DIETARY FIBER

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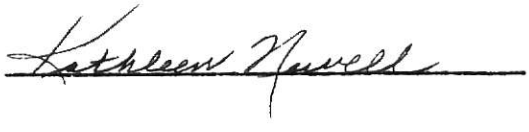

TABLE OF CONTENTS

INTRODUCTION

For many years, dietary fiber was considered to be an insignificant part of man's diet because it was believed to contribute little nutritionally. Recent epidemiological observations, however, have suggested important roles of dietary fiber in maintaining man's health. These observations have led to a revival of interest in the fiber content of foods and the effects of its intake on man (1).

Although extensive research in the area of fiber has been conducted during the last few years, there is still no consensus among researchers regarding terminology. For many years, the term crude fiber has been used to express the fiber content of foods, even though it is known that the term does not include the total fiber in foods. Crude fiber consists of cellulose and lignin that are the residues remaining after treatment with acids and alkalis. Trowell (2) coined the term dietary fiber to describe plant constituents that are resistant to digestion by secretions of the human gastrointestinal tract. Dietary fiber includes cellulose, hemicellulose, pectin, lignin, gums and mucilages. New methods of measuring dietary fiber accurately are being developed.

There is renewed interest in the effects of dietary fiber on the metabolism of nutrients. Recent studies have focused primarily on the relationship between dietary fiber and minerals and fat, and to lesser degrees on carbohydrates and protein. There have been very few investigations concerning the effects of dietary fiber on vitamin metabolism.

The therapeutic value of fiber in various disease states has been investigated. These conditions include diseases of the gastrointestinal tract, circulation-related diseases and metabolic disorders.

The following report is a review of some of the research conducted in the area of dietary fiber. It includes discussions of methods of fiber analyses, effects exerted by passage of dietary fiber through the gastrointestinal tract, effects of fiber on metabolism of nutrients and the role of fiber in certain disease states.

FIBER ANALYSIS

Early work with fiber involved the chemical extraction of crude fiber from feeds. It was well known that the methods used were not good predictors of the nutritive value of animal feedstuffs. Moreover, they were even worse predictors of the nutritive values of foods eaten by nonruminants. The results often were not reproducible among researchers using the same method. Various other methods were developed in the latter half of the twentieth century that were more reproducible. Selected studies are reported in this section.

Extraction and Fractionation Studies

In 1960, the Association of Official Agricultural Chemists (3) reported the Weende crude fiber procedure. In this method, cellulose, pentosans and lignin are hydrolysed in varying degrees.

Crampton and Maynard (4) proposed methods for the determination of cellulose and lignin in animal feeds and feces. The methods consisted of a partitioning of the carbohydrate portion of a feed into cellulose, lignin and other carbohydrates. They concluded that the fractions obtained were of greater usefulness in predicting feeding values than the division into crude fiber and nitrogen-free extract.

Southgate (5) developed a lengthy fractionation and analytical method for the measurement of unavailable carbohydrates in foods. The scheme provided values for water-soluble polysaccharides, hemicellulose and lignin. The procedure was technically easy to perform and required only simple apparatus. The method was time-consuming and required about 5 days to

perform; however, several samples could be carried through the schemes simultaneously.

Edwards (6) developed a simple, fast and reproducible method of lignin determination that utilized the solubility of lignin in hydrochloric acid-activated triethylene glycol (trigol) at 121°. The values obtained for lignin content related well to in vitro organic matter digestibility for both grasses and legumes.

Use of Detergents in Fiber Analysis

Van Soest (7) examined anionic, cationic and nonionic detergents in differing buffering media to determine their capacity to dissolve nitrogenous constitutents in forage dry matter so that a fiber of low nitrogen content could be prepared. Of the combinations examined, cetyl trimethylammonium bromide in strongly acidic solution and sodium lauryl sulfate in slightly alkaline solutions appeared most effective.

Van Soest (8) made use of the capacity of cetyl trimethylammonium bromide to dissolve proteins under acidic conditions in the development of an acid-detergent fiber method. The method also served as a preparatory step in the determination of lignin. Acid-detergent fiber consisted chiefly of lignin and polysaccharides. The procedure was incorporated into the Official Methods of Analysis by the Association of Official Analytical Chemists (9).

Van Soest and Wine (10) developed an indirect method for lignin analysis using permanganate. The method also permitted the determination of cellulose and insoluble ash in the same sample. Permanganate lignin

values were significantly correlated (0.997) with those of 72% sulfuric acid lignin (4) prepared from acid-detergent fiber. Permanganate lignin values were higher than those obtained by the 72% sulfuric acid method and were convertible using the factor 0.81. The ratio between the values obtained by the two methods depended upon the material analyzed. The permanganate lignin method was more advantageous than the 72% sulfuric acid method because the determination of lignin, cellulose and insoluble ash could be obtained in one sample with an amount of labor equal to that required for the 72% sulfuric acid lignin procedure. Permanganate reagents were not corrosive nor did they require any standardization. No filter aids were required and permanganate lignin values were not subject to some interferences that affected the 72% sulfuric acid treatment. Permanganate lignin may have yielded a value closer to the true theoretical lignin value. Polyphenolic and other unsaturated substances such as tannins, pigments or protein that may not be completely removed in the acid-detergent fiber reacted and appeared as lignin. Both permanganate and 72% sulfuric acid lignin were affected by increased heating, but permanganate lignin was somewhat less susceptible. Cutin was largely retained in the lignin by the 72% sulfuric acid method and excluded by the permanganate method.

