Dietary Fibre: Part 1

Uptodate: Clinical Nutrition

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<Opening titles>

<Dr Cummings to camera>

Many people are not clear exactly what is meant by the term dietary fibre. This is not surprising because even the fibre experts cannot, at the moment, agree on a suitable definition of fibre. Reasons for this are several. It's partly due to the fact that fibre is, in fact, a mixture of substances, a complex mixture and not a single substance. Because of this, chemical analysis of fibre is very difficult and it is only in recent years that methods have been developed which are suitable for measuring the whole of dietary fibre. Because of this problem in chemical analysis, the term 'crude fibre' came in to use many years ago. This now complicates our ideas of fibre and has, in fact, been very much superseded. However, wrangling over definitions is not a profitable exercise and I think we can look simply at dietary fibre and say that it is largely plant cell walls. At least, it is the polysaccharides and lignin present in plant cell walls and other plant substances that are not digested in the upper human gastrointestinal tract.

<Cummings narrates over slide listing the main components of dietary fibre>

Here is a list of the main components of dietary fibre. With what we now know about fibre, it is probably convenient to think of them as three main components rather than four. The cellulose is one, the hemicelluloses and pectins can now be thought together as being the non-cellulosic polysaccharides, and thirdly, the lignins. Cellulose is well known to everybody and it consists purely and simply of glucose molecules joined together in straight chains. It is present in all plant cell walls. The non-cellulosic polysaccharides, of which the hemicelluloses are the main group, are a much more varied group of substances and contain many different basic sugar units. The commonest sugar units present in the hemicelluloses are 5-carbon sugars, like xylose and arabinose, but there are many others as well, including glucose and galactose. The pectins are known for their gel forming properties, particularly in cooking and things like this, and they are also present in most plant cell walls. And finally, the lignins: these are something of an odd man out in that they are not carbohydrate and they are extremely inert substances. As far as human food is concerned, however, there are relatively small amounts of lignin present in the human diet.

Now, these main constituents of fibre are all enmeshed and intertwined together in the plant cell wall. They don't exist separately. Also different plants will have different combinations of these and, therefore, different properties. Clearly, such a complex mixture is exceedingly difficult to analyse chemically, hence the idea of crude fibre is still very much with us today.

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<Cummings to camera>

The concept of crude fibre was introduced many years ago by the animal nutritionists. It's a concept which is based on a very simple chemical technique for measuring dietary fibre; unfortunately it only measures a very small proportion of the total dietary fibre. During the chemical analysis for crude fibre, approximately 80% of the non-cellulosic material is lost, about half the cellulose is lost and about 60 to 80% of the lignins are lost. Consequently, crude fibre measures only a small fraction of the total dietary fibre and, what is worse, it measures a variable fraction of it from plant to plant. Its use therefore today in human nutrition is quite misleading and it should be totally abandoned. Unfortunately, nearly everything we read in the literature at the moment and as far as food composition and food labelling on products in the supermarket are concerned, the term crude fibre is still well entrenched and in common use. An example of how misleading it can be is […]

<Cummings narrates over print advertisement with image of a large stack of vegetables piled up between slices of bread>

[…] shown in this advert for a bread made in the United States of America at the moment. The advert suggests that there is more fibre in the two slices of bread than there is between them. This is somewhat misleading because the fibre they referred to in the advert is, in fact, crude fibre. Now, this bread is made by adding a cellulose to the flour and consequently it has a very high crude fibre content but not a particularly high dietary fibre content.

The crude fibre value for the vegetables in between the two slices of bread, however, will be very low – misleadingly so. If the true dietary fibre content of both the bread and the vegetables were measured, they would probably be very similar, but at the present time, crude fibre is the most widely used term and, unfortunately, it can be rather misleading.

