Progress report

Fibre and enteral nutrition

Clinical experience during the last decade has confirmed that enteral nutrition is an efficient and cost effective means of providing nutritional support to patients with normal or near normal gastrointestinal function. Before and during this period the knowledge gained of the processes involved in the physiology of nutrient absorption has been applied to the formulation of enteral diets and if comparisons are made of the composition of present day diets with those used 10 to 15 years ago several differences can be seen. These relate mainly to the nitrogen and energy concentrations of polymeric diets and the sources of nitrogen and energy and electrolyte compositions of predigested chemically defined elemental diets.

Until recently all the commercially produced liquid enteral diets continued to have one thing in common, namely that they contained a low ‘residue’ or ‘fibre’ content. Historically it must be remembered that the very earliest low residue enteral diets were specifically designed not only to provide balanced nutrition to astronauts in space but also to reduce their stool weight and stool frequency. Subsequently it was realised that one clinical advantage of low residue diets was that they had a low viscosity and could be administered easily through ‘fine bore’ nasogastric or nasoenteric feeding tubes. Furthermore as it became clear that there could even be a number of therapeutic advantages in administering low residue diets their widespread use became accepted without question.

Although the 1970s and early 1980s has been the time when advances have been achieved in the field of enteral nutrition the same period has seen also significant advances in the field of fibre research and as a consequence there has developed a belief that many of the diseases of Western civilisation such as atherosclerosis, obesity, appendicitis, constipation, irritable bowel syndrome, colon cancer, diverticular disease, diabetes mellitus, and gall stones were related to a deficiency in dietary fibre and that supplementing the diet with fibre would prevent and might even cure these conditions.

Although not all recent studies have been in complete agreement the observations made by Heaton and colleagues over 10 years ago that ingestion of bran accelerated slow intestinal transit and delayed rapid intestinal transit lead to suggestions that the ingestion of fibre produces a more regular bowel habit. Based largely on this premise, as well as on the above doctrine that dietary fibre is good overall, suggestions are beginning to be made that there could be benefits to supplementing commercially produced liquid enteral diets with fibre.

This article seeks to critically examine the premises on which the proposed use of fibre supplemented enteral diets are based. In the ensuing text, attempts have been made to determine whether there is any substantive evidence to support the use of fibre supplemented enteral diets clinically. Finally, potential areas of interest requiring further research have been highlighted. A proper understanding of the potential applications of fibre to
enteral nutrition can only be achieved by taking into account recent progress that has been made in the understanding of the physiological and biochemical processes that are involved in the intestinal assimilation of the major components of dietary fibre – these are therefore reviewed before other discussions.

Definition of dietary fibre

One of the most confusing aspects of fibre and enteral nutrition has been the difficulty in agreeing on a definition of the term 'fibre' or 'dietary fibre'. This problem is by no means unique to enteral nutrition as many previous discussions testify. It is thus important to realise that fibre is not a single substance, nor is it an inert, indigestible, 'unavailable' material which simply passes through the gut. Progress in understanding fibre has been slow because it is difficult material to handle in the laboratory, its action is dependent on its physical and chemical properties and adequate methods for its measurement are still being developed.

For the purposes of the present discussion about the role of fibre in enteral nutrition, the simple and precise definition proposed by Cummings will be used (Table 1). His proposal is to call the major fraction of fibre non-starch polysaccharide (NSP). Non-starch polysaccharide is then divided into cellulose and non-cellulose polysaccharides (NCP). Non-cellulose polysaccharides includes those polysaccharides like inulin and guar and the plant gums and mucilages.

Lignin is not a carbohydrate, and Cummings suggests that if it is to be included as part of fibre, it must be considered separately. Chemically lignin is reasonably well defined and comprises a group of polyphenolic compounds of widely varying molecular weights. It contributes to the structural rigidity of the plant cell wall and is an inhibitor of microbial cell wall digestion. As the amount of lignin in the human diet is so small (1 g/day), it is probably unjustifiable to single lignin out to be included under the term 'dietary fibre'.

Assimilation of dietary fibre

As outlined above, the initial interest of fibre in the context of enteral nutrition has centred around its effect on bowel function. This in turn relates to the undigestibility of fibre. It should be appreciated, however, that recent research has shown that there is striking variation in the apparent digestibility of the different components of dietary fibre outlined in Table 1.

