

The effect of a natural high-fiber diet on serum lipids, fecal lipids, and colonic function¹⁻³

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ABSTRACT In a cross-over experiment, 46 young healthy volunteers consumed in succession a high-fiber and a low-fiber diet for 3 weeks at two levels of dietary cholesterol. Half of the dietary fiber came from fruits and vegetables, and the rest from bread and other cereal products. On the high-fiber diet, concentrations of serum cholesterol decreased on average by 0.44 mmole/liter with high-cholesterol and 0.31 mmole/liter with low-cholesterol regimes; high density lipoprotein-cholesterol decreased by 0.1 mmole/liter; on average fecal weight increased by 115 g/day and mean transit time through the gut was decreased by 18 hr. Only part of the decrease in serum cholesterol may be due directly to the high intake of dietary fiber components. The remainder is due to differences in fat intake: during the high-fiber period subjects consumed less fat and cholesterol than had been planned. *Am. J. Clin. Nutr.* 32: 1881-1888, 1979.

It has been suggested (1, 2) that the high incidence of atherosclerosis and large-bowel disorders in Western communities is linked to a low intake of dietary fiber. Dietary fiber was defined by Trowell et al. (3) as the plant polysaccharides and lignin that are resistant to hydrolysis by the digestive enzymes of man. The main components of dietary fiber are cellulose, hemicelluloses, pectic substances, and lignin.

In controlled experiments, pectin is the only component of dietary fiber that has been shown to lower significantly the concentration of serum cholesterol and enhance steroid excretion (4-6). Fiber-rich cereal products only increase the volume of feces and shorten intestinal transit time (7). In these experiments dietary fiber was added to the diet in the form of bran, isolated pectin etc.

We have investigated the effect of a high-fiber diet composed entirely of natural food-stuffs on serum lipids and colonic function; 46 volunteers were given diets high and low in dietary fiber for 3 weeks each, and serum cholesterol, fecal mass, steroids, electrolytes, and intestinal transit time were measured. As the effect of pectin on serum cholesterol has

been reported (8) to depend on cholesterol intake, this experiment was performed at two levels of dietary cholesterol.

Subjects and methods

The volunteers were 23 male and 23 female university students ages 20 to 27. The 46 volunteers were divided into four groups. Two groups started on a high-fiber diet and two on a low-fiber diet for 3 weeks. After 3 weeks the groups changed to the opposite fiber regime and continued on that for another 3 weeks. Half of the subjects received a high-cholesterol and the other half a low-cholesterol diet throughout the entire 6-week period. For statistical evaluation, mean values per group at the beginning and the end of the second dietary period were compared, using a paired two-tailed *t* test (13). Each subject thus served as his own control. In addition, multiple regression analysis was used to check the contributions made by dietary cholesterol, fiber intake, and sex, to the effects measured.

Different nomenclatures for dietary fiber and meth-

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²Supported by The Netherlands Heart Foundation Grant 75.035.

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ods for measuring its concentration in foodstuffs have been used (9-12), but the figures obtained are comparable (9). In planning dietary fiber intake we borrowed figures for "dietary fiber" from Southgate et al. (9), for "indigestible residue" from Hellendoorn et al. (10), and for "unavailable carbohydrates" from McCance and Widdowson (11). For calculating actual dietary fiber consumption the dietary fiber content of fiber-rich foodstuffs used during the experiment was measured afterwards as "unavailable carbohydrates plus lignin" by the subtraction method of McCance et al. (12).

The composition of the diets is given in Table 1. The intake of dietary fiber depended on energy intake: the high-fiber diet was planned to contain at least 16 g dietary fiber per 1000 kcal (4.2 MJ), the low-fiber diet not more than 7 g/1000 kcal (on average 36 and 16 g/day, respectively). At least half of the dietary fiber was derived from vegetables and fruits and the rest came from cereals. A subject whose energy intake was about 2300 kcal (9.7 MJ)/day, consumed during the high-fiber period 450 g apples, 300 g cooked vegetables (spinach, cabbage, endive, carrots, and french beans; fresh weight 400 to 500 g) and 200 g (seven slices) of whole wheat bread. During the low-fiber period this subject took 125 g raw vegetables (cucumber, tomato, salad) and 200 g (eight slices) white bread. About 25 mg vitamin C was added to the low-fiber diet. The high-cholesterol groups consumed 1.5 eggs a day. The amount (and type) of fat, protein, and carbohydrates was planned to simulate the "average" Netherlands diet.