<Cummings narrates over slide showing list of dietary substances found in plants>

<Table>

protein	**cellulose**	**gums and mucilages**
minerals	**hemicelluloses**	

phytate **pectins** **storage polysaccharides**

lipids **lignins** **algal polysaccharides**

waxes

cutins

The plant cell wall, of course, isn't just composed of fibre. I think it's important to remember that in the plant cell wall are a number of other substances which are also enmeshed with the fibre and taken in our diet with it. This list on the left-hand side here shows a number of these materials. You will note that amongst them is phytic acid, which is present in quite large amounts in cereal foods and is therefore associated with cereal-fibre diets in quite large quantities. There are also a number of other substances which are biochemically very similar to the fibres we've been talking about so far but which aren't part of the plant cell wall. These substances are also legitimately considered under the heading of dietary fibre. Most important of these are the plant gums and mucilages. Examples of these are guar and sterculia. These substances are widely incorporated into foods in the food manufacturing industry and are also prescribed as proprietary preparations for faecal bulking. There are several of these available, including sterculia, ispaghula, psyllium, guar and methylcellulose which is not a true plant derivative.

There are also a number of other plant substances, such as the storage polysaccharides, which are biochemically very similar to dietary fibre. An example of this is inulin, and also in the algae there are polysaccharides in the plant cell wall which differ slightly from these other dietary fibre constituents, but must also be considered part of the whole picture of dietary fibre.

<Cummings to camera>

What then about the chemical structure of fibre? Not surprisingly, a lot of work remains to be done on this, but there are one or two basic structures which we can have in our mind when thinking about the properties of fibre.

<Cummings narrates over diagrammatic slides showing structures of dietary fibres>

As I mentioned earlier, cellulose consists of straight chains of glucose and so one basic model of the structure of fibre is the straight linear polymer. In fact, apart from cellulose, there are very few other linear polymers in the dietary fibre world. A more common arrangement is to have a backbone of sugar molecules with side chains, such as I've illustrated here. An example of this would be guar gum, which has a backbone of mannose and galactose residues placed at fairly regular intervals along the backbone.

A different type of structure is shown here in which the backbone has a branch attached to it with several sugar residues attached to it. Often, however, the structures are quite complex. Many of the non-cellulosic polysaccharides have quite complex branching and side chain structures, as I've illustrated here: a backbone consisting of one or two sugar molecules with quite complex branching arrangements. An example of a molecule like this would be sterculia. In addition to this, there is an important additional component to the basic structure which one ought to bear in mind and that is the presence of uronic acids in the structure. These are illustrated here by the carboxyl groups attached to these side chains. The presence of uronic acids with their carboxyl groups in the dietary fibre molecule confers upon it quite distinct and important properties.

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<Cummings to camera and then over various examples of fibre preparations displayed on table>

These physical properties of fibre influence very much how it behaves in the human gut and how it influences human metabolism. Here I have four examples of relatively pure fibre preparations: from bran, from carrot, cabbage and pectin. You will see immediately, if you look at them, that they are physically very different. Although these aren't completely pure, they contain 60 or 70% of the fibre from these particular materials. They are obviously very different in volume and very different in texture. All of them have the capacity to take up water and this is one of the most important physical properties of dietary fibre. Not surprisingly, however, each one takes up water to a different extent. Depending on how you measure water uptake by fibre will depend on the exact result one gets, but using a technique we've developed, the bran, which I've illustrated here, takes up about 8 ml of water for every gram of bran fibre. Carrot takes up about 24, cabbage about 16, and pectin forms quite a stiff gel with 50 or 60 ml of water with the same amount of fibre. So, different types of fibre have the capacity to take up very different amounts of water.

<Cummings to camera and then over photomicrograph of plant cell wall>

Another property of fibre is the fact that it is, in fact, fibrous – at least some of it is. This is a picture of a plant cell wall showing cellulose microfibrils crisscrossing within it. Now, this pretty pattern isn't of importance to us in itself, but what is important is the fact that when we eat fibre-containing foods, we have to chew them; we can't drink them down like a can of Coca-Cola or a bottle of milk. And this itself may be one of the more important properties of fibre. A third property of fibre is its capacity to bind metal ions in the gut.