Table 1  Classification of dietary fibre*

<table>
<thead>
<tr>
<th>Non-starch polysaccharide (NSP)</th>
<th>non-cellulosic polysaccharide (NCP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellulose</td>
<td></td>
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<tr>
<td></td>
<td>.hemicellulose</td>
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<tr>
<td></td>
<td>.pectin</td>
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<tr>
<td></td>
<td>.inulin</td>
</tr>
<tr>
<td></td>
<td>.guar</td>
</tr>
<tr>
<td></td>
<td>.plant gums and mucilages</td>
</tr>
</tbody>
</table>

*After Cummings.
Fibre components

\[ \text{Intestinal microflora (anaerobic)} \]

VFA (acetate, propionate, butyrate) gas \( (\text{CO}_2, \text{H}_2, \text{CH}_4) \)

and energy

\[ 34.5 \text{C}_6\text{H}_{12}\text{O}_6 \rightarrow 48 \text{CH}_3\text{COOH} + 11 \text{CH}_3\text{CH}_2\text{COOH} + 5 \text{CH}_3(\text{CH}_2)_2\text{COOH} + 23.75 \text{CH}_4 + 34.25 \text{CO}_2 + 10.5 \text{H}_2\text{O} \]

Figure  Digestion and fibre.

As the ensuing text will show, present day concepts about some of the potential benefits of supplementing enteral diets with fibre relate as much to the action of the products of colonic fibre digestion as to the stool bulking effect achieved by undigested fibre components. The Figure summarises the processes involved in the intestinal assimilation of the different components of dietary fibre.

Sites of fibre assimilation

Recent evidence overwhelmingly implicates the colon as the major site of non-starch polysaccharides (NSP) degradation. In three recent and important studies carried out in ileostomists, 87.9–100% of administered fibre was recovered in ileostomy effluent. Two earlier studies also undertaken in ileostomy subjects, suggested that some fermentation of fibre occurs in the small intestine. In the first, significant quantities of NCP were digested in the small intestine. This particular study is open to some criticism, not only on methodological grounds (vide infra) but also because ileostomy effluent may have been permitted to ferment for some hours during collection. In the second, in which \(^{14}\text{C}\)-labelled cellulose degradation was studied in man, a peak of \(^{14}\text{C}\) CO\(_2\) in expired air was noted as early as 30 minutes after the oral ingestion of labelled cellulose. Quantitatively much smaller than the later and main peak, its occurrence was thought to indicate a minor degree of degradation in the small intestine. An alternative explanation, however, as discussed by the authors is that there may have been some contamination of the labelled cellulose with starch.

As the Figure shows, volatile fatty acids (VFA's) are a major product of fibre degradation. The virtual absence of VFA's in the ileostomy effluent of two of the ileostomy studies discussed above provides supportive evidence for the lack of fibre degradation in the small intestine. Finally, in a recent study in which jejunal ileal and colonic contents were obtained within four hours of sudden death the concentrations of VFA's were at least an
order of magnitude greater in colonic as compared with small intestinal contents, again implicating the former as the major site of degradation of fibre components.

Microbial action

No luminal or mucosal enzymes have been identified in man that are capable of catalysing the hydrolysis of NSP, and there can be little doubt that the breakdown of NSP is accomplished anaerobically by intestinal microflora (predominantly colonic). Available bacteriological data indicate that a number of NSP-degrading bacteria are present in the human colon. Although some of the polysaccharidases produced by human colonic bacteria are extra cellular, most of the enzymes studied appear to be bound to the bacterial cell wall. Potentially of great importance to enteral nutrition is the observation that many of the microbial polysaccharide degrading enzymes are inducible.

Products of NSP degradation

Volat ile fatty acids (VFA)

Acetic, propionic, and butyric acids are the acids produced as a consequence of NSP degradation. Volatile fatty acids are avidly absorbed in the human colon and at the same time stimulate colonic sodium and water absorption. Their presence in the colon affects and indeed controls the pH of the colonic lumen, which in turn may indirectly affect transport of other solutes such as ammonia. Once absorbed, VFA’s are available for aerobic metabolism in body tissues and as such are an energy source. In certain circumstances VFA metabolism may make a significant contribution to daily energy balance. Lactitol, a synthetic disaccharide which is not absorbed in the human small intestine, but extensively (>90%) metabolised to VFA in the colon, has been calculated to have a calorific value close to 2.5 kcal/g.

Gas

Methane, carbon dioxide, and hydrogen are the gases produced during NSP degradation. They are either absorbed and excreted in expired air or passed as flatus per rectum. A variety of abdominal symptoms such as colic, feelings of distension and bowel disturbance have been attributed to colonic gas production, not always with justification. A recent study rather disappointingly indicated that end alveolar breath hydrogen and methane analysis provides no clear indication of fibre digestibility.