Van Soest and Wine (11) developed a method for determining the cell wall constituents of plants by determination of the fiber insoluble in a neutral-detergent solution. Neutral-detergent fibers represented the cellulose and lignin portion of the cell wall of plants. The researchers stated that the procedure was inappropriate with concentrated materials since much gelatinous matter was likely to form starches and protein which tended to clog the filter. If decahydronaphthalene was added before the

neutral-detergent solution, filtration was poor and yields were high. Addition of ethoxyethanol partly inhibited this effect. Ethoxyethanol also appears in some cases to facilitate solution of starches. After continued use, crucibles tended to become clogged with residual matter that was resistant to the commonly used chromic acid cleaning solutions.

Enzymatic Procedures

Hellendoorn et al. (12) developed a method in which indigestible residue was determined by a 1-hour neutral pancreatin digestion preceded by digestion with pepsin. The procedure did not give rise to any hydrolysis of pentosans, but gave maximum digestion of protein and starch leaving a minimal residue. The method was reproducible within 99.8%. Pectin and galacto-oligosaccharides could not be determined using this method. The procedure reflected the physiological behavior of the enzymes in the digestive tract of man.

A papain-amylase digestion procedure with subsequent dialysis to isolate both the water-soluble and water-insoluble components of dietary fiber in fat-extracted samples was developed by Asp et al. (13). This procedure removed the protein and starch of the fat-free food samples almost completely. Because the dialysis membrane used has a molecular weight cutoff of 6,000 to 8,000 daltons, the undigestible oligosaccharides such as raffinose, stachyose and verbascose, that constitute up to 8% of the dry weight of leguminous vegetables, also were removed during dialysis. Asp et al. (13) theorized that the total undigestible residue remaining after the papain-amylase treatment and dialysis should be dietary fiber.

This fraction contained pectins, gums and some hemicellulose.

Many of the methods which are employed in research at the present time estimate fiber content by analyzing crude fiber content and were originally formulated to analyze feeds. Foods eaten by man and other nonruminant omnivores may be composed of indigestible gums and mucilages which are not included in crude fiber. Research is needed to develop methods which are relatively short and reproducible to analyze the total indigestible polysaccharides in foods.

EFFECTS EXERTED BY THE PASSAGE OF DIETARY FIBER THROUGH THE GUT

Many studies have been reported on the passage of cellulose, hemicellulose and lignin through the human gut. Little attention has been focused on the movement of plant mucilages, gums and other constituents of dietary fiber through the human intestinal tract, although extensive research on their prophylactic properties have been documented. The studies to be reviewed in this section center mostly on the passage and effects of dietary fiber through the gut of man.

Markers

The use of markers are very common in studies of the passage of fiber through the gut. French et al. (14) stated that biologically inert markers could be used to measure the time of passage of ingesta through the gut and to estimate the dilution, transit time and absorption of fed or infused meals or test solutions. Provided a suitable marker compound was used,

quantative estimation of volume change from the ratio of the concentration of marker infused to the concentration of marker recovered allowed a reasonably accurate calculation of the absorption of a fed or infused nutrient without the necessity of complete recovery of intestinal contents. A suitable marker should not be absorbed by the segment(s) of the gastrointestinal tract under study. The marker should be distributed homogeneously among the intestinal contents at all points between introduction and recovery, be physiologically inert with respect to the metabolic processes encountered in the study, be nontoxic for the concentrations and total amounts used and be easily and accurately measured in the fluids with which the study was concerned. With these criteria in mind, French et al. (14) examined two commonly used markers, phenol red and polyethylene glycol during perfusion studies of absorptive capacity for dextrose in limited segments of human jejunum. No significant differences in the apparent absorption were found between the two markers and it was concluded that their use in intestinal studies was appropriate.

Hinton et al. (15) developed a technique for measuring gastrointestinal transit times using radioopaque pellets of barium-impregnated polythene. The technique was studies in 25 normal subjects. All passed the first marker within 3 days and most passed 80% of the markers within 5 days. Hinton et al. (15) stated that the use of these markers was advantageous because the passage of the markers could be observed either by taking serial radiographs of the abdomen or of the stools.

