The relation between diet and the gut microflora in man

By B. S. Drasar, J. S. Crowther, P. Goddard, Gabrielle Hawksworth, M. J. Hill, Susan Peach and R. E. O. Williams, *Department of Bacteriology*, and A. Renwick, *Department of Biochemistry, St Mary's Hospital Medical School, London W2 1PG*

The chemical nature of the diet has long been considered to exert a controlling influence on the bacterial flora of the intestine (Rettger & Cheplin, 1921; Dugeon, 1926). The type of diet and frequency of feeding influences the distribution of bacteria within the small intestine of both man and animals (Smith, 1965; Drasar, Shiner & McCleod, 1969). But, in adult man, attempts to change the colonic flora by dietary manipulation have produced equivocal results, at least in so far as alterations can be detected by culture of faecal specimens (Sanborn, 1931*a*,*b*; Haenel, Müller-Benthow & Scheunert, 1957).

In this paper we describe differences in the faecal flora of groups of people living on very different diets and the results of some studies of individuals whose diet was varied. Because of the variations in bacteriological technique and to facilitate direct comparisons detailed results are presented only for our own studies. The methods used have been described in detail (Drasar, 1967).

Differences between the faecal flora of various dietary groups

As part of a larger study on the aetiology of cancer of the colon the faecal flora of people living in Uganda, India, and Japan was compared with that of people living in England, Scotland, and the USA. Although there are many other differences between these groups the principal dietary variations were in the amount of carbohydrate, fats, and animal proteins consumed (Hill, Crowther, Drasar, Hawksworth, Aries & Williams, 1971). The Ugandan diet consisted principally of matoke (boiled, mashed banana) whereas the Indians and Japanese consumed a rice diet. Compared with these people the western diet was rich in fat and animal protein. The people living on the high-carbohydrate diet had significantly ($P<0{\cdot}001$) fewer bacteroides and more enterococci in their faeces than did those on a Western diet (Table 1); aerobic bacteria were also more prominent.

Study of the bacteria isolated from these groups revealed other differences. Eubacteria occurred more often in specimens from people on a high-carbohydrate diet and there was also greater variation in the aerobic bacteria isolated from these specimens (Table 2).

Table 1. *The faecal flora of normal people belonging to various dietary groups (mean log_{10} viable count/g faeces). From the results of Hill* et al. (1971) *and Aries, Crowther, Drasar, Hill & Ellis* (1971)

Diet	Mixed Western				Wholly or primarily vegetarian			
Country of origin	USA	Scotland	England	Uganda	Rice India	Matoke Uganda	Rice Japan	Vegan* England
Enterobacteria	7·4	7·6	7·9	7·4	7·9	8·0	9·4	7·0
Enterococci	5·9	5·3	5·8	5·3	7·3	7·0	8·1	4·8
Lactobacilli	6·5	7·7	6·5	5·3	7·6	7·2	7·4	7·4
Clostridia	5·4	5·6	5·7	4·7	5·7	5·1	5·6	5·4
Bacteroides	9·7	9·8	9·8	9·8	9·2	8·2	9·4	9·7
Gram-positive, non-sporing anaerobes	10·0	9·9	9·8	9·5	9·6	9·3	9·7	9·6

*Subject living on strictly vegetarian diet.

Table 2. *Comparisons of the prominence of certain bacterial species within some groups of faecal bacteria*

Group	Species	Percentage of group identified as species designated: England, Scotland and USA	Uganda, India and Japan
Enterobacteria	*Escherichia coli*	92	81
Enterococci	*Streptococcus faecalis*	65	38
	Streptococcus faecium	30	45
Bacteroides	*Bacteroides fragilis*	92	98
Gram-postive anaerobes	*Bifidobacterium bifidium*	13	10·5
	Bifidobacterium adolscentis	35	28
	Bifidobacterium eriksonii	6	4·5
	Eubacterium biforme	16	33·5

The influence of vegetarianism on the intestinal flora was studied in an attempt to elucidate the differences between the developed and under-developed countries. The high-carbohydrate diets eaten in Uganda, India, and Japan are basically vegetarian. However, when a group of people living on a balanced but strictly vegetarian diet were studied, their flora was similar to that of people eating a normal Western diet (Table 1). *Sarcina ventricula* was the only bacterial species found solely in the faeces of vegetarian groups (Crowther, 1971).

Dietary alteration of the flora

Although differences are demonstrable between groups of people living on different diets, attempts to change the composition of the flora by variations in diet have, in general, proved unsuccessful. A change to a vegetarian diet produces no demonstrable change in the predominant faecal flora (Moore, Cato & Holdeman, 1969). One study on the faeces of astronauts (Gall, 1965) showed changes in the flora on a synthetic diet; however, a further study demonstrated no such effect (Cordaro, Sellers, Ball & Schmidt, 1966). On the other hand, cellulose (Haenel, Gassman, Gratte & Müller-Benthow, 1964) and lactulose (Haenel, Feldham, Müller-Benthow

& Ruttloff, 1958) apparently produced slight changes. In one long-term study in which one subject was fed successively for periods of some weeks on high-protein, high-carbohydrate and high-fat diets, the protein diet did not affect the flora whereas the high-carbohydrate diet increased the relative numbers of the bifidobacteria, and the high-fat diet favoured the bacteroides (Hoffmann, 1964).