Bacterial growth

The third important end product of anaerobic colonic bacterial fermentation of NSP is energy which bacteria use for growth and maintenance. In man the presence of fermentable polysaccharides in the diet has been shown to stimulate colonic microbial growth and the increased bacterial mass is one of the mechanisms whereby NSP in the diet leads to an increase in human faecal output. Associated with stimulated microbial growth is increased nitrogen excretion as a result of the incorporation of nitrogen into microbial protein. Theoretically other activities of colonic microflora, such as bile acid dehydroxylation, hydrolysis of glucuronide conjugates, and vitamin
synthesis might also be affected by NSP degradation. As yet these have not been fully investigated.\textsuperscript{30}

**Factors affecting the breakdown of non-starch polysaccharides (NSP) in man**

As shown in Table 1, cellulose and non-cellulose polysaccharides (NCP) are the two major components of NSP. Published evidence indicates that in man NCP digestion is more efficient than cellulose digestion, some components of NCP being very extensively degraded in the human gut. Data from eight studies quoted by Cummings\textsuperscript{30} show that an average 80\% NCP from various sources was degraded. The cellulose component of the same fibre sources appears to be less well degraded. In 10 studies quoted by Cummings\textsuperscript{30} on average 50\% of the cellulose fraction from various fibre sources was degraded. This compares favourably with 42-8\% digestibility found in one of the more recent studies of cellulose degradation in man.\textsuperscript{29} A number of important physical factors have now been identified that explain the observed differences in the extent of colonic degradation of the different components of fibre.

The pattern of absorption of digestible dietary carbohydrate is dependent in part on the accessibility of substrate to luminal \(\alpha\)-amylase.\textsuperscript{35} Breakdown of NSP by bacterial polysaccharides is also dependent on these enzymes gaining access to its surface.\textsuperscript{36} The rate of breakdown of cellulose, being a relatively insoluble material, will be very much related to the form and particle size that in turn will both determine the surface area that is accessible to colonic bacterial polysaccharidases. Highly crystalline forms present a relatively small surface area which is probably one of the reasons why pure cellulose isolated from wood is more poorly digested than the non-crystalline forms of cellulose in fruit and vegetables.\textsuperscript{37,38} Particle size, which is dependent on the source and method of processing equally influences the degree of digestibility.\textsuperscript{39} Reducing particle size increases available surface area, resulting for example in an increased digestibility of the cellulose component of finely ground as compared with coarse bran.\textsuperscript{40,41}

Lignin, as mentioned above, is not a carbohydrate and comprises a group of polyphenolic compounds of widely varying molecular weights. Although not broken down to any extent in the gut,\textsuperscript{38} it does influence the extent of NSP degradation. In general, the more lignified a cell wall of a plant structure, the less liable it is to complete degradation in the gut. Thus the NSP in wheat bran is degraded much less than those present in the less lignified cell walls such as cabbage and apples.\textsuperscript{37-39,42}

Cellulose digestion is a relatively slow process, studies in rumens indicating that it can proceed for up to 48 h.\textsuperscript{43,44} Contact time between substrate and enzyme will also clearly affect digestibility. Thus cellulose digestion is more complete the slower the colonic transit time.\textsuperscript{45} Factors that affect colonic transit such as treatment with codeine phosphate and senokot will therefore influence cellulose digestibility.\textsuperscript{44}

The majority of NSP in plant cell walls are in fact NCP.\textsuperscript{46} These are chemically very different from cellulose in that they have a much more open chemical structure and many are water soluble at the pH of luminal contents, which is the reason why these substances are metabolised to a greater extent by colonic bacterial polysaccharides than cellulose.\textsuperscript{30} Some of
the water soluble NCP such as pectin are completely degraded in the normal human colon.44

Clearly one further factor that will affect the degradability of NSP is the activity of the colonic bacterial polysaccaridases themselves. Recent studies of these enzymes have been reviewed.35 Many of the polysaccharide degrading systems are complex, more than one enzyme being involved. None of the polysaccharide degrading species appears to be restricted to the production of one particular type of polysaccharide degrading system and given the number of enzymes that are needed to degrade any one of the NSP substrates, the versatility of these colonic organisms is remarkable. All of the polysaccharidases studied to date in human colonic bacteria have proved to be inducible – that is, an appreciable amount of enzyme is produced only when the organism is exposed to the polysaccharide substrate. It follows from this discussion that the degree of digestibility of a single fibre source could be expected to increase with time, a situation which might occur during longterm administration of a fibre supplemented enteral diet. In contrast, antibiotic therapy could be expected to reduce the activity of colonic bacterial polysaccharidases, reducing in turn the digestibility of enterally administered NSP.

Fibre and enteral nutrition

The two main areas of current interest are concerned with the possible benefits of fibre on bowel function during enteral feeding and its effects on small and large intestinal mucosal cell morphology and function. Before considering these, the pitfalls that exist in interpreting available clinical data should be appreciated as well as the effects that fibre supplementation may have on nutrient absorption during enteral feeding.

Problems in interpretation of clinical data

Two major problems exist in interpreting much of the published clinical data. As mentioned above, it is clear that different components of NSP are degraded to different extents in the human gut, and consequently their physiological properties will vary. Moreover, factors such as fibre source, particle size and lignin content all influence intestinal assimilation. To achieve a full understanding of the significance of published data therefore, detailed information of the physiochemical characteristics and composition of the fibre sources tested is required – this is, rarely, if ever, presented in clinical papers. As outlined by Southgate and Englyst46 as well as by Cummings,10 problems with the methodology of fibre measurements are considerable. A satisfactory analytical method for dietary fibre must measure all the NSP (cellulose, NCP, soluble and insoluble), and a method such as described by Englyst et al47 appears to meet these criteria.