Malagelada et al. (16) reported a study of alpha-cellulose radioionated with ^{131}I as a marker for gastric emptying and intestinal transit of fiber using a dog model. The radiocellulose remained stable when exposed to both

acid and alkali within the pH range of the gut. The original fibrous appearance was conserved after passage through the gut and consisted of strands that were resistant to mechanical forces. Moreover, it could be subjected to repeated washing and drying without appreciable change. Malagelada et al. (16) postulated that this technique would be a useful tool for studies on gastric emptying, intestinal transit time, fate and actions of dietary fiber in nonruminant experimental animals and eventually in man.

Cellulose-splitting Microorganisms

It is generally believed that the human gut does not contain cellulases or other enzymes that split the molecules of the components of dietary fiber so that they are available for utilization in the body. In 1942, Hirschberg (17) discovered cellulose-splitting microorganisms in the feces. He examined 171 stools from normal persons for cellulose-splitting microorganisms using cultures grown on an Acetobacter xylinum medium consisting of 3% maltose, 4% sucrose, 0.5% powdered yeast and 0.2% acetate to which 2% alcohol was added after sterilization. Acetobacter xylinum were able to synthesize pure cellulose membranes. Thus, the material to be cultured was spread over the surface of the medium and any cellulose-splitting microorganisms would "eat" depressions into the membrane. They could then be collected from the depressions for study and identification. Cellulose-splitting fungi were isolated from 65 of the 171 stool samples. From the 65 stools that were positive for cellulose-splitting fungi, 111 strains of fungi were isolated and identified (table 1). Aspergillus was the predominant group.

THIS BOOK CONTAINS NUMEROUS PAGES WITH DIAGRAMS THAT ARE CROOKED COMPARED TO THE REST OF THE INFORMATION ON THE PAGE.

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TABLE 1

Cellulose splitting fungi isolated from stool samples of normal subjects (17)

Strains	Number of strains	Total number of strains	Number which utilize cellulose
Aspergillus		45	45
Aspergillus fumigatus-glaucus group	32		
Aspergillus with pitted stalk	1		
Aspergillus niger	12		
Hormodendrum		22	22
Oidium		20	15
Penicillium		14	14
1 Conidiophore	1		
2 Conidiophores	3		
3 Conidiophores	1		
Many Conidiophores	9		
Endomyces		4	1
Monila		3	3
Actinomyces		1	1
Alternaria		1	1

In the same study (17), 65 stool specimens from constipated subjects were examined. Of the 65, 24 stools were positive for cellulose-splitting fungi and 52 strains of fungi were isolated and identified (table 2). Cellulose-splitting fungi were isolated from approximately the same percentage of stools of constipated persons as from normal stools. Hirschberg (17) stated that it was possible that constipated subjects utilized approximately the same amount of cellulosic food material as normal persons. Any additional cellulosic food material that remained unchanged, contributed to the bulk of the stool. He concluded that many human stools contain large numbers of fungi capable of decomposing cellulose. Since it was known that man could digest a certain amount of cellulose but had no known enzyme for its digestion, he postulated that these microorganisms played a role in the human use of cellulosic foods.

Intestinal Transit Time, Water Holding Capacity, Stool Volume and pH

Intestinal transit time and water holding capacity (the amount of water that can be absorbed by a unit weight of dry fiber) are frequently studied in fiber research because they are generally thought to affect fecal bulk. Volatile fatty acid excretions frequently contribute to stool pH. Yang et al. (18) stated that although products of cellulose degradation in monogastric animals including humans were unknown, these products probably included volatile organic acids. According to Cummings (19), volatile fatty acids were the major solute of the feces and probably resulted from the digestion of carbohydrates that were undigested by gastric and intestinal enzymes in the cecum. Selected studies on these parameters are reviewed.

TABLE 2

Cellulose splitting fungi isolated from stool samples of normal subjects (17)

Strains	Number of strains	Total number of strains	Number which utilize cellulose
Aspergillus		26	26
Aspergillus fumigatus-glaucus group	16		
Aspergillus niger	10		
Penicillium			
1 Conidiophore	1	8	8
2 Conidiophore	2		
Many Conidiophore	5		
Hormodendrum		6	6
Oidium		6	5
Aleternaria		3	3
Actinomyces		1	0

Wyman et al. (20) compared the effects of two doses of raw bran upon intestinal transit time and wet and dry fecal weight in 10 healthy male subjects (one 11 year old and nine 25 to 41 year olds) in a 98-day study. Each subject agreed to eat a low fiber diet in which all fiber-rich cereal and breads were omitted and fruits and vegetables were limited to six specified small portions each day during the entire study. On the tenth day of the diet, 25 radioopaque pellets were ingested and all stools were collected for 5 days. On the 15th to 29th days of the experiment, 12 g raw bran containing 7.91% crude fiber were added to the diets daily. Stools were collected after pellet ingestion from days 25 to 29. Five other random study periods followed the first control and raw bran periods. These included a second control period or supplements of either 13.2 or 22 g cooked bran or 20 g raw bran per day. After each bran period, there was an 8-day resting period before beginning another dose of bran. Each fiber supplement was fed for 14 days and stools were collected during the last 5 days of each period. The second control period was preceded by a 9-day resting period.