<Cummings narrates over slide of graph demonstrating the calcium binding capacity of various fibres>

This slide shows a study in which several different types of fibre were taken and their capacity to bind calcium ions was measured. When this was correlated with the uronic acid content of the fibres, a very close relationship was seen. You will recall that when we were discussing the structure of fibre earlier, we mentioned that the non-cellulosic polysaccharides, particularly, often had uronic acid residues in them. These residues contribute to this property of ion binding.

A fourth property of fibre is the fact that it is digested in the human gut.

<Cummings narrates over slide listing breakdown products of polysaccharides in gut>

Cellulose is broken down to its basic units, glucose, and these in turn are then broken down in the large bowel by the colonic microflora to short-chain fatty acids, of which acetate is an example, and then to various gases like carbon dioxide, hydrogen, methane and water.

The non-cellulosic polysaccharides are similarly broken down in the large bowel, first to their constituent monosaccharides and then these in turn go to short-chain fatty acids and these various other components.

Lignin, in fact, is not digested, as far as we know, in the human gut. So these, then, are four important properties of fibre which determine how it behaves in man: its capacity to take up water, the fact that it is fibrous, its ability to bind ions and other materials in the gut, and its digestibility.

<Cummings to camera>

The next question I think we need to ask ourselves is, how much fibre do we take in our diet everyday? Surprisingly, there's very little information available about this. This is largely because, as we said earlier, fibre is very difficult to analyse, and it's only in the last year or two that figures for the fibre content of commonly eaten foods have become available.

<Cummings narrates over slide showing daily fibre intake in Britain through various foodstuffs>

With these figures, however, we can look at the National Food Survey and get an approximate idea of fibre intake in Britain. The total intake is about 20 grams a day. The sources from which we get this fibre are listed here: about half of it from vegetables including potatoes, some from cereals, and very little from fruit and nuts and things like this.

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<Cummings narrates over slide showing fibre intake in different parts of the world>

If we now look at what fibre intakes are in different parts of the world, we'll see that, in fact, there is very little information available. These circles represent fibre intakes in different countries in the world, and the area of the circle is proportional to the fibre intake in that country. We've just said that fibre intake in Britain is about 20 grams a day, and in a diet from the United States, which was analysed using the same techniques, fibre intakes were also about 20 grams a day. However, in a country like the United States, one would expect fibre intakes to vary considerably. At the moment no detailed information is available on fibre intakes in different parts of this area of the world.

In a recent study in Scandinavia in middle aged men, dietary fibre intakes were found to be 17 grams a day in Denmark; and in a similar population in Finland, about 30 grams a day. The only other figure available is for Uganda where we've estimated that dietary fibre intakes are probably about 150 or 180 grams a day, but this is the total extent, at the moment, of knowledge about dietary fibre intakes in different parts of the world.

<Cummings to camera>

Let's now turn our attention to the physiological properties of fibre and try and relate what we've been saying about its chemistry and its physical properties to what happens when it's eaten. In turn, we should be able to relate the physiology to the clinical aspects of fibre, which will become evident in the second part of the presentation. Now the first and most obvious and best-known physiological property of dietary fibre is its capacity to increase faecal bulk.

<Cummings narrates over slide of graph showing effects of dietary fibre on faecal output>

In an experiment in which we took a group of medical students and gave them a standard, ordinary Western-type diet, faecal output, as shown on this graph here, for the group of students was about 80 grams a day during the 3 weeks in which they were taking the ordinary British-type diet. We then altered their diet, adding into it an extra 27 grams of fibre, from wheat sources, per day, by giving them wholemeal instead of white bread, by adding All Bran instead of cornflakes, giving them some bran and some bran biscuits. Their faecal weight responded immediately to this change in diet, increasing almost 3-fold to an average of about 210 grams a day.

This sort of study has been done by many people and it's a reasonably consistent finding that fibre, particularly that from wheat, has this striking effect of increasing faecal weight. A direct consequence of this is a second important physiological effect which fibre has in the large bowel particularly. As a consequence of faecal weight increasing and, in fact, the general bulk of colonic contents increasing, everything in the large bowel becomes diluted.