During the study all foodstuffs except for 200 kcal (0.84 MJ)/day were separately weighed out for each subject, appropriate to his caloric needs. On week days, hot meals were prepared and served at the laboratory. Detailed instructions were given for preparation of hot meals during the week-end, and for spending the "free" 200 kcal. Body weight was recorded weekly. Energy intake was adjusted when necessary, in order to keep

fluctuations in body weight within 2 kg. Subjects were asked to note illness, drug use, and departures from the diet in diaries.

Before the experiment and again during the high-fiber and low-fiber periods, the actual intake of nutrients was measured on 3 (separate) days by weighing plus questionnaire, using Netherlands food tables. Data for pectin and total dietary fiber were obtained as described in the footnote to Table 1.

Fasting blood samples were collected once in weeks 1, 2, 4, and 5. In weeks 0, 3, and 6, two samples were taken at 1-day intervals and the results were averaged. The blood serum was analyzed for total cholesterol (by an indirect method by Abell et al. (16)), for high density lipoprotein (HDL)-cholesterol (after manganese-heparin precipitation) (17) and for triglycerides (18). Blind control sera for cholesterol analysis were provided by the Center for Disease Control, Atlanta, Ga. Long-term reproducibility for these control sera was $\pm 1.3\%$ (1 SD) and accuracy was within 1.0% of the "true" (target) values. Feces were collected at the end of both experimental periods of 3 weeks for 89 and 108 hr, respectively. The stools were usually frozen within 12 h of being passed. Mean transit time through the gut (MTT) was measured using radioopaque pellets (19). Fecal neutral steroids (20), bile acids (21), and fat (22) were measured as described. Fecal electrolytes were measured after nitric acid digestion using flame photometry (Na^+ , K^+) and atomic absorption spectrophotometry (Ca^{2+} , Mg^{2+}).

Results

Nutrient intake

Measurement by weighing plus individual records of the actual intake of nutrients revealed (Table 1) that there had been no im-

TABLE 1
Mean daily intake of nutrients before and during the experiment^a

	Before experiment	During experiment			
		Planned		Actual	
	Actual	High fiber	Low fiber	High fiber	Low fiber
Energy (MJ)	9.5	9.5	9.5	10.0	9.4
Total dietary fiber (g)	35 ^b	36 ^b	16 ^b	45 ^c	12 ^c
Polygalacturonic acid (pectin) (g)	3.1 ^d			6.2 ^d	1.3 ^d
Cholesterol (mg) ^e					
High-cholesterol groups	235	600	600	663	766
Low-cholesterol groups	231	200	200	161	179
Total fat (energy %)	30	40	40	35	42
Polyunsaturated fat (energy %)	5	5	5	4	5
Carbohydrates (energy %)	49	44-48	44-48	48	41
Polysaccharides (energy %)				23	24
Sugars (energy %)				25	17
Protein (energy %)	15	12	12	13	13
Alcohol (energy %)	4	0-4	0-4	3	3

^a Actual: measured by 3-day weighing plus questionnaire; planned: nominal composition. ^b Calculated using figures from (9-11). ^c Fiber-rich products used during the experiment were analyzed (32) for "unavailable carbohydrates plus lignin" (=dietary fiber) by the subtraction method of McCance et al. (12). These figures were supplemented with data from (9-11). ^d Based upon analysis of vegetables and fruits according to (14, 15) as described in detail (32). ^e 100 mg = 0.258 mmole.