Wyman et al. (20) observed that although there were variations in individual values between the first and second control periods, there were no significant differences in transit time, wet and dry fecal weights, stool volume, individual stool size, fecal water content, and frequency of an interval between bowel actions. Age, body weight or surface area had no apparent effect on any of the measured values. Of the treatments, a significant change from control values occurred only with 20 g raw bran per day. Fecal wet weight of subjects fed the control diet and supplements of 12 and 20 g raw bran and 13.2 and 22 g cooked bran were 131.1, 182.8,

158.8, 131.1 and 164.0 g per day, respectively, while fecal dry weights on these diets were 30.0, 42.1, 37.6, 36.5 and 35.3 g per day, respectively. Compared to the control, wet weight was not significantly altered by any of the four doses but dry weight was increased significantly by both doses of raw bran. Cooked bran did not change dry weight at either dosage.

There was no significant change in the interval or frequency of bowel movements with either bran compared to the control. Transit time decreased in 7 subjects, increased in two and did not change in one when diets containing bran supplements were compared with the control. Of the treatments, individual stool size was significantly increased only by 12 g raw bran per day compared with the control. Wyman et al. (20) concluded that raw bran, at least of the coarse variety, was effective in accelerating intestinal transit time at a dose of 20 g per day, probably effective at 16 g per day and probably ineffective at 12 g per day. Cooked bran appeared to be less effective than raw bran and was not significantly effective at 22 g per day. It was suggested that cooking altered the effect of bran on the gastrointestinal tract and that amounts greater than 22 g per day would need to be ingested to produce an effect on the stools.

Anderson et al. (21) studied transit time, as estimated from the passage through the gut of an isotope ^{131}I-containing capsule, in 10 constipated geriatric patients (ranging in age from 66 to 87 years) on a bulk laxative regimen and during treatment with wheat bran. The patients received 6 g of a conventional bulk laxative, Vi-Sibilin (with a water holding capacity of 15 g water per g Vi-Sibilin) twice daily during the 8-week period. Measurements of transit time were taken after 4 and 6 weeks on each regimen.

Anderson et al. (21) observed that transit time decreased in all but two patients during treatment with bran as compared with the results for the bulk laxative treatment. The mean transit time for the group as a whole was 126 hours for the bulk laxative regimen and 89 hours for the bran regimen, the difference being statistically significant. The effect of the two therapies on the transit time in different parts of the colon was compared by arbitrarily dividing the abdomen into three segments and registering the time the capsule was in each segment. No significant difference in transit time through the upper part of the colon was found when the two therapies were compared. In contrast, the mean transit time through the rectosigmoid part of the bowel was faster on the bran (23 hours) than on the bulk laxative regimen (62 hours) and the difference was statistically significant. No significant change occurred in the number of bowel evacuations between the two treatments. The need for additional laxative therapy was much greater during the bulk laxative treatment (required in 9 patients) than the bran (required in 1 patient).

Anderson et al. (21) concluded that the administration of bran decreased transit time in subjects with an initially long transit time (3 days or more), whereas the time became slower in subjects with a short transit time (1 day or less) when compared to the bulk laxative treatment. Thus, the supplementation of the diets of geriatric patients with a 20 g coarse bran a day was superior to a conventional dose of bulk laxative (Vi-Sibilin) in effecting a fast transit through the most distal part of the bowel. An indirect sign of the favorable effect of bran was the reduced need for additional laxative therapy during the period of bran administration. Moreover, the low cost of bran favored this treatment.

McCallum et al. (22) described a trial of bran and bran biscuits in 6 elderly psychiatric and 17 mentally handicapped subjects, aged 19 to 96 years, over a period of 9 weeks. In each of three, 3-week periods, each patient was fed either 3 bran biscuits (containing 10 g bran), 10 g unrefined bran or 10 ml Senokot syrup daily (for the elderly group) or three times weekly (for the mentally handicapped group). The treatment periods were in random order. Enemas were given to the mentally handicapped group when considered essential. There was no significant difference in the number of bowel movements among the 3 groups although there was a tendency for bran biscuits to produce fewer movements. There was no significant difference among the groups given enemas nor in the number of loose or constipated movements between the different treatments. However, Senokot induced diarrhea in four patients and was withdrawn because of this in one elderly patient in the psychiatric hospital. According to McCallum et al. (22) the results indicated that bran or bran biscuits could be substituted for laxatives in at least some of these patients. However, none of the treatments was successful in eliminating the use of enemas in the mentally handicapped group.