<Cummings narrates over X-rays>

Now, these X-rays are of the stools of one of our subjects during, on this side, the control diet. You can see these three stools here are relatively small and the inert markers, which the subjects were taking with their diet, are fairly densely packed together in the stools. When fibre was added to the diet, the subject's stools became much larger and the inert markers are much more spread out in the faecal matter. These inert markers are examples of what happens to many constituents in the large bowel and in the faeces when wheat fibre is added to the diet. What, one may ask, is this significance of having things diluted in the large bowel? As we'll see when we come to the later part of the presentation, there are things in the large bowel which can be quite harmful, particularly carcinogenic substances which might lead to the development of large bowel cancer. And wheat fibre may well have the property of diluting these and so rendering people less susceptible to develop these large bowel diseases.

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<Cummings to camera and then over slide of chart showing effects of fibre from different sources on faecal weight>

There are, of course, other types of dietary fibre than that found in wheat and bran, but very few people have fed these different sorts of fibre and measured their effect on colonic function. Recently, we were able to feed fibre extracted from various fruits and vegetables and observe its effect on faecal weight. This slide shows the faecal output in four groups of subjects during the time they were taking a control diet. We then supplemented their diet with fibre extracted from bran, cabbage, with pectin, and fibre from carrot. This shows the resulting change in their faecal weight. When the bran fibre was added to the diet, faecal weight increased by over 100 grams a day; whereas with a similar amount of cabbage fibre – by only 55 grams a day; with pectin, even less – 35 grams a day increase; and with carrot – about 70 grams a day increase. So fibre from different sources tends to increase faecal weight by different amounts. It's also worth remembering, if we go back and recall the water-binding facts about fibre, that these increases in faecal weight don't bear any relationship to the in vitro water-uptake capacity of these particular materials.

<Cummings narrates over previous display of various fibre preparations>

Whereas if we look at the water-uptake capacity in a test tube, pectin has a very good capacity to take up water and bran has very little capacity to take up water. When we feed these materials to people, bran seems to come out as the most affected increase of faecal waste, whilst pectin hardly increases faecal weight at all. Now, the link between these two apparently unconnected sets of results is the fact that these fibres are digested in the bowel and it is likely that pectin is considerably more digested than bran and so, in the end, bran is able to exert much greater effect on faecal weight than is pectin.

Now, another important physiological property, which often goes hand in hand with the effect on faecal bulk, is the effect which fibre has on transit through the gut.

<Cummings narrates over slide of graph demonstrating effect of fibre on transit time through gut>

This shows the transit time measured in one of our subjects over a period of about 40 days. During the initial 3 weeks, a high fibre diet was being given, and during the final 3 weeks, the fibre was taken out of the diet and an ordinary standard diet was given. It's evident that whilst transit time was between 1 and 2 days on the high fibre diet, it crept up to almost 3 days on the low fibre diet. The significance of these changes in transit time remains to be fully evaluated, but it's quite probable that different transit times will enable different types of bacterial reaction in the large bowel to come to completion. And this, again, could be an important effect that dietary fibre has on the large bowel.

<Cummings narrates over slide listing physiological effects of fibre>

To summarise the physiological effects in the large bowel so far, we have fibre affecting: faecal weight, diluting colonic content, shortening transit time, and through its digestibility, altering the metabolic processes in the large bowel. Dietary fibre has also been shown to alter the pressure responses which we see in the large bowel with different diets.

<Cummings to camera>

Fibre does, in fact, have other effects apart from those on the large bowel and we will now go on to look at the effect of specific sorts of fibre on intestinal absorption.