Many authors quote values obtained by one of the Van Soest detergent fibre methods.4 Neutral detergent fibre (NDF) has often been used46 to signify ‘insoluble’ dietary fibre. A proportion of NCP, such as the pectins, is water soluble and therefore is not measured in the detergent fibre methods.14 50 Thus although this method gives accurate values for some cereals, especially wheat products (which contain low proportions of soluble NCP), that are numerically of the same order as total dietary fibre values
obtained by the summation of cellulose and NCP, direct analysis of 
the different fractions shows this is fortuitous. In fruits and vege-
tables therefore, which contain significant water-soluble NCP, the 
nuetral detergent fibre method will considerably underestimate dietary 
content very significantly. This discussion should help the reader 
to understand why there is often such a discrepancy between figures quoted 
for neutral detergent fibre and total fibre contents (9.3 g versus 
30 g).

Effects of added fibre on intestinal nutrient absorption

Recent research shows that the blood glucose response to the ingestion of 
different carbohydrate sources varies considerably. Although a number of 
factors such as the mono and disaccharide contents, as well as protein and 
fat contents, are thought to influence postprandial circulating blood 
glucose levels, other experimental data indicate that the fibre content is 
likely to have an important effect on the pattern of absorption of glucose 
from different carbohydrate sources. Thus certain forms of purified dietary 
 fibre have been shown to modify carbohydrate absorption. Amongst these, 
the viscous predominantly NCP forms such as guar, pectin, and tragacanth 
have the greatest modifying effects. In contrast, wheat fibre has little 
modifying effect on the postprandial glucose response. The principles 
gained from studying the modifying effects of the viscous forms of dietary 
fibre on the patterns of glucose absorption from dietary carbohydrate have 
been applied to the treatment of diabetes and post gastrectomy 
hypoglycaemia. Interestingly the addition of guar to one liquid glucose 
meal not only modified immediate plasma glucose concentrations and serum 
inulin levels, but its effect persisted to modify the same responses after a 
fibre free glucose meal administered four hours later.

It follows from these discussions that the effects of fibre on intestinal 
nutrient assimilation will vary according to the physiochemical properties of 
the fibre source tested. As the NCP forms such as guar, pectin and 
tragacanth have been shown to have the greatest modifying effect on glucose 
absorption, these are the sources that have been most frequently used to 
investigate the mechanisms involved in the modifying effects of dietary fibre 
on nutrient assimilation. Thus, in different experiments fibre has been 
shown to affect gastric emptying, small intestinal flow and transit, pancreatic 
enzyme secretion, the rate of nutrient digestion by pancreatic 
enzymes, solute diffusion, the apparent Michaelis constant of amino acid 
and monosaccharide uptake, as well as postprandial gastrointestinal polypeptide hormone responses.

In patients with normal gastrointestinal function it would be difficult to 
envisage on account of the large functional absorptive capacity of the 
gastrointestinal tract, that fibre supplementation of enteral diets would have 
a clinically significantly deleterious effect on the assimilation of the major 
classes of nutrients, carbohydrate, fat and protein. The situation with regard 
to mineral absorption is by no means as clear. Thus over 11 day feeding 
periods the addition of 40 g soy fibre/d to a polymeric liquid enteral diet 
resulted in a significant decrease of absorption of iron and copper, and a 
pattern of decreased absorption (not statistically significant) of calcium, 
magnesium, zinc, potassium, and phosphorous. Similar changes were not
Fibre and enteral nutrition

observed when 20 and 30 g soy fibre were added.75 Although fibre supplementation of enteral diets administered to diabetic patients would seem an attractive proposition, bearing in mind the results of work in this field75-80 no clinical data in enterally fed patients have been reported.

As yet no studies have investigated the possible effects of fibre supplementation on nutrient assimilation from predigested 'chemically defined' elemental diets administered to patients with severely impaired gastrointestinal function. In such patients, particularly those with the nutritionally inadequate short bowel syndrome, such factors as gastric emptying, small intestinal motility and transit, unstirred water layer resistance, as well as morphology are all likely to assume important roles in determining the extent of nutrient absorption. Because each may be affected by fibre, there remains a clear indication to pursue investigations into the effects of supplementing the predigested 'chemically defined' elemental diets with fibre.

Effect of added fibre on bowel function

One of the main areas of interest of fibre enriched liquid enteral diets is bowel function. If one accepts that normal bowel function can be defined as absence of diarrhoea or constipation with adequate nutrient absorption,52 then the significant proportions of patients receiving low residue liquid enteral diets without added fibre who develop constipation of diarrhoea can be considered to have abnormalities of bowel function.