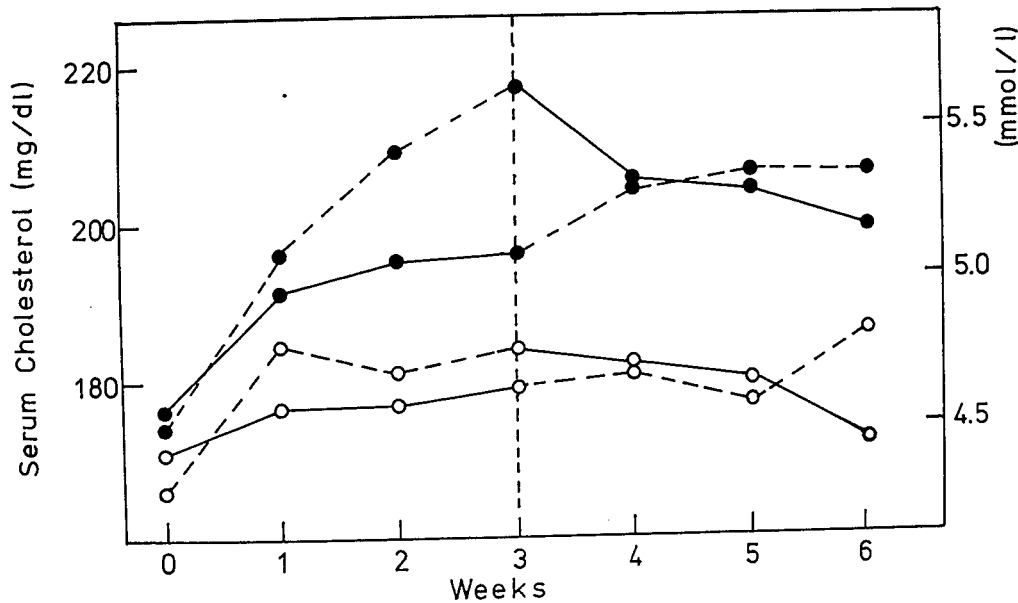


FIG. 1. Mean serum-cholesterol levels per group during the cross-over trial comparing a high-fiber and a low-fiber diet. —, high-fiber diet; ---, low-fiber diet; ●, high cholesterol intake; ○, low intake of dietary cholesterol.

portant differences in the intake of total energy, total protein, polyunsaturated fat, and alcohol between the dietary periods, and that the planned difference in fiber intake had indeed been achieved. In accordance with the experimental design, more than half of the dietary fiber was derived from vegetables and fruits: during the high-fiber period on average 27 g "vegetable fiber" and 19 g "cereal fiber" was consumed per day; the low-fiber diet contained 6 g of both vegetable and cereal fiber. The actual intake of pectin (polygalacturonic acid) was 6.2 g/day with the high-fiber diet, and 1.3 g/day with the low-fiber diet.

The food consumption records showed that there had been systematic deviations from the planned intake of total fat, cholesterol, and carbohydrates; during the high-fiber period, 45 out of the 46 subjects had consumed less total fat than in the low-fiber period (on average 35 against 42 energy %), 41 had consumed less cholesterol, and 44 had had a higher carbohydrate (mostly sugars) consumption. During the high-fiber period the intake of animal protein was slightly lower (on average 4 g/day), while the intake of vegetable protein was higher (about 8 g/day), as was vitamin C intake (about 28 mg/day).

Blood lipids

Figure 1 and Table 2 show the concentrations of serum cholesterol. Throughout the experiment the concentration of serum cholesterol in the groups with high intake of cholesterol was about 0.5 mmole/liter higher than in the groups with low cholesterol consumption.