In a study by Cummings et al. (23) approximately 20 g per day of concentrated dietary fiber from carrot, cabbage, apple, bran or guar gum were added to the controlled basal diet of 19 healthy male subjects, aged 20 to 38. Each subject consumed the control basal diet for 3 weeks. The control diet included "Weetabix," milk, orange juice, jam, biscuits, meat, vegetables, fruit, tea, coffee, white bread and butter. The subjects also participated in two 3-week dietary trials during one of which additional fiber was added to the basal diet. At least 3 weeks were allowed to elapse

between the two dietary periods to ensure that one dietary period had no residual effect on the next. Radioopaque pellets were used as markers and indicators of mean transit time.

Cummings et al. (23) observed that each fiber preparation increased fecal output in every subject except in one person taking guar gum. Fecal weight increased by 127% on bran, 69% on cabbage, 59% on carrot, 40% on apple and 20% on guar gum compared to the control and all increases were significant ($P<0.01$) except for guar gum. Adding fiber also significantly diluted the concentration of inert markers in the stools from 33 markers per 100 g stool (control) to 16 on bran; 36 to 23 on cabbage; 25 to 17 on carrot; 24 to 17 on apple; and 27 to 22 on guar gum. Mean transit times were shortened usually by the addition of fiber to the diet compared to the control and were significant for bran, cabbage and apple but not for carrot. Of the two subjects who ingested guar gum, one showed an increase and the other a decrease in mean transit time over control values. Cummings et al. (23) concluded that fiber from four common food sources and guar gum produced very different responses to colonic function and these differences were related to the intake of pentose-containing polysaccharide in the fiber.

Gramstorff Fetzer et al. (24) examined the apparent disappearance of three forms of purified dietary fibers (14.2 g cellulose, hemicellulose or pectin per day) when fed to 8 normal adolescent boys. The 21-day study was divided into an introductory 2-day depletion period, a 3-day adjustment period and four experimental periods of 4 days each randomly arranged for each of the subjects. During the experimental periods, the subjects were fed a basal diet alone or with one of the fiber supplements. The basal

diet consisted of 6.8 g fiber per day and was composed of 300 g starch bread, 100 g each peanut butter, applesauce, peaches, pears and orange juice, 50 g nonfat dry skim milk and vitamin and mineral supplements. To meet the energy requirements of the subjects, varying amounts of soft drinks, hard candy, jelly and butter oil were also added. All subjects were fed all diets. Complete collections of the feces were made by each subject throughout the study. A dye marker, brilliant blue, was used to mark the beginning of each trial period.

The feces during the cellulose and hemicellulose periods generally were not as well formed as those in the control collection. The stools in the hemicellulose period also had a shiny, glossy appearance. The physical appearance of the feces during the pectin-supplemented period was generally claylike and well formed. Mean fecal weights were not statistically different. When subjects received no added fiber, cellulose, hemicellulose or pectin, the mean percentages of dry feces excreted as neutral-detergent fibers were 27.2, 42.3, 30.3 and 25.9%, respectively. Cellulose supplementation resulted in significantly higher and pectin significantly lower percentages of neutral-detergent fiber in the feces than did other fiber supplements. The apparent disappearance of cellulose was 40%, hemicellulose 90%, and pectin close to 100% because no pectin was detected in the feces. Gramstorff Fetzer et al. (24) concluded that in adolescent boys, cellulose appeared to be less digestible than hemicellulose, whereas pectin appeared to be completely digestible.

Holladay et al. (25) designed a study to determine whether or not digestion of cellulose, hemicellulose and lignin occurred in the small or large intestine of humans. For the small bowel study, 6 ileostomy subjects

(3 men and 3 women) were included. Ten normal healthy subjects (5 men and 5 women) also participated in the study. A basal diet was fed to all subjects over a 10-day period, which provided 2,400 kcal, 8.38 g cellulose, 13.82 g hemicellulose and 1.06 g lignin for male subjects and 1,800 kcal, 6.35 g cellulose, 10.72 g hemicellulose and 0.84 g lignin for female subjects. After 4 days on the diet, two fecal collections of 3 days each were made for analysis. Results for normal subjects and patients with ileostomies are presented in tables 3 and 4. For both men and women ileostomy subjects, the weight of cellulose and hemicellulose in the stools was greater ($P<0.001$) than that of the corresponding male and female normal control groups. The lignin content of the feces of the women ileostomy subjects was not significantly different from that of the normal subjects but stools of male ileostomy subjects contained significantly more lignin than those of control subjects. The study indicated that 84.5% of the cellulose and 96% of the hemicellulose components of dietary fiber were digested and that this digestion occurred mostly in the large intestine for cellulose and in the small intestine for hemicellulose. Holloway et al. (25) stated that cellulases were not present in the human digestive juices, thus intestinal bacteria were responsible for the digestion of cellulose. Hemicellulose was postulated to contribute to the caloric value of foods. Lignin was resistant to digestion and was proposed as an aid in the prevention of metabolic disorders.

