-menopausal women consuming higher fibre diets, the majority of prospective studies have not confirmed this association. There is some evidence, however, that whole grain intake is protective against breast cancer, and that the risk of stomach cancer correlates inversely with whole grain consumption. Claims that diets rich in whole grains (and fruit and vegetables) reduce the risk of some cancers are approved for labelling purposes in the US, but not elsewhere.

Coronary heart disease and related disorders

In a recent meta-analysis of ten prospective studies from Europe and the US, dietary fibre intake was inversely associated with the risks of both fatal and non-fatal coronary events. The analysis was adjusted for demographic and lifestyle factors and body mass index. Intervention studies show moderate beneficial effects of dietary fibre on risk factors for coronary heart disease such as blood lipids, blood pressure and arterial wall thickness. According to the US *Institute of Medicine* (2002) and also the *Health Council of The Netherlands* (2006), an effect of total fibre intake on the risk of coronary heart disease is plausible enough to serve as a basis for guidelines on dietary fibre intake. Fibre from cereals and fruits seems of particular importance.

Various mechanisms have been put forward to explain the apparent protective effects of dietary fibre on the cardiovascular system. These include changes in the absorption of cholesterol and in re-absorption of bile acids, alterations in the production of lipoproteins in the liver and changes in the clearance of lipoproteins from the bloodstream. All of these may result in lower plasma levels of total and LDL cholesterol, which would decrease the risk of coronary heart disease. Dietary fibre can delay absorption of fat and carbohydrate from the small intestine and can have concomitant effects on insulin metabolism. It may also lower the level of circulating triglycerides and as a result reduce the risk of coronary heart disease.

Increases in consumption of highly viscous fibres such as ß-glucans, pectins and guar gum are associated with significant reductions in blood cholesterol levels in normal, overweight and obese subjects, as well as in hyperlipidaemic subjects. However, dietary fibre components such as non-viscous fibres (e.g. wheat fibre and cellulose) do not influence blood lipids.

Many intervention studies in humans have shown that isolated viscous fibres (ß-glucans, oat bran, pectins, guar gum and psyllium) have cholesterol-lowering properties, but only if their intake is much higher than levels consumed in most habitual diets. But, the results of a meta-analysis of studies in patients with raised cholesterol levels suggested that an increased intake of viscous types of dietary fibre can be useful in addition to other dietary changes such as reducing fat consumption. In some countries, the data are considered sufficiently robust to permit health claims for oat and oat bran products, and in the US also for psyllium products.

Supplementation of normal meals with resistant starch does not appear to lower fasting blood lipid levels or to have significant effects on postprandial blood lipids in normal subjects. It does, however, seem to improve triglyceride metabolism among individuals with baseline triglyceride levels at the upper end of the normal range.

Data on the effects of inulin or fructo-oligosaccharides on blood lipid concentrations are also inconsistent. In some short-term studies, in both hyperlipidaemic subjects and in normolipidaemic healthy young men, a daily intake of 9-10 g inulin lowered triglyceride and cholesterol levels in the blood in the healthy normolipidaemic men. However, other studies of healthy individuals did not show such effects. Similar results have been seen with polydextrose.

Whole grain intake is inversely associated with heart disease risk in both men and women, and fruit and vegetable intake is inversely associated with such risk in women. There is also evidence that increasing total dietary fibre intake by increasing the consumption of whole grains, fruit and vegetables, in conjunction with a reduced fat diet, reduces triglyceride levels, especially among subjects with initially elevated levels. The evidence base for an influence of whole grain consumption on heart health is considered sufficiently robust for claims to be accepted in the US, UK and Sweden, and in the US for fruit and vegetable consumption as well.

Type 2 diabetes mellitus and related factors

Some cohort studies show an inverse association between total dietary fibre intake and the risk of type 2 diabetes mellitus, whereas other such studies do not. The US *Institute of Medicine*, and more recently the *Health Council of The Netherlands*, have looked into these findings, as well as into studies on risk factors for diabetes. They concluded that total dietary fibre *possibly* decreases the risk of type 2 diabetes. The evidence that dietary fibre from whole grain food, or perhaps the consumption of such foods as a whole, decreases the risk of type 2 diabetes is stronger than that for total dietary fibre.