As the experimental diets contained more fat than our subjects were accustomed to (38 against 30 energy %), levels of serum cholesterol increased in all four groups during the first 3 weeks. This effect is more marked in the high-cholesterol groups than in the low-cholesterol groups, and more marked with the low-fiber than the high-fiber diet. After the cross-over, concentrations of serum cholesterol decreased with the high-fiber diet by 0.44 ± 0.41 (SD) mmole/liter ($P < 0.01$) at the high level of cholesterol intake, and by 0.31 ± 0.23 mmole/liter ($P < 0.002$) at the low cholesterol level. This decrease in serum cholesterol on changing to a high-fiber diet was larger than the increase on changing to a low-fiber diet, which amounted to 0.26 ± 0.47 mmole/liter ($P < 0.10$) and 0.18 ± 0.34 mmole/liter (not significant) with high and low cholesterol diets, respectively. Multiple

TABLE 2
Total serum cholesterol and HDL-cholesterol per group (mean \pm 1 SD)^a

	High cholesterol intake		Low cholesterol intake	
	Group 1 (n = 12)	Group 2 (n = 10)	Group 3 (n = 12)	Group 4 (n = 12)
Total serum cholesterol (mmole/liter)				
Before experiment	4.55 \pm 0.75	4.50 \pm 0.54	4.42 \pm 0.72	4.29 \pm 0.49
Change from wk 0 to 3	+0.52 \pm 0.44	+1.11 \pm 0.65	+0.23 \pm 0.31	+0.47 \pm 0.39
Change from wk 3 to 6	+0.26 \pm 0.47 ^b	-0.44 \pm 0.41 ^c	+0.18 \pm 0.34 ^d	-0.31 \pm 0.23 ^e
HDL-cholesterol (mmole/liter)				
Before experiment	1.37 \pm 0.26	1.55 \pm 0.36	1.50 \pm 0.23	1.40 \pm 0.23
Change from wk 0 to 3	+0.23 \pm 0.21	+0.36 \pm 0.21	+0.16 \pm 0.16	+0.23 \pm 0.18
Change from wk 3 to 6	+0.10 \pm 0.08 ^e	-0.10 \pm 0.16 ^f	+0.10 \pm 0.23 ^d	-0.10 \pm 0.13 ^e

^a Groups 1 and 3 started with a high-fiber diet during the first 3 weeks and then changed to a low-fiber diet; groups 2 and 4 received these regimes in the opposite sequence (cf. Fig. 1). ^b Statistically significant; $P < 0.10$; ^c $P < 0.01$; ^d not significant; ^e $P < 0.002$; ^f $P < 0.025$; ^g $P < 0.05$.

regression analysis revealed that in the high-cholesterol groups the changes in concentration of serum cholesterol were more marked in females than in males, while there was no sex-difference in the low-cholesterol groups.

HDL-cholesterol accounted for on average 34% of the total concentration of serum cholesterol throughout the experiment (cf. Table 2). Thus, about one-third of the changes in total serum cholesterol was accounted for by changes in the HDL-fraction: changing to a high-fiber diet caused a reduction of HDL-cholesterol by on average 0.1 mmole/liter, while with low-fiber diets HDL-cholesterol was increased by 0.1 mmole/liter. Any effect on serum triglycerides was obscured by the large intraindividual variations.

Transit time and feces production

The data for feces production, transit time, and for fecal fat and electrolytes are given in Table 3. As there were no differences between the high and low cholesterol groups, and no effect of the order in which high-fiber and low-fiber diets were given, the results of all four groups are presented together.

Fecal weight, frequency of stools, and intestinal transit time were strongly and significantly ($P < 0.001$) influenced by dietary fiber intake.

The calculation of transit time was hampered because collection of the 20 pellets was not always complete (especially on low-fiber diets). In Table 3 the results of only 32 persons are given. Only 14 subjects showed complete marker recovery in both periods. For these 14 subjects the time of appearance of

TABLE 3
Feces production, MTT and fecal fat and electrolytes on high-fiber and low-fiber diets (mean \pm 1 SD; 43 subjects)