In another study, Holloway et al. (26) studied the digestion of hemicellulose in 7 normal healthy subjects (4 women and 3 men) and 4 healthy subjects (2 men and 2 women) with ileostomies who were fed a diet of known fiber content for 10 days. After 4 days on the diet, two total fecal

TABLE 3

Women--normals and patients with ileostomy (25).

	Fecal Weight			Cellulose			Hemicellulose			Lignin		
	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
Food Intake (g/24 hr)				6.35	0.21	3.3	10.72	1.76	16.4	0.84	0.10	11.5
Fecal Excretion (g/24 hr)												
Normal	66.0	21.8	32.0	0.8	0.50	62.5	0.30	0.20	66.7	1.10	0.30	27.3
Ileostomy	753.6	140.9	18.7	4.4	2.40	54.3	3.80	2.00	52.6	1.40	0.40	28.6

TABLE 4

Men--normals and patients with ileostomy (25).

	Fecal Weight			Cellulose			Hemicellulose			Lignin		
	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
Food Intake (g/24 hr)				8.38	0.28	3.3	13.82	2.27	16.4	1.06	0.12	11.5
Fecal Excretion (g/24 hr)												
Normal	113.8	47.9	42.1	2.70	2.00	74.1	0.70	0.30	42.9	0.90	0.20	63.2
Ileostomy	741.0	165.3	32.3	8.70	2.00	23.0	2.7	1.00	37.0	1.80	0.98	22.2

collections of 3 days each were made. An average of 65% of the hemicellulose was digested by female ileostomy subjects, 83% by male ileostomy subjects and 97% and 95% by normal female and male subjects, respectively. Holloway et al. (26) stated that this study confirmed that there was some digestion of hemicelluloses in the small and large intestines in humans although the mechanism by which this occurred was unknown.

Floch and Fuchs (27) obtained daily dietary histories and 72-hour stool collections each week over a period of 8 weeks from 6 healthy subjects (4 males and 2 females, ranging in age from 23 to 47). Subjects were studied first for a 3-week control period, followed by 3 weeks of 5.4 g crude fiber supplementation daily (Kellogg's All Bran, 3 oz) and then by a 2-week control period. Analysis of the diets revealed that the subjects increased the average total crude fiber intake to approximately 10 g per day during the experimental period as compared to about 3 g per day during both control periods. The color of the stool was observed to change from either light brown or brown to a more gray-brown appearance. There was an increase ($P<0.001$) in total stool weight on the fiber-supplemented diet compared to the control. However, the percentage of water in the stool remained the same, indicating that the total water output increased as well as the total solid output. Although the volume and water excreted per day increased greatly, the pH of the stool remained the same during the high fiber intake period when compared to the control periods. Floch and Fuchs (27) concluded that fiber, crude or dietary, was necessary to increase stool bulk and that the quantity and type were relative and varied from individual to individual in effect. Nevertheless, nondigestible carbohydrates were necessary to maintain adequate stool bulk and motion.

Volatile Fatty Acids

Yang et al. (18) studied the effects of dietary cellulose on the quantities or change in proportions of volatile organic acids in the cecum and feces of rats, using three dietary groups of 8 rats each. A basal grain ration that was nutritionally adequate in all respects was fed to the first group. The percentage composition of the basal ration was as follows: 60.7% ground corn, 28% soybean meal, 2% alfalfa meal, 2.5% fish meal, 2.5% dried whey, 1.6% limestone, 1.75% dicalcium phosphate and 1.5% iodized salt. The second and third groups were fed rations in which part of the corn of the basal ration was replaced with cellulose so that the final diets contained 5 and 10% added cellulose, respectively. The rats were fed the three diets and water ad libitum. Consumption of the rations was measured for each rat for 7 days, 4 and 8 weeks after the initiation of the trial. After 9 weeks of feeding, feces from each rat were collected for 3 consecutive days. After the fecal collection period, the rats were not disturbed for 7 to 10 days except for feeding. Afterwards, all rats were decapitated and cecal contents were removed for analysis.

No significant differences were observed for the quantities of rations consumed by the groups of rats. The wet weight of the cecal contents averaged 9.06, 9.64 and 11.13 g for groups fed diets containing no supplement, 5 and 10% added cellulose, respectively. Those fed the 10% added cellulose had greater ($P<0.05$) cecal contents than those fed the basal diet. Cecal volatile acids increased from an average of 64.51 mg for the control group to 71.76 and 78.64 for the groups fed the 5 and 10% added cellulose, respectively and fecal volatile acids for the three groups averaged 64.44, 65.59 and 72.57 mg, respectively. There were no

significant differences in the quantities and proportions of individual volatile fatty acids (butyrate, acetate and propionate) in the cecum and feces of the rats fed diets containing no supplement, 5 or 10% cellulose. Yang et al. (18) concluded that cellulose was partially digested by rats and that the higher the concentration of cellulose in the diet, the greater was the quantity of the cecal volatile acids.