CONSTIPATION

Studies of healthy volunteers have shown that the majority of the population in the Western world pass one bowel movement per day with an average daily output of 120-130 g stool.76 Similar findings were reported in normal subjects taking part in dietary studies and consuming metabolically controlled diets.77 Large individual variation is seen, however, both in frequency and weight of bowel movements, without complaints of either constipation or diarrhoea.78 Such variability in normal bowel habit makes it difficult to define an abnormal or constipated state and to date this somatic difficulty has not been overcome.78 Clearly therefore the true incidence of constipation during feeding of low residue liquid enteral diets is not known.

Fibre added to the diet affects bowel function in three ways. Faecal weight is increased, intestinal transit time is increased and frequency of bowel evacuation is increased.79 It is important to appreciate that different sources of fibre increase stool weights to different extents and by different mechanisms.78 Thus cabbage and other vegetable fibre sources which are rapidly and extensively degraded stimulate growth of microflora within the colon.80 Bacteria are 80% water81 and their increase in mass in stools with degradable fibre materials largely accounts for the increase in faecal weights. On the other hand, poorly digestible bran stimulates bacterial growth to a lesser degree, but survives itself to hold water. There are therefore, two water holding components in the stool with added bran, fibre, and bacteria and together these produce larger faecal weights than equivalent supplements of the vegetable sources of fibre.76,80 Defecation is initiated by mechanoreceptors in the anorectal area, by movements of the rectal mucosa and by rectal distension.82 Sensory receptors respond to
distension so that faecal bulk is an important determinant of the defecatory mechanism. The bulking effect of digestible and undigestible fibre is, therefore, associated with an increase in frequency of defecation. 

**Clinical Studies in Enteral Nutrition** (Table 2)

The author is aware of five controlled crossover studies that have compared bowel function in healthy volunteers or patients receiving liquid enteral diets with and without added dietary fibre. The fibre sources used were either not stated, or described as a soy fibre product derived from the soy coteleden high in the NCP hemicellulose, soya bran, soya polysaccharide, and carrot fibre. With the exception of 60 g/d of soy fibre and 20 g/d undescribed fibre, both administered to healthy volunteers, no significant effect of fibre supplementation on stool frequency was seen. The addition of 30 and 60 g soy fibre to a polymeric diet administered to normal subjects both resulted in significant increases in mean daily stool weights. In four of the other five studies, however, no significant effect of fibre supplementation was seen on mean daily stool wet weights, range 24.1–110 g/24 h without added fibre: 40.4–139 g/24 h with added fibre. All were short term studies with the fibre supplements being administered for between four and 14 days. No longer term studies of fibre supplementation in patients receiving liquid enteral diets have yet been reported.

The most recent estimate of dietary fibre intake in the UK, based on the analytical method of Englyst and Cummings, is 13.7 g/d. It is of interest therefore that a range of fibre supplementation of 21.2–30 g/d produced such modest changes in stool weights. At first sight it would seem that the lack of consistent beneficial effects of added fibre in these studies is predictably related to an inappropriate choice of fibre source. Thus the fibre supplements used contained a predominance of NCP. As discussed previously this is not the component of fibre that exerts maximal change in stool weight. There is at least one study, however, that has shown that supplementing a normal diet with 20 g dietary fibre per day derived from carrot results in a significant increase in stool weight. As outlined above, the physical form of NSP affects digestibility. One does wonder therefore whether acceptable viscosity of the fibre supplemented enteral diets used in

<table>
<thead>
<tr>
<th>Author</th>
<th>Fibre source</th>
<th>n</th>
<th>Duration of study</th>
<th>Fibre intake g/d</th>
<th>Faecal wet wt g/d mean (SD)</th>
<th>Daily stool frequency</th>
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<tr>
<td>Slavin et al</td>
<td>Soy fibre product</td>
<td>16</td>
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<tr>
<td>Lubke et al</td>
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<td>4</td>
<td>0</td>
<td>110.0 (42)</td>
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</tr>
<tr>
<td>Matzkies &amp;</td>
<td>Soy-bran</td>
<td>8</td>
<td>14</td>
<td>30</td>
<td>57.1 (15)</td>
<td>0.6 (0.5)</td>
</tr>
<tr>
<td>Fischer et al</td>
<td>Polysaccharide</td>
<td>13</td>
<td>30</td>
<td>0</td>
<td>24.1 (2.8)</td>
<td>0.45</td>
</tr>
<tr>
<td>Patil et al</td>
<td>Carrot-fibre</td>
<td>5</td>
<td>5</td>
<td>24</td>
<td>52.0 (16)</td>
<td>0.64 (0.18)</td>
</tr>
</tbody>
</table>

Mean (SD). *p<0.05 v no added fibre.
these studies was achieved by processing the fibre sources to very small forms, thereby increasing digestibility and reducing water holding capacity, two factors known to mitigate against stool bulking.