<Cut to Dr Jenkins. Jenkins to camera and then refers, with indicator stick, to various fibre-containing foods displayed on trays next to him>

Just before looking at the specific effects of fibre on intestinal absorption, let's take a glance at the types of fibre, or the types of fibre-containing foods, which are readily available to us in the form of, here, fruit: pectin contained in apples, about half a gram per apple; bananas, a staple food in many parts of the world, especially in Africa. And leguminous seeds, which I'd like to emphasise in that they're a rather neglected human nutrient. Here we have: mung beans, eaten in China as both a savoury and dessert; black-eyed peas, the apocryphal diet of the Deep South; green lentils – dahl – a very common source of nutrition in India; okra, a food eaten in Africa and India and rich in pectic substances, as anyone who's eaten okra will know; and chickpeas – chickpeas from which Cicero, in fact, got his name apparently because the family had chickpea-like lesions on their nose, so these were known to the ancients and form part of their staple nutrition.

And turning again to the cereals, which we've focused on hitherto quite a lot today already: corn, a staple in Africa and grown right the way across the world; the cereal of Asia, perhaps, rice, brown rice; oats, again the apocryphal diet of the Scots as porridge; and our own wheat bran, as I say, the epitome of the Northern European cereal.

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<Jenkins to camera and then demonstrates the viscosity of various fibres on addition of water>

In relation to absorption, let us look at one further physical property, that of viscosity. We've already discussed the other physical properties related to dietary fibre, but there is this one important physical property, viscosity, which I think bears a great deal on absorption as such. We've selected three different types of fibre-rich or purified fibre substances. We've selected wheat as our cereal fibre, pectin as our fruit fibre, and guar as our legume seed powder.

Let me now show you the effects of mixing these with water. These are 1 gram aliquots of the fibre mixed with 50 ml of water, giving us a 2% solution. As you can see, the bran has little effect, has no effect, in fact, on the viscosity, on one's ability to pour this particular mixture – this slurry which is what it amount to. If we do the same with pectin, making a 2% solution, one has to stir rather vigorously. And, as one can see, one's beginning to get some thickening, but there's a very poor mixing and stirring has to be very rapid. It takes us a little time to mix this, but, I think, now you'll be able to see that here we have the beginnings of a fairly viscous solution – quite a difference, quite a difference when one looks at the bran that one has here where this is merely a slurry with water.

Let's mix up the guar now, which is perhaps the substance which causes the greatest increase in viscosity and is, again, the most difficult substance to mix. <*Cut to few minutes later*> Now, after about 4 or 5 minutes mixing, one can see that one has a very viscous solution. Within a little while, in fact, one will be able to stand this beaker on its end and, in fact, one can stand a spoon up in this sort of a mixture. Pectin, again, viscous but nothing like as viscous as the guar. And the bran – still no viscosity. So we've got the bran slurry, the pectin 2% viscous solution, and the very viscous 2% guar.

<Jenkins to camera and then over slide of graph showing effect of guar gum on xylose absorption>

It's perhaps not surprising that this property of dietary fibre may lead to very marked effects on the intestinal absorption of nutrients.

The figure here shows the effect of the gel-forming leguminous fibre guar gum, already shown, on xylose absorption, taken as 25 grams by mouth and given really as an index or a marker of carbohydrate absorption. As one can see, there's a much slower rise and lower levels are reached over the first two hours in terms of the rise in blood xylose. However, the urinary xylose excretion, as an overall index of the completeness of carbohydrate absorption, over an 8 hour period was, if anything, greater when the guar had been taken. So, in fact, there was no malabsorption or increased colonic loss of xylose when guar was taken, merely a smoother flatter rise.

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<Jenkins narrates over animation illustrating rates of gastric emptying with various nutrients>

How then might this be explained? As one can see here, gastric emptying with the control of the rate of delivery through the pylorus of nutrient to the absorptive area may be a factor. Let's look at this and assume that this is the normal situation. When we take guar, however, it's likely to be quite some delay in the rate of gastric emptying due to the viscosity of the guar gum itself. And with this slower delivery, one would expect that this was a factor in controlling the rate of rise in peripheral blood of absorbed material; in other words, the rate of absorption of material and its appearance in the peripheral blood.