Hoover and Heitmann (28) studied effects of diets containing either 14.7 or 29.4% acid-detergent fiber on cecal volume and rates of cecal volatile fatty acid production in 20 weanling rabbits that were divided into two equal groups. A low fiber diet consisting of 28.5 kg ground alfalfa hay, 33.3 kg hominy feed, 9.5 kg soybean oil, 28.3 kg wheat and 0.5 kg sodium chloride per 100 kg feed was fed ad libitum to one group. The high fiber diet that was fed ad libitum to the other group consisted of 67 kg ground alfalfa hay, 3.3 kg soybean meal, 7.3 kg oats, 11.9 kg wheat, 5 kg cellulose and 0.5 kg sodium chloride. The rations were fed for 11 weeks and water was available at all times. During the tenth week, feces were collected for five consecutive 24-hour periods. At the end of 11 weeks, the animals were sacrificed and the cecal contents were analyzed. Cecal volume of the rats fed the low and high fiber rations were 70 and 92 g, respectively, but the difference was not significant. Cecal volatile fatty acids in mmoles per g dry matter in rats fed the low fiber diets were acetate, 0.178; propionate, 0.020; and butyrate, 0.029 mmole per g dry matter in rats fed the low fiber diet. Cecal volatile fatty acids in mmoles per g dry matter in rats fed the high fiber diet were acetate, 0.183; propionate, 0.018; and butyrate, 0.018, which was equivalent to 0.219 g total cecal volatile fatty acids, and fecal volatile acid content was 0.039 mmole per g dry matter.

Butyrate was found in higher concentrations ($P<0.05$) in the ceca of the rabbits on the low fiber compared to the high fiber rations. Levels of acetate and propionate were similar and not significantly different in rats fed both diets. Comparisons between total volatile fatty acids in the cecal and fecal contents indicated that absorption of the volatile fatty acids occurred in the lower gut.

Cummings et al. (29) studied the effect of adding wheat fiber for 3 weeks (divided into two periods) to the metabolically controlled diets of 6 healthy male subjects, aged 21 to 25 years. Two subjects were fed the high fiber diet in one period and four subjects in the other period. The low fiber diet used in the experiment contained 17 g fiber and provided 2,802 kcal, 351 g carbohydrate, 122 g fat and 88 g protein. The fiber content of this diet was raised to 45 g by adding 30 g Allison's Bran Plus and substituting equal amounts of wholemeal for white bread (120 g), bran biscuits for "Nice" biscuits (52 g) and All Bran for Cornflakes (25 g). The high fiber diet provided 2,755 kcal, 340 g carbohydrate, 117 g fat and 97 g protein. The subjects took 5 radioopaque markers with each meal during the study periods. Feces were collected throughout and one week after the termination of the experimental periods. The addition of 28 g of dietary fiber to the diet was associated with a large and significant increase in fecal weight (79.3 and 228 g for the low and high fiber diets, respectively). Volatile fatty acid concentrations showed no overall change but there was marked increase in output ($P<0.005$). Cummings et al. (29) observed that volatile fatty acid excretion increased as fecal weight increased but suggested that whether or not colonic volatile fatty acid production played a key role in determining fecal bulk still needed to be established.

Spiller et al. (30) studied the effect of purified cellulose (solka-floc, that was 99% cellulose on a dry weight basis), purified pectin and a natural low-residue diet on fecal acetate, propionate, butyrate, valeric and isovaleric acids in 42 healthy male and female adults, aged 23 to 60 years. The subjects were chosen on the basis of slow intestinal transit time and low fecal output while consuming their normal diet. These parameters were determined by using radioopaque markers and by daily fecal collections during a screening period of 5 days. Only refined breads and cereals, meats, milk products and a limited selection of cooked vegetables and canned fruits (2 servings per day) were permitted on the low residue diet. The subjects were fed the low residue diet for 2 weeks followed by 3 weeks on the same diet plus 14 g cellulose, 6 g pectin or a sucrose nonfiber placebo each day. All the treatments were in powder form and were flavored with sucrose and natural lemon flavor. The daily dose of the appropriate treatment was mixed with 10 oz water before ingestion and taken after the evening meal. Feces were collected for 7 days during the second and fifth weeks. Only subjects with baseline transit times greater than or equal to 3 days were included in the analysis of transit time. Because of this, each group analyzed consisted of 10 subjects who met this criterion. Baseline mean transit times were comparable among treatment groups ($P=0.069$) and ranged from 4.9 to 5.7 days. The mean transit time for the cellulose treatment group was lower ($P<0.05$) than for the baseline group. The pectin and placebo groups had comparable transit time changes which were not significantly different from the baseline. The treatments resulted in significant changes from baseline in the total amount of fecal volatile acids ($P<0.05$). Total fecal volatile acids decreased from the baseline by 1.2 g per week with the sucrose placebo, 1.3 g with cellulose and 0.6 g with