	High-fiber	Low-fiber
Fecal wet weight (g/24 hr)	184 \pm 75	69 \pm 50 ^a
Dry weight (g/24 hr)	44 \pm 14	18 \pm 10 ^a
Dry weight (g/100 g wet weight)	25 \pm 6	29 \pm 6 ^a
Frequency of stools/24 hr	1.4 \pm 0.6	0.7 \pm 0.5 ^a
MTT (hr) ^b	37 \pm 12	55 \pm 17 ^a
Fecal fat (g/day)	2.5 \pm 0.9	1.2 \pm 0.9 ^a
Fecal Na ⁺ (mmole/day)	2.4 \pm 2.6	0.9 \pm 1.8 ^a
K ⁺ (mmole/day)	19.0 \pm 7.7	6.6 \pm 4.7 ^a
Ca ²⁺ (mmole/day)	22.9 \pm 8.4	18.8 \pm 11.9 ^c
Mg ²⁺ (mmole/day)	11.6 \pm 3.8	4.6 \pm 2.8 ^a

^a Statistically significant difference between high-fiber and low-fiber periods; $P < 0.001$. ^b Data of 32 subjects. ^c $P < 0.025$.

the 5th and 10th pellet was plotted against the MTT by linear regression ($r = 0.74$ and 0.87 , respectively), and from these plots the MTT for 18 other subjects who had not produced all 20 pellets was estimated. For three persons no meaningful values could be calculated at all. For eight subjects only a minimum value for the difference between the high-fiber and low-fiber periods could be calculated. Inclusion of these values did not influence the general picture: average transit time is at least 18 hr shorter on the high-fiber diets.

Fecal lipids and electrolytes

Fecal steroid excretion is recorded in Figure 2. The groups with low cholesterol intake excreted significantly ($P < 0.002$) more neu-

tral steroids during the high-fiber period, while there was no such effect in the groups with high cholesterol intake: the high-cholesterol group that started on the high-fiber diet and changed to low-fiber intake during the second 3 weeks excreted 0.19 mmole/day more neutral steroids during the low-fiber period, while the group that first received a low-fiber diet and afterwards a high-fiber diet excreted 0.21 mmole/day more neutral steroids during the high-fiber period.

In all groups, excretion of bile acids was higher with the high-fiber diets. However, these differences were not statistically significant, due to the large interindividual variation. Total steroid excretion amounted to 2.61 ± 0.96 (SD) mmole/day and 2.53 ± 1.27 mmole/day with the high-fiber and low-fiber diets, respectively, in the high cholesterol groups. The groups with low cholesterol intake excreted 2.24 ± 0.68 mmole/day with the high-fiber diet, and 1.71 ± 0.74 mmole/day with the low-fiber diet.

In the groups with high cholesterol intake, fecal steroid excretion exceeded cholesterol intake by 0.92 and 0.55 mmole/day during the high-fiber and low-fiber periods, respectively. In the groups with low cholesterol

intake the net daily steroid loss was also greater with the high-fiber diet (1.82 mmole/day) than with the low-fiber diet (1.24 mmole/day).

There were no consistent changes in the ratio of secondary to primary neutral steroids or bile acids, the ratios for neutral steroids being 3.7 ± 3.3 (SD) and 3.9 ± 2.6 with high-fiber and low-fiber diets, respectively, and for bile acids 16 ± 19 and 12 ± 9 . Five out of 43 subjects excreted a larger part of their neutral steroids as cholesterol rather than its bacterial conversion product coprostanol (ratio less than 1.0). For four of these subjects this behavior persisted throughout both dietary periods. This behavior was only weakly reflected in the ratio between secondary and primary fecal bile acids.

As shown in Table 3 total fat excretion was significantly higher ($P < 0.001$) with a high-fiber intake. A high consumption of dietary fiber was also accompanied by a significantly higher excretion of all minerals analyzed.

Discussion

The interest that has been aroused by the dietary fiber hypothesis has resulted in a