The rise in blood glucose level that occurs following the ingestion of carbohydrates is referred to as the glycaemic response. Rapidly digested and absorbed starches and other carbohydrates derived from starch induce a large and rapid glycaemic response, which subsequently evokes a rapid and large insulin response. The concept of glycaemic index (GI) has been developed to classify foods according to the glycaemic response they evoke, expressed per amount of food containing a standard amount of carbohydrates. The GI is not necessarily correlated with the dietary fibre content of a food. For instance, wholemeal bread does not have a lower GI than white bread, despite a higher dietary fibre content, unless it contains intact cereal grains. Furthermore, the GI of a fruit is lower than that of the juice obtained from the fruit, and added fibre has a much smaller effect on GI reduction than intact cell walls that encapsulate the digestible carbohydrates. This indicates the importance of the intrinsic structure of the food.

The effect of whole grain foods may result from their rather limited glycaemic effects. The presence of some types of dietary fibre delays the uptake of glucose from the small intestine, slowing down the rise in blood glucose and lowering maximum blood glucose level. This in turn attenuates the insulin response, resulting in a slower decline in blood glucose level.

In a recent meta-analysis of intervention studies in subjects with type 2 diabetes, viscous (soluble) fibres, both in intact foods (oats and legumes) and in isolated supplement form (guar gum and pectin), significantly reduced the glycaemic response. Mechanistic data indicate indeed that these viscous fibres delay gastric emptying and glucose absorption. Thus, on the one hand viscous fibres seem particularly effective in decreasing the glucose and insulin response and therefore helpful in the management of glycaemic control in patients with diabetes. On the other hand, in the prospective observational studies the non-viscous fibre content of the diet – mainly found in whole grain foods – is more closely (and inversely) related to the risk of developing insulin resistance and type 2 diabetes.

Satiety and body weight

Obesity is a rapidly escalating public health problem throughout the western world and, more recently, even in developing countries. Foods rich in dietary fibre tend to be bulky and have a low energy density. Therefore, it is contended that dietary fibre could promote satiation and satiety and play an important role in the control of energy balance and body weight. This is supported by observational prospective data showing a negative association between dietary fibre consumption and body mass index, percentage of body fat and body weight. There are indications that whole grains may also assist in the regulation of body weight. Furthermore, it is suggested that foods with a low GI are more satiating than high–GI foods.

Intervention trials indicate that gastric emptying may be delayed by the consumption of viscous (soluble) fibres such as pectins. Most important, however, seem to be the effects that occur in the small intestine. By forming gels, these types of dietary fibre expand the unstirred layer and slow the absorption of carbohydrates from the small intestine by making them less accessible to digestive enzymes and reducing contact with the intestinal mucosa. This seems to extend the sensation of fullness. There is also some evidence that the prolonged presence of nutrients in the upper intestine promotes satiety.

Research on the effects of different types of dietary fibre on appetite, energy and food intake has not shown consistent results. The findings differ according to the type of dietary fibre and according to whether it is added as an isolated dietary fibre supplement rather than naturally occurring in food sources. Large amounts of total dietary fibre (30 g/meal) may reduce the energy intake, not only in a meal that contains such an amount, but also in subsequent meals. The longer-term relevance of these effects is not yet clear.

Improved mineral availability

The large intestine is a poorly recognised site of mineral absorption. In animal and some human studies the colonic fermentation of non-digestible carbohydrates, such as non-digestible oligosaccharides, improved the absorption of minerals such as calcium, magnesium and iron. This could have positive implications, such as increasing bone density. Several mechanisms for enhanced mineral absorption have been proposed. The presence of short chain fatty acids, generated by the fermentation of these substances, reduces the pH of the colonic contents, thereby increasing the solubility of calcium, making it more available for passive diffusion across the colonic epithelium. It has also been suggested that butyrate and polyamines (metabolites of various microbial strains), both of which have the potential to stimulate cell growth, indirectly expand the gut's absorptive area and increase the quantity of mineral transport proteins. This would increase the proportion of minerals absorbed. However, it is not faecal but colonic pH which is the most important mechanism (as evidenced by faecal pH).

