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Substrate for fermentation in man

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ABSTRACT

A variety of different substrates are excreted from the small bowel as possible substrates for bacterial fermentation in the large bowel. Ileostomy studies have shown that 50–90 g/d of dry weight (800–1700 kJ/d) is excreted from the small bowel. Although the amount of non-starch polysaccharides (NSP), the main component of dietary fibre in the diet, causes considerable changes in excretion patterns, NSP is not the dominant part of the energy excreted to the large bowel. Resistant starch in common Western diets amounts to 3–4% of the starch intake, if the diet is not high in e.g. beans. Oligosaccharides, sugars and fat contribute only a few grams each, whereas the excretion of protein can be estimated to 10–15 g/d. Calculation of substrate and energy shows that a considerable amount of energy, equivalent to 15–40 g of carbohydrate, is metabolised in the large bowel.

Keywords: Bacteria, colon, energy, fermentation, nutrients

Introduction

The intestinal content excreted from the ileum constitutes the substrate for the colonic fermentation. It is a mixture of digested and non-digested nutrients, endogenous fluids, cells and mucus. The bacteria in the large bowel are dependent on the type and amount of substrate excreted from the small bowel and it is therefore of interest to quantify and characterise the energy-giving nutrients reaching the large bowel.

Methods to estimate small bowel excretion

Breath hydrogen test

An early and frequently used technique is to measure breath hydrogen excretion after consumption of test meals (1). The breath test was the first to show that carbohydrates are fermented in the gut, but the method is only semi-quantitative.

The intubation technique

The quantitative assessment of ileal flow can be made by using the intubation technique and estimating the quantity with an unabsorbable marker (2,3). Volunteers are intubated with a triple lumen tube lead by a mercury bag, which can be inflated with air to accelerate the progression of the tube. The tip of the catheter is confirmed by X-ray with the subject in a semi-recumbant position. The method is, however, time-consuming and invasive. Consequently, few studies have been performed with this technique.

The ileostomy model

Although studies in ileostomy subjects had been performed earlier (4), reliable results of specific analyses of the ileostomy contents could not be obtained until the ileostomy model was introduced in the late 70s (5). Ileostomy subjects were given a controlled diet, and efforts were made to minimise bacterial degradation by frequent collection of ileostomy contents and immediate freezing. The main advantage of the ileostomy model is that the intestinal transit time is short, and the effluent corresponding to one day's intake is excreted before the next morning (6,7). The within-patient, within-diet and day-to-day variations are small, making short-term balance studies feasible (8). The coefficient of variation between days for dry matter excretion in ileostomy subjects is about 5% (9). A complete quantitative collection of ileostomy contents is relatively easy to perform for ileostomy subjects, as handling of ileostomy excreta is a routine matter for these subjects.

The ileostomy model is the most frequently used technique to measure the excretion from the ileum.

Total amount of substrate

The total amount of substrate needed to maintain the bacterial flora in the large intestine has been estimated to 50–70 g/day (10,11). Ileostomy studies have shown similar figures, with 50–60 g/day of dry matter excreted from the small intestine when subjects are eating an ordinary Western diet (Table 1). It can be noted that on a low-fibre and low-resistant starch diet the amount of dry matter is about 50 g/day. As soon as more dietary fibre or resistant starch is added to the diet the amount of dry matter increases. On high-dietary fibre or high-resistant starch diets the excretion of dry matter from the small intestine easily reaches 80–90 g/day (12), Table 1. As seen, there is a fairly good correspondence between the dry weight and energy content. The energy excreted on the low-fibre, low-resistant starch diets is around 800–1000 kJ/d, and on the high-fibre or high-resistant starch diets about 1400–1700 kJ/d.