One is forced to conclude that on the basis of published data there is little evidence to support the use of currently available fibre enriched diets as far as increasing stool frequency and weights of enterally fed patients is concerned. It is clear that further research is still required to identify suitably processed fibre sources that on the one hand result in significant increases in stool frequency and weights of enterally fed patients and on the other hand do not have adverse effects on diet viscosity.

**DIARRHOEA**

Diarrhoea is a significant problem in enteral nutrition. According to basic physiological principles, which take into account the capacity of the normal small and large intestine to assimilate fluid and electrolytes, diarrhoea can be defined as the passage of more than 200 g of stool/24 h on an average Western diet. It follows that the diagnosis of diarrhoea is dependent on accurate measurements of stool outputs, hardly a feasible proposition in uncooperative enterally fed patients with faecal incontinence. For the purposes of our clinical studies we have therefore defined enteral feeding related diarrhoea as the passage of too frequent stools or stools of too loose a consistency that are of inconvenience to the nursing staff and/or the patient. In our experience, diarrhoea so defined, occurs in up to 25% of patients receiving enteral nutrition. A number of factors have been implicated in its pathogenesis. These include use of infected feeds, lactose intolerance, intolerance of high osmotic loads of nutrients administered, inappropriate release of gastrointestinal polypeptide hormones, concommitant antibiotic therapy, ingestion of laxatives, and hypoalbuminaemia.

The role of lactose intolerance in the pathogenesis of the diarrhoea has been discussed in some detail. In brief, the deleterious effect of lactose in enterally fed patients with lactose intolerance will depend on the load (concentration x rate) of lactose administered. Bolus feeding in lactose intolerant patients results in the production of stool volumes in excess of 1 l/24 h. In contrast, when a low load of lactose is presented to the upper small intestine, as occurs during constant 24 hour intragastric infusion of liquid lactose containing diets, diarrhoea does not occur. In a prospective controlled trial of continuous 24 hour nasogastric infusion of polymeric diets to patients with normal or near normal gastrointestinal function, the development of diarrhoea was not related to osmotic load of nutrients presented for absorption but to concommitant antibiotic therapy. Animal studies carried out in our laboratory have not confirmed that the onset of diarrhoea is related to an inappropriate release of gastrointestinal polypeptide hormones. Finally, hypoalbuminaemia has been related in one study to the development of diarrhoea. No mention was made however, as to whether those patients with low serum albumins (who one could presume were sicker) were receiving antibiotic therapy.

As far as one can determine from these clinical studies, there appears to be a link between concommitant antibiotic therapy and the development of diarrhoea during enteral feeding. The incidence of diarrhoea in these patients on antibiotic therapy is higher than one would expect if they were on antibiotics alone, so it would seem possible that there is an interesting and
deleterious synergistic effect between antibiotic therapy and the administration of fibre free liquid enteral diets. As outlined previously, the absorption of VFA’s in the colon provides a powerful stimulus to colonic fluid and electrolyte absorption. One explanation therefore which would explain these associations is that antibiotic therapy reduces the bacterial enzyme catalysed production of VFA’s within the colon, and in turn this reduces VFA stimulated water and electrolyte absorption in the colon, the end result being the too frequent passage of watery stool.

To prove this hypothesis it would be necessary first to ascertain colonic inflows of substrate. Such information is currently not available. Furthermore, it would then be necessary to investigate the effects of antibiotics on colonic microflora and VFA production in an in vitro stool culture system. A potential area of great interest would then be to determine if supplementation of enteral diets with an NCP such as pectin would result in a diminuation in the incidence of enteral nutrition associated diarrhoea and moreover if diarrhoea occurs whether it can be reversed by NCP administration.

Until such information is available, no firm recommendation can be made as to the benefits of fibre supplementation of enteral diets in respect of reducing the incidence of enteral feeding related diarrhoea.

**Enteral diets and intestinal epithelial cell proliferation**

**Experimental studies**

The intestinal epithelium can respond to a wide variety of stimuli by altering its proliferative rates. There is now a large and interesting literature on the effect of low residue liquid enteral diets on intestinal morphology, cell turnover kinetics and function. Almost all experiments have been performed in the rat and low residue chemically defined elemental diets and polymeric diets have been studied. In general, in the jejunum, intestinal mass is maintained or increased, the specific activity of brush border hydrolase activity maintained, or increased DNA synthesis rates maintained, and absorptive function maintained. In sharp contrast, administration of these low residue diets is associated with pronounced atrophy in the ileum and colon as compared with the feeding of a normal fibre containing rat chow diet.