It is too early to say whether fermentable dietary fibre improves overall mineral status and bone health in humans. Consequently, this physiological characteristic has not yet been included in definitions of dietary fibre.

NATURALLY OCCURRING FIBRE, ISOLATED OR SYNTHETIC FIBRE

Many components that meet the definition of dietary fibre seem to have potentially beneficial effects when part of the intact structure of foods. Do isolated or synthetic, so-called functional components have similar effects when added to foods or taken separately as supplement? There is good evidence that the benefits of whole grains, fruits and vegetables outweigh those of the isolated or synthetically produced components of these foods (used either as supplements or added to foods). Possibly other, as yet unidentified, substances in such foods can explain this. Perhaps it is the overall combination of the dietary fibre, nutrients and bioactive substances, acting in concert, that is critical to health. Cell walls have complex structures in which the carbohydrates are intimately associated with non-carbohydrate substances including vitamins, minerals, trace elements and bioactive compounds such as polyphenols and phytosterols. This is particularly pertinent to the glycaemic response, which may be influenced by intact cellular and gross structures in foods.

In line with this perspective, the World Health Organization, in its 2003 expert report entitled *Diet and the prevention of chronic diseases*, did not conclude specifically that dietary fibre itself is crucial, but it did recommend ample consumption of fruits, vegetables and whole-grain foods. Other dietary recommendations, in Europe and worldwide, also emphasise the importance of fibre-rich foods such as whole grain cereals, vegetables and fruits. Nonetheless, there are also indications that isolated types of dietary fibre, such as resistant starch, non-digestible oligosaccharides and polydextrose, help in the prevention and alleviation of bowel disorders, coronary heart disease and type 2 diabetes.

ADVERSE EFFECTS

Compromised energy intake

Diets that contain large amounts of dietary fibre tend to be bulky and have a low energy density. Therefore, in individuals with a limited appetite, such as very young or very old persons, such diets will potentially satisfy appetite too readily and therefore make it difficult to achieve adequate intakes of energy and nutrients. However, in many healthy adults the consumption of fibre-rich foods is self-limiting due to their bulking character. This characteristic applies to a lesser extent to foods enriched with fibre, and much less to fibre supplements.

Gastrointestinal discomfort

There are reports of flatulence and abdominal fullness when dietary fibre is consumed at very high levels (75-80 g/day), but this is hardly relevant for the level of consumption of dietary fibre seen in most people's diets. Apart from this, dietary fibre has been reported to cause gastrointestinal discomfort in some people with irritable bowel syndrome. Isolated or synthetic types of dietary fibre can cause gastrointestinal discomfort, although mainly when consumed at high levels. For example, subjects in experimental studies with an intake of 10-50 g/day of inulin or fructo-oligosaccharides have reported symptoms of gastrointestinal distress, including laxation, flatulence, bloating and abdominal cramping. At lower levels of intake (5-10 g/day), the only reported effects were bloating and flatulence.

The most commonly reported adverse effect following the consumption of large amounts of resistant starch is flatulence. Much research data for resistant starch are derived from the experimental studies of high-amylose maize. This is a form of resistant starch that is now added to some foods, including breakfast cereals, biscuits and other baked goods, pasta and breads. Other commonly reported effects in healthy individuals are bloating and mild laxative effects, which have been described at levels above 30 g resistant starch per day. However, resistant starch was given together with other types of dietary fibre in some studies, which limits the interpretability of their results. Perhaps resistant starch is well tolerated because of the very low gas production resulting from its fermentation.

The gastrointestinal tolerance to polydextrose is relatively good. It does not appear to cause gastrointestinal discomfort at lower levels of intake (12-15 g/day). Even a single dose of up to 50 grams and a daily intake up to 90 grams are tolerated without adverse effects.

Decreased mineral bioavailability

The fermentation of fibres in the colon is associated with the release and solubilisation of minerals, which facilitates colonic absorption. In contrast with this, diets rich in certain other types of dietary fibre, particularly those associated with phytate, seem to decrease the absorption in the small intestine of several minerals, notably iron, calcium, magnesium and zinc. This has been seen in both animal and human studies. Phytate binds with these minerals thereby potentially reducing their availability for absorption from the small intestine.