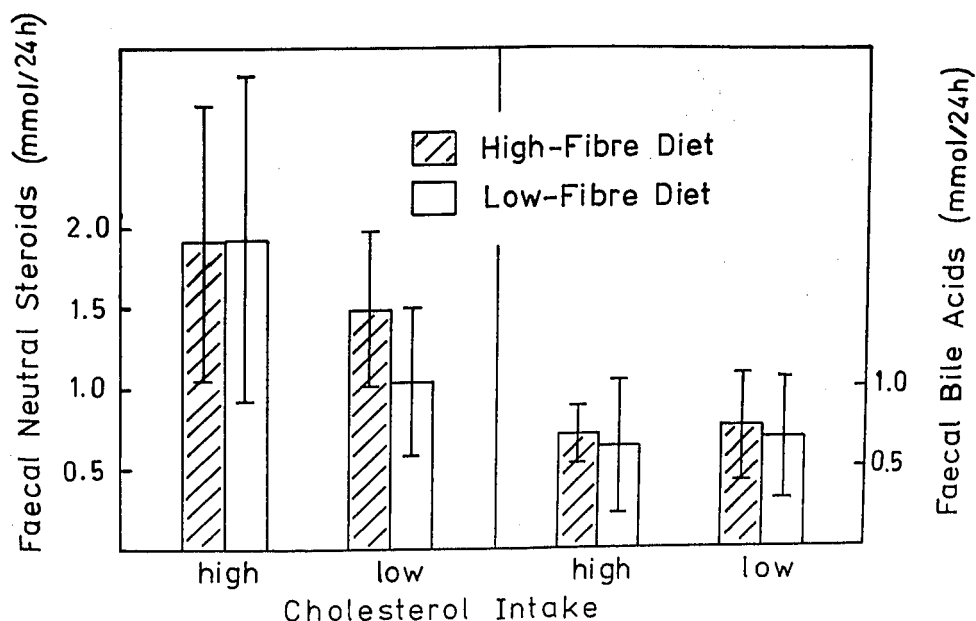


FIG. 2. Steroid excretion at high or low cholesterol intake on high-fiber and low-fiber diets (mean \pm 1 SD). The high-cholesterol groups contained 20 and the low-cholesterol groups 23 persons. None of the differences between the dietary periods was statistically significant at the 95% confidence level, except for the excretion of neutral steroids in the groups with low cholesterol intake ($P < 0.005$).

series of experiments that have used cereal bran (6, 7) or pectin as fiber sources (4, 5). In this experiment a diet composed entirely of natural foodstuffs has been used, providing more varied types of fiber.

Changing from a low-fiber diet to a high-fiber diet caused a lowering of serum cholesterol by 0.44 and 0.31 mmole/liter at a high and low level of cholesterol intake, respectively. The effect on serum cholesterol of dietary fiber per se is difficult to evaluate in our experiment, because the high-fiber diets contained less fat (7 energy %) and less cholesterol (and more sugars) than the low-fiber diets.

In retrospect, these differences in fat and cholesterol intake can be explained by two causes. First, problems were encountered in preparing high-fiber dishes containing enough fat, so that the rations given to the subjects contained less fat than originally planned. Second, during the high-fiber period the subjects tended to spend their 200 "free" kcal/day on fruits and wholemeal products; it should be noted that their customary diet is rather low in fat and high in dietary fiber (Table 1). During the low-fiber regime they ate more high-fat products for the 200 kcal/day because fiber-rich products were forbidden. The excess intake of carbohydrates during the high-fiber period was partly due to imperfect data for the sugar content of fruits and vegetables in the Netherlands food table used for planning the diets. Furthermore, whenever fiber-rich foodstuffs were chosen for the 200 free kcal during the high-fiber period, these contained more sugars than the low-fiber, high-fat products that were consumed in spending the free kcal during the low-fiber period.

Nevertheless, the differences in fat and cholesterol intake probably do not completely explain the changes in serum cholesterol observed. Keys et al. (23) and Hegsted et al. (24) have developed formulas predicting the effect of changes in fat and cholesterol intake on the concentration of cholesterol in serum. Calculation of the potential effect of the differences in fat and cholesterol intake observed, using these formulas suggests that part of the decrease in concentration of serum cholesterol with the high-fiber diets (about 0.10 to 0.23 mmole/liter out of the total change of 0.39 mmole/liter) may be due di-

rectly to dietary fiber components. Of these, pectic substances seem to be the most effective in decreasing concentrations of serum cholesterol. Palmer and Dixon (25) reported that adding 6 g pectin per day to the diet lowered serum cholesterol by 0.28 mmole/liter. The pectin consumption during the high-fiber periods in this study was on average 6.2 g polygalacturonic acid per day, which is equivalent to about 8 g isolated citrus pectin. The differences in vitamin C and vegetable protein intake between the high-fiber and low-fiber periods were too small to have any significant effect on the concentration of serum cholesterol.