As fibre has been shown experimentally to have a proliferative effect on intestinal epithelium, Suggestions have been made that the atrophy and reduced intestinal proliferation seen in rats fed on liquid enteral diets arises because of the lack of fibre in these diets. To prove this hypothesis it would be necessary to compare the responses of ileal and colonic epithelia to the same liquid enteral diet fed in the absence and presence of added fibre. Results of published studies in general are supportive. Ryan and colleagues showed that cellulose and petroleum jelly added to an oral liquid fibre free diet resulted in significant increases in colonic weight and DNA synthesis rates compared with values seen when the fibre free diet was fed. When the same liquid polymeric diet with and without 9% added bulk was administered orally to rats for four weeks, however, the total weight of ileal segments were similar. In the most comprehensive study to date, Goodlad and colleagues have studied crypt cell production rate in starved rats refed with a liquid elemental enteral diet supplemented with very large (1:1)
quantities of different fibre sources, inert bulk (kaolin), a poorly digestible fibre source (purified wood cellulose), a more readily digestible fibre source (purified wheat bran), and a soluble NSP (prepared from ispaghula husk). Crypt cell production rate in the terminal ileum and colon was unaffected by the addition of inert bulk. Of the fibre sources, the most marked crypt cell production rates in terminal ileum and colon were seen when purified wheat bran was added to the diet. Unfortunately, no firm conclusions could be reached as to the effect of soluble NSP as not all this diet was consumed.

As outlined above (Figure) VFA's are the main products of colonic fibre digestion. One of the implications of the study of Goodlad et al is that the proliferative effect of added fibre on the distal ileum and colon is related to its digestibility, and thence possibly VFA formation. It is of interest therefore that other research shows that intraluminal VFA's stimulate colonic mucosal proliferation. If the trophic effects of fibre are caused by VFA release, do they act directly or as a consequence of metabolite function or by some other systemic factor?

Of the three VFA liberated during colonic fibre digestion, acetate, propionate, and butyrate, butyrate is preferentially metabolised by isolated colonocytes. When butyrate (20 mmol/l) was infused for seven days into the colon of caecectomised rats fed on fibre free elemental diets, colonic mucosal growth, as evidenced by changes in mucosal weight protein and DNA content, was stimulated as effectively as when a mixture of acetate 70 mmol/l, propionate 25 mol/l, and butyrate 20 mmol/l was infused. One explanation of these findings is that VFA's exert a direct trophic effect on colonic epithelium, and that of the three, butyrate exerts the prominent role.

Liberation of VFA's in the lumen of the right colon in man is associated with a lowering of luminal pH, and lowering of colonic luminal pH simulates colonic mucosal proliferation. Other research shows that pectin diets and the intraluminal presence of VFA's increase intestinal blood flow, which may facilitate both small and large intestinal adaptation. Finally, in the study of Goodlad et al, crypt cell proliferation rates at all sites of the intestine correlated with plasma enteroglucagon concentrations. Enteroglucagon has been implicated in playing a role in promoting intestinal cell renewal.

Enteroglucagon secretory cells are localised predominantly in the colon and terminal ileum so it is possible that VFA's and specifically butyric acid, may exert their trophic effect by directly or indirectly stimulating release of enteroglucagon.

Rombeau and colleagues have recently moved forward to investigate the effect of a pectin supplemented elemental diet on colonic anastomotic integrity, and on intestinal adaptation to massive small bowel resection, both experiments being performed in the rat. In the colonic anastomosis model, pectin significantly enhanced colonic mucosal cell proliferation and higher pressures were required to disrupt the anastomosis in animals fed the pectin supplemented diet. In the model of massive small bowel resection, clear evidence of enhanced intestinal adaptation was seen in animals fed the pectin supplemented diet.

**Potential areas of clinical application**

In the animal studies discussed above the administration of fibre free enteral...
diets was generally associated with a maintenance or enhancement of mucosal growth in the jejunum with a corresponding atrophy in the ileum and colon.\textsuperscript{96–102} The addition of fibre appears to prevent the distal mucosal atrophy.\textsuperscript{102–106} As yet no data are available concerning morphology, cell kinetics or function in the ileum and colon of normal subjects or patients with normal gastrointestinal function receiving enteral nutrition. Although there is a clear need to pursue this line of research, it would be premature to conclude in respect of ileal and colonic morphology and function that there are clinically significant advantages of routinely prescribing fibre supplemented enteral diets to patients with normal gastrointestinal function. It should be remembered that the small intestine and colon both have functional absorptive capacities far in excess of that normally required to assimilate nutrients, water and electrolytes. It would seem unlikely therefore, that even if the administration of fibre free enteral diets to patients is found to have a deleterious effect on morphology and function of the ileum and colon experimentally, that there will turn out to be any clinically significant improvement of absorption or nutrients, water and electrolytes if fibre is added.

Animal studies clearly show that when nutrition is provided solely by the parenteral route intestinal atrophy occurs (see review 117). In the light of the experimental animal studies showing that supplementation of enteral diets with fibre has a beneficial effect on ileal and colonic morphology\textsuperscript{102–108} there would seem to be theoretical reasons for supposing that there might be advantages to administering fibre supplemented enteral diets to patients who have been receiving total parenteral nutrition. Again, however, more research is needed before such a concept is applied in a wide clinical setting. In our experience it is actually rather unusual for patients who have received TPN to be fed enterally. This is so because when the decision is made to stop TPN, most patients have entered the anabolic phase of the metabolic response to the underlying injury,\textsuperscript{122} gastrointestinal function is returning to normal, and they are generally started on a normal diet.