The overall results of studies on these effects suggest: dietary fibre intake does not decrease absorption or balance of magnesium or calcium; the consumption of large amounts of cereals, vegetable and fruit fibres have no effect on calcium absorption and balance; soluble fibres such as inulin have no effect on the absorption in the small intestine of iron or zinc; and resistant starch derived from high-amylose maize (30 g/day) does not reduce calcium absorption in the small intestine. However, the addition of unprocessed wheat bran to meals can significantly reduce the absorption of iron. Reduced bioavailability of minerals may in practice be – partly – compensated by the fact that fibre-rich foods tend to be rich in minerals as well.

GLOSSARY

Adenoma: A benign tumour of epithelial origin that is derived from glandular tissue; it may become malignant.

Bioavailability: The fractional amount of a nutrient or other bioactive substance that, after ingestion, becomes available for use in target tissues.

Carcinogen: A substance capable of causing cancer.

Case-control study: An observational study that compares the exposure to a suspected cause of a disease in people with that disease (cases) to the exposure in those without that disease (controls); exposure is thus assessed retrospectively.

Codex Alimentarius Commission: An organisation that creates and compiles standards, codes of practice and recommendations. Membership is open to all countries associated with the Food and Agricultural Organisation of the United Nations and the World Health Organization.

Cohort study: Observational study in which data on exposure to suspected causes of e.g. a disease are collected in a selected/recruited group of people (cohort) who do not yet have the disease(s) under investigation. The subjects are then followed for a period of time, after which it can be assessed whether the onset of disease is related to (the presence of) suspected causes.

Colon: Large intestine.

Degree of polymerisation: The number of monosaccharide units in a specific carbohydrate.

Epidemiology: The study of health and the occurrence of diseases and their predictors and causes.

Fermentation: Metabolism to extract energy from substrates by microorganisms. In the context of dietary fibre, fermentation involves anaerobic (without oxygen) degradation of indigestible carbohydrates by the micro flora (mainly bacteria) of the large intestine.

Gelatinisation: When applied to starch, which is the most common use of this term: Loss of the initial crystalline structure.

Glycaemic index (GI): The incremental area under the blood glucose response curve of a 50 g carbohydrate portion of a test food expressed as a percentage of the response to the same amount of carbohydrate from a standard food consumed by the same subject (standard: glucose or white bread).

Glycaemic response: The rise in blood glucose concentration following the ingestion of a food.

Hyperlipidaemia: Abnormal elevations of fat (lipids) in the blood, including LDL-cholesterol, and triglycerides.

Hypertension: Elevated blood pressure.

Insulin resistance: Impaired insulin sensitivity, impairing insulin-stimulated uptake of glucose by tissues.

Intervention study: Study in which investigators intervene by allocating one or more treatments or other interventions in certain subjects, after which they observe outcomes of interest.

Low-density lipoprotein cholesterol: Cholesterol carried in aggregates with specific proteins from the liver to other tissues. High levels are associated with an increased risk of heart disease.

Meta-analysis: Review of intervention or observational studies that quantitatively summarises results.

Observational study: Study in which researchers do not intervene but only observe outcomes of interest and their suspected causes, e.g. case-control study and prospective study. Observational studies are often loosely referred to as epidemiological studies.

Postprandial: Occurring after a meal.

Prebiotic: Non-digestible food components that benefit the host by selectively stimulating the growth or activity of beneficial bacteria (mostly lactic bacteria such as bifidobacteria and lactobacilli) in the colon.

Quintile: One fifth of a distribution of a certain parameter.

Risk: In epidemiology it usually refers to the probability or chance of meeting a certain – generally unwanted – event. In toxicology it typically expresses both the probability and the severity of a certain unwanted event.

Satiation: Regulation of energy intake per eating occasion.

Satiety: Delayed return of appetite following a meal.

Whole grain: Whole grains and foods made from them consist of the seed usually referred to as the kernel. The kernel is made of three components: the bran, the germ and the endosperm. If the kernel is cracked, crushed, flaked or milled, then in order to be called whole grain, it must retain nearly the same proportions of bran, germ and endosperm as the original grain.

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