Table 1. Amount of dry weight, energy and nutrients excreted from the small bowel in groups of 7–11 ileostomy subjects on different diets. Mean figures per 24h.

per 24h	DW[1] g	E[2] kJ	N[3] g	Fat g	TS[4] g	DF[5] g	Ref
Low fat, low-fibre, 15 g/d, diet	46	790	1.8	1	3	13	13
Low fat, high-fibre, 35 g/d, diet	81	1430	2.4	3	4	33	13
Low-fibre, low-resistant starch diets with addition of:							
Wheat flour, 187 g/d	47	870	1.8	0.8	5.3	12	14
Potato flakes, 102 g/d	52	1000	2.1	3	3	22	15,16
Ordinary corn starch, 100 g/d	55	1099	2.4	2.5	5	11	17
Retrograded high amylose corn starch, 100 g/d	93	1547	2.3	2.8	39	11	17
Bean flakes, 174 g/d	89	1590	2.7	3.5	13.2	44	15
Oat bran, 135 g/d + wheat flour, 90 g/d + wheat gluten, 20 g	91	1690	3.6	5.5	4.8	31	14

[1]Dry weight, [2]Energy, [3]Nitrogen, [4]Total starch, [5]Dietary fibre

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Carbohydrates

Starch

Studies using different techniques have shown that part of the ingested starch, i.e. resistant starch (RS), escapes digestion and absorption in the small intestine in humans, as shown in breath-hydrogen studies (18), in intubation studies (19) and in ileostomy studies (12,16). The total amount of resistant starch in the human diet differs according to the food items consumed. In ileostomy studies, Table 1, with diets low in fibre and resistant starch, the amount of excreted starch is around 3–4% of the daily ingested starch, but as soon as high-RS products, such as beans, are included in the diet the amount increases. Calculations from *in vitro* measurements of RS in food items have shown figures from 3 to 6 g of daily RS intake in 10 different countries and in a separate study on the Italian diet 7–9 g/d (20,21). In a recent study in Swedish ileostomy subjects eating their normal diet the excretion of starch was on average 7 g/d (*unpublished*). In countries where the diets are based on starch-rich foods the amounts can probably be considerably higher (22).

Non-starch polysaccharides

A major group of polysaccharides to be fermented by the colonic microflora is the non-starch polysaccharides (NSP). They comprise the main components of the plant cell wall and include cellulose, hemicellulose, pectins, and also substances like gums, mucine and guar. NSP products added to the diet are recovered to a degree of 80–100% in the ileostomy content (6).

The average intake of NSP in European diets is estimated as 12–25 g/d (23) and is probably similar in other Western diets. In other parts of the world the amount can be considerably higher. Interestingly, however, only less than half of the amount of energy in the ileostomy content is NSP, which means that the main components are derived from substrates which are not NSP from the diet.

Sugars and oligosaccharides

Lactose (in lactose-intolerant subjects), stachyose and raffinose escape the small bowel. In a recent study (16) 65–78% raffinose and 67–70% stachyose was found in the ileostomy content. Sugars were recovered only in very small amounts (16).

The amount of inulin could vary very much depending on the amount available in the foods. Wheat flour contain 1–4% fructans, dry matter basis, artichoke 20–65%, asparagus 30% and onion up to 50%. Ileostomy studies have shown that inulin and oligofructose are recovered in the ileostomy effluent to about 90% (24,25).

Protein and fat

The daily amount of nitrogen excreted from the small bowel in ileostomy studies varies from 1–2 g/d on low-fibre, low-RS diets to almost 3 g/d on high-fibre or high-RS diets (Table 1). The major part of the nitrogen excreted is protein, 48–51%, and peptides, 20–30%, with only small amounts of urea, ammonia and nitrate (26,27). There is a correlation between the amount of nitrogen excreted and dietary nitrogen (28). Ileal nitrogen losses amounted to 1–3 g/24 h when the nitrogen intake was 0–20 g/24 h (28). This is in accordance with the figures in Table 1.

It has been discussed whether or not dietary fibre increases the excretion of nitrogen and it has been shown that intake of the viscous fibre pectin increases the excretion by less than 1 g/d (29).

Mucus

The amount of mucus (acidic glycoprotein from the goblet cells) has been estimated to 2–5 g per day (7,13,14). The amount has been analysed in one ileostomy subject (19). The quantitative determination of key mucus constituent sugars in this fraction revealed the presence of 0.45 g N-acetyl-glucosamine, 0.2 g N-acetyl-galactosamine, 0.2 g fructose and 0.4 g sialic acids.

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