The experimental observation that pectin supplementation of a chemically defined elemental diet has a beneficial effect on colonic anastomotic integrity\textsuperscript{120} is certainly of interest, and has potential clinical applications in colonic surgery. At present, however, even the concept of early postoperative nutritional support is a controversial area.\textsuperscript{123} Thus, although some benefits of routine early postoperative enteral feeding have been found, the clinical significance of these remains dubious.\textsuperscript{123}

**Nutritionally inadequate short bowel syndrome**

As discussed by Koretz,\textsuperscript{123} nutritional support is required in patients with the nutritionally inadequate short bowel syndrome, and at least in the early phases of management, a predigested chemically defined ‘elemental’ diet is indicated.\textsuperscript{2} In the elegant animal study of Koruda et al\textsuperscript{121} significantly enhanced intestinal adaptation (1.3–2-fold) was seen in animals after massive small bowel resection who were fed on an elemental diet supplemented with 2% citrus pectin as compared with a pectin free diet. The nutritionally inadequate short bowel syndrome is a rare condition, and it may be technically and practically impossible to confirm these experimental findings in patients. The management of these difficult cases demands that
all possible steps be taken to manipulate the situation towards minimising the intestinal loss of nutrients, fluid and electrolytes. In the light of our current knowledge of the effects and mechanisms of action of pectin serious consideration could be given towards developing a pectin supplemented predigested chemically defined elemental diet for these patients. Two points of caution are warranted, however: the first relates to the fact that in the animal study discussed above pectin supplementation was associated with a small but statistically significant diminution in nitrogen balance. This was caused by increased faecal nitrogen losses probably as a consequence of increased excretion of bacteria or desquamated intestinal mucosal cells in the faeces. Maintenance of body weight and serum albumin concentrations were, however, unaffected.

The second point of caution relates to the fact that fibre supplementation of enteral diets may have a deleterious effect on mineral absorption and if fibre supplemented diets are to be developed for use in patients with the nutritionally inadequate short bowel syndrome, additional mineral supplementation may be required.

**Enteral nutrition in Crohn’s disease**

Chemically defined ‘elemental’ diets have been shown to be as effective as corticosteroids in the treatment of acute exacerbations of Crohn’s disease. Various mechanisms as to how these diets influence the disease have been suggested. Improved nutritional status, exclusion of toxic dietary factors, the anergic properties of the diet and bowel rest have all been discussed. The recent observation that atrophy of the ileal mucosa occurs in animals fed Vivonex raises an interesting possibility that this property may in some way be beneficial in ileal Crohn’s disease. Caution is required therefore before consideration is given to using fibre supplemented chemically defined elemental diets in patients with Crohn’s disease.

**Summary and conclusions**

The recent launch of a number of fibre enriched polymeric diet in the United States and Europe has stimulated considerable interest in the topic of fibre and enteral nutrition, and several commercial concerns appear to be under considerable pressures from their consumers to produce similar products.

As a means of identifying areas of potential application of fibre to enteral nutrition some of the recent knowledge gained about the physical properties of dietary fibre and the processes involved in the intestinal assimilation of fibre has been reviewed. Two areas of interest are identifiable. The first relates to the bulking properties of fibre and the application of this to the regulation of bowel function in enterally fed patients. It is clear from the clinical studies that have been reviewed that there remains a paucity of controlled data, and a great deal more research is needed before widespread use of fibre supplemented diets can be supported. Perhaps of greater interest academically is the potentially beneficial effects that appear to be exerted by the VFA's, liberated as a consequence of colonic bacterial fermentation of fibre, on morphology and function of ileal and colonic mucosa. Although there are a number of potential applications of fibre supplemented enteral diets in this area, more research is required before any firm recommenda-
tions can be made about recommending their use. The one exception concerns patients with the nutritionally inadequate short bowel syndrome. There does seem to be sufficient experimental evidence to suggest that clinical studies should be commenced using a pectin supplemented pre-digested 'elemental' diet in these patients.

Overall therefore, one is forced to conclude that the increasing interest and use of fibre supplemented enteral diets is being driven more by market than scientific forces. Nevertheless, the promotion of these diets has already provided a powerful stimulus to the scientific community, and it remains entirely possible that many of the potential applications of these diets will be realised in the near future.

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References

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73 Taylor RH, Jenkins DJA, Goff DV, Nineham R, Bloom SR, Sarson D. Enteroglucagon
release stimulated by carbohydrate malabsorption a clue to its physiological role [Abstract]. *Gut* 1980; 21: A44.


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