Winitz, Adams, Seedman, Davies, Jayko & Hamilton (1970) reported the disappearance of most of the faecal flora (total count as low as 10^3/g faeces) when volunteers were given a 'no-residue diet'. Our studies did not support this finding, the total bacterial numbers remaining unchanged. A similar study reported by Attebery, Sutter & Finegold (1972) showed that 'extremely oxygen-sensitive anaerobes' disappeared from faeces if a completely absorbable diet was consumed but that no other consistent change occurred.

Changes in the metabolic activity of the flora

Although changes in the bacterial species and genera comprising the flora are difficult to demonstrate, changes in the metabolic activity of the flora due to changes in dietary compounds do occur. This is best illustrated by reference to our studies on cyclamate metabolism (Drasar, Renwick & Williams, 1972). The giving of a dose of 3 g cyclamate daily for 10 d was accompanied by the urinary excretion of cyclohexylamine in one of our volunteers. In this subject but not in the two others studied the flora had changed in its ability to metabolize cyclamate; initially the flora had not metabolized the cyclamate but after exposure the flora converted the cyclamate to cyclohexylamine (Table 3).

Table 3. *The change in the ability of faecal flora to metabolize cyclamate by feeding a cyclamate diet in one human subject*

Dietary conditions	Percentage conversion of cyclamate to cyclohexylamine by faecal flora
Cyclamate-free diet	0·06
Cyclamate diet (3 g/d) for 10 d	74·9
Cyclamate-free diet for 6 d after cyclamate diet for 18 d	0·14

Physiological considerations

There is little information concerning the composition of the intestinal fluid entering the large intestine. Intestinal secretions and cells together with dietary residues probably comprise the greater part of this material. The difficulty in changing the flora of individuals by changes in diet probably reflects the efficiency of intestinal absorption. However, the studies on cyclamate demonstrate that, if dietary compounds reach the flora, changes do occur.

Furthermore, studies on bile salt metabolism have demonstrated that diet can control intestinal secretions and therefore the composition of the fluid entering the colon (Hill, 1971). In this context it should be noted that the faeces of the Ugandans,

Indians, and Japanese studied contained much lower concentrations of bile salts than do those of Western people (Hill *et al.* 1971). The influence of diet may be indirect.

The problem of demonstrating changes in bacterial flora may be partly explained by the nature of bacteriological procedures for bacterial identification. These have been developed to distinguish bacterial groups in the laboratory, not biological types in an ecological situation. Thus many of the substrates whose utilization is important in bacterial identification may be without significance in the bio-economics of bacterial growth in the intestine.

We acknowledge the financial support of the Cancer Research Campaign and the Wellcome Trust.

REFERENCES

Aries, V., Crowther, J. S., Drasar, B. S., Hill, M. J. & Ellis, F. R. (1971). *J. Path.* **103**, 54.
Attebery, H. R., Sutter, V. L. & Finegold, S. M. (1972). *Am. J. clin. Nutr.* **25**, 1391.
Cordaro, J. T., Sellers, W. M., Ball, R. J. & Schmidt, J. P. (1966). *Aerospace Med.* **37**, 594.
Crowther, J. S. (1971). *J. med. Microbiol.* **4**, 343.
Drasar, B. S. (1967). *J. Path. Bact.* **94**, 417.
Drasar, B. S., Renwick, A. G. & Williams, R. T. (1972). *Biochem. J.* **129**, 881.
Drasar, B. S., Shiner, M. & McCleod, G. M. (1969). *Gastroenterology* **56**, 71.
Dugeon, L. S. (1926). *J. Hyg.* **25**, 119.
Gall, L. S. (1965). Communication of Aerospace Medical Centre, Houston, Texas.
Haenel, H., Feldham, W., Müller-Benthow, W. & Ruttloff, H. (1958). *Zentbl. Bakt. ParasitKde* Abt. I, Orig. **173**, 76.
Haenel, H., Gassman, B., Gratte, R. K. & Müller-Benthow, W. (1964). *Zentbl. Bakt. ParasitKde* Abt. I, Orig. **192**, 491.
Haenel, H., Müller-Benthow, W. & Scheunert, A. (1957). *Zentbl. Bakt. ParasitKde* Abt. I, Orig. **168**, 37.
Hill, M. J. (1971). *J. Path.* **104**, 239.
Hill, M. J., Crowther, J. S., Drasar, B. S., Hawksworth, G., Aries, V. & Williams, R. E. O. (1971). *Lancet* i, 95.
Hoffmann, K. (1964). *Zentbl. Bakt. ParasitKde* Abt. I, Orig. **192**, 500.
Moore, W. E. C., Cato, E. P. & Holdeman, L. V. (1969). *J. infect. Dis.* **119**, 641.
Rettger, L. F. & Cheplin, H. A. (1921). A Treatise on the Transformation of the Intestinal Flora, with Special Reference to the Implantation of *Bacillus acidophilus*. New Haven: Yale University Press.
Sanborn, A. G. (1931*a*). *J. infect. Dis.* **48**, 541.
Sanborn, A. G. (1931*b*). *J. infect. Dis.* **49**, 37.
Smith, H. W. (1965). *J. Path. Bact.* **89**, 95.
Winitz, M., Adams, R. F., Seedman, D. A., Davies, P. N., Jayko, L. G. & Hamilton, J. A. (1970). *Am. J. clin. Nutr.* **23**, 546.

Printed in Great Britain