<Jenkins narrates over animation illustrating the effect of viscosity on the rate of transport of substances from intestinal lumen to site of absorption>

So that's one factor: gastric emptying in the control of the delivery of substrate to the small intestine and its absorption. The other factor that I think is most important, especially when dealing with fibre of the viscous nature, is the rate of transport of that material in the intestinal lumen to the mucosal surface where it will be absorbed. Under normal conditions, the unstirred layer, that layer closest to the absorptive surface, will pose a barrier and substrate will move across at a rate determined by gastric emptying, perhaps predominantly.

When one adds substances which have a greater viscosity, one is likely to increase the thickness of this theoretical layer and therefore act as a barrier – well, this layer will then act as a barrier to diffusion of substrate from the intestinal lumen through the enterocyte, through the absorptive cell, and into the body. So that here is another factor which is going to cut down on the rate of delivery of substrate to the body, and therefore, again, influence the rise of various substrates in the peripheral circulation.

<Jenkins narrates over slide of graph showing effect of guar intake on glucose tolerance test>

Is this relevant, then? I think this is the question one must ask, and let's therefore look at the effect of taking 50 grams of glucose with and without added fibre in the form of guar gum. As you can see from the graph here, this is the response of the normal glucose tolerance test in 6 volunteers, showing a rise in blood sugar after taking the 50 grams at zero time. If one adds guar to the 400 ml, then a really quite remarkable flattening occurs of the glucose tolerance. Here showing a flatter peak and, in fact, evidence of delayed absorption again through the higher, 120 minute, value seen after taking guar as compared with the lower value on the control. So here we have a definite effect on carbohydrate absorption: a delay and a flattening.

<Jenkins narrates over slide of graph showing effect of guar intake on serum insulin>

If we look at the next slide, we can see insulin response; this flattening was not, in fact, due to an increased insulin release. Here's the normal insulin response, a good rise here, followed by a fall down towards normal at 120. When one takes guar, this too shows quite a dramatic flattening. So the endocrine background and the carbohydrate rise are both flattened when one takes viscous forms of dietary fibre.

<Jenkins narrates over slide of graph showing effect of high fibre on electrolyte output>

What other things are relevant here? Well, other things are likely to have delayed absorption, some, in fact, are likely to be malabsorbed. Things that we don't absorb completely are likely to increase in greater concentrations, or greater quantities perhaps, not concentrations, greater quantities in the stool. On example would be bile salts and another fat, both of which will be lost in increasing quantities in the stool.

Here's a slide showing the increase in electrolyte output on giving high-fibre diets in the form of bran. And this is the effect on faecal losses of sodium, chloride, a big loss in potassium – but remember that bran also contains quite large amounts of potassium, and also a big increase in volatile fatty acid loss. This is, of course, colonic loss. And perhaps of greater importance, one has an increased loss of calcium and of magnesium, again remembering that bran is, if you like, a good source of magnesium, so we are going to discuss later what the effects are on balance, but let me just conclude this part by saying that substances which are normally completely absorbed will be absorbed more slowly, and substances where there is some loss are likely to be washed into the colon and lost in increasing quantities in the stool.

<Cut to Cummings. Cummings to camera, then narrates over slide summarising physiological effects of fibre intake>

These, then, are some of the effects which fibre has on the absorption of various nutrients. Let's finish this part by summarising the physiological effects we've been talking about. We've talked initially about the effects dietary fibre had on colonic function: increasing faecal weight, diluting colonic content, shortening transit time, and having various metabolic and other effects. And in the small intestine, Dr Jenkins dealt with the effect on carbohydrate absorption, and there is also increased loss in the stool of lipids, nitrogen and minerals. Changes also occur in the absorption and excretion of bile acids and cholesterol, and it is also possible that there may be effects on appetite and satiety, as we mentioned earlier in relation to the effects of chewing etc. by dietary fibre.

<Cummings to camera>

So much for the physiological effects of fibre. In the second part of this presentation, we will be going on to deal with the clinical aspects of fibre.

<End credits>