Our results do not confirm the suggestion (8) that dietary fiber (pectin) lowers serum cholesterol only when the diet is supplemented with two eggs per day. Even at a cholesterol intake of less than 200 mg/day, we found a decrease of serum cholesterol of on average 0.31 mmole/liter, although the effect of dietary fiber was more pronounced with the high-cholesterol diets (decrease on average 0.44 mmole/liter).

About one-third of the changes in total serum cholesterol was accounted for by changes in HDL-cholesterol content. This result could mean that the favorable effect of dietary fiber on total serum cholesterol is somewhat counteracted by the effect on HDL-cholesterol, as a high level of HDL-cholesterol is thought (26) to protect against the development of atherosclerotic complications. However, it cannot be decided whether these changes in HDL-cholesterol are really due to differences in fiber intake or are caused by the concomitant changes in fat and carbohydrates consumption, so that this conclusion must remain tentative.

With the high-fiber diets stools were significantly bulkier, wetter, and more frequent, and intestinal transit was faster, although transit time data were not available for all subjects because of incomplete marker recovery. The changes in feces production and transit time are similar to those reported in experiments with bran (7). The individual variation in colonic response to the high-fiber and low-fiber diets is very striking, as was also pointed out by Cummings et al. (27).

The excretion of bile acids was slightly higher (not significant) during the high-fiber diets. The low cholesterol-intake groups also


excreted more neutral steroids during the high-fiber period, but in the high-cholesterol groups there was no systematic effect of dietary fiber on neutral steroid excretion. The high-cholesterol group that started on high-fiber diet and changed to low-fiber intake during the second 3 weeks, excreted more neutral steroids during the second, low-fiber period. Perhaps this result is a delayed effect of the high-fiber diet similar to that reported by Eastwood et al. (7). Possibly this also explains the lower increase in serum cholesterol with low-fiber diets after the cross-over than the decrease with high-fiber diets.

The difference between daily dietary cholesterol and daily total fecal steroids gives an index of net daily steroid loss. With the high-cholesterol diet, the net loss is less than with the low-cholesterol diet. With the low-fiber diet the net loss is less than with the high-fiber regime. These results are compatible with the changes in serum cholesterol.

It has been suggested (28, 29) that if dietary fiber intake is low and intestinal transit prolonged, more primary bile acids and neutral steroids are converted into secondary, possibly (co)carcinogenic products. We found, however, no consistent effect of dietary fiber intake on the ratio between primary and secondary steroids. Furthermore, transit time was not correlated with these ratios. The low conversion of cholesterol to its secondary derivative coprostanol in some of our subjects is similar to that found for "normal" North Americans (30).

Despite the lower fat intake on high-fiber diets, fat excretion was increased by about 1.5 g/day. Higher fat excretion was also reported to occur when pectin was added to the diet (4). However, the amounts involved are negligible compared with total daily fat intake (cf. Table 1) and we doubt whether these small changes can account for the observed effects on serum cholesterol. The excretion of various electrolytes (Na^+ , K^+ , Ca^{++} , and Mg^{++}) was increased with the high-fiber diets, as was previously observed in studies with wheat bread (31). The data are hard to interpret because we have no information on electrolyte intake.

In view of the marked effects of the "natural" diets used in this study on feces production and transit time, we suggest that there is no need to add bran to a well-balanced

high-fiber diet. Furthermore, a natural high-fiber diet may indirectly reduce serum cholesterol levels, because of its low fat and cholesterol content. 

The authors thank the volunteers for their cooperation and are grateful to the Department of Clinical Chemistry of the Western General Hospital, Edinburgh, for measurements of fecal electrolytes. The help of all those who through their assistance and advice made this experiment possible is gratefully acknowledged.

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