pectin. Volatile fatty acid changes with the placebo and cellulose paralleled changes in fecal weight. Total fecal wet weight increased by 34 g per day from baseline with cellulose, but decreased by 15 g with the sucrose placebo and by 0.32 g with pectin ($P<0.05$). Thus, fecal volatile fatty acid concentration did not change. Conversely, volatile fatty acid increase of the pectin group was not paralleled by fecal weight increase, indicating an increase ($P<0.05$) in volatile fatty acid concentration. The major fecal volatile fatty acid was acetate (approximately 50% of measured fecal volatile fatty acids) for all diet periods and all groups. Propionate and butyrate were present in approximately equivalent amounts and were the most important components after acetate. Isovaleric and valeric acids were present in small amounts (about 5% of each) and only traces of isobutyrate were found. Spiller et al. (30) stated that it was important to consider that the amount of volatile fatty acids excreted in the feces was the difference between the amount produced by bacterial action and the amount absorbed through the colonic mucosa. Thus, any factor affecting production such as the amount and type of fiber present in the diet, and/or absorption would affect the output of these volatile organic anions in the feces.

The Effect of Particle Size

Brodribb and Groves (31) measured the daily stool weights of 21 adults (9 men and 12 women), aged 20 to 40 years, before, during and after eating coarse and fine bran. A normal diet was consumed for the first week of the study and stool specimens were collected. One type of bran was then fed for two weeks and was replaced with the other type for an additional 2-week period. Stool weights were measured during the second week in both periods.

No bran was eaten for the sixth and seventh weeks and stool weight was measured for the seventh week. Subjects were allocated randomly to be fed coarse or fine bran first and were asked to maintain a similar diet throughout the 7-week period, without changes in fiber intake apart from the bran. The basal daily stool weight was calculated as the mean of 14 days during the first and seventh weeks. The increase in daily stool weight was calculated as the difference between the basal and mean daily stool weights for weeks 3 or 5. With coarse bran, stool weight was greater ($P<0.01$) than with the fine bran (219.4 g coarse bran per day compared to 199.0 g fine bran). The coarse bran also had a greater water holding capacity (7.3 and 3.9 g water per g coarse and fine brans, respectively). Brodribb and Groves (31) concluded that it could no longer be assumed that fiber of the same chemical composition had the same biological or therapeutic effect on the colon, even if it came from the same source and was consumed in identical quantities. Three different ways in which particle size could influence stool weight were suggested. First, larger particles of bran have a higher water holding capacity and could therefore increase the relative amount of water present in the stool. Secondly, coarse bran particles probably are less digested by intestinal bacteria and may contribute to a higher fecal fiber content compared to fine bran. Thirdly, the larger particles may trap more finely dispersed gas produced by the colonic bacteria, increasing stool bulk and thereby increasing transit time, with a consequent increase in stool weight.

Heller et al. (32) fed 8 men 32 g fine bran (180 μ) and coarse bran (720 μ) g each for 14 days to determine if the particle size of the bran had any effect on colonic function. The water holding capacities were 5.27 g and 3.60 g water per g bran dry weight, respectively. Following the

treatments with fiber, the subjects were fed the low fiber basal diet for 24 days. Measurements of mean transit time were made using polyethylene glycol and barium-impregnated radioopaque pellets. Values of mean transit time for coarse bran were 42.3 hours (polyethylene glycol) and 37.4 hours (radioopaque pellets) while 57.9 hours (polyethylene glycol) and 56.5 hours (radioopaque pellets) were measured for fine bran. Coarse bran produced a shorter mean transit time (P=0.95) than did finely ground bran in subjects fed equal levels of both bran diets. Daily fecal wet and dry weights from the coarse bran diet were found to be greater by 14% (P=0.99) and 7% (P=0.95) than the weights found during the ingestion of fine bran. The moisture content of feces from subjects fed the coarse bran diet was 75.2%, which was higher (P=0.99) than the value of 72.3% found with fine bran. This indicated that coarse bran was able to hold more water in the feces than finely ground bran. No significant differences in the number of defecations per day were noted although there was a trend towards an increase in the number of defecations in subjects fed the coarse compared to the fine bran. The mean digestibility of the fiber components of the coarse and fine bran in the 8 subjects were respectively: 35 and 42% neutral-detergent fiber, 50 and 54% hemicellulose, -3 and 10% acid-detergent fiber, 6 and 23% cellulose and -34 and 36% lignin. Although significant differences in digestibilities were not shown by Heller et al. (32), mean digestibilities were greater for fine bran than coarse bran components. The researchers suggested that the greater digestibility of fine bran than coarse bran partially explained the longer mean transit time observed for fine bran. Finely ground wheat bran was less effective than coarse bran in holding water in the feces and in promoting the rapid transit of digesta through the gut.

Dietary fiber encompasses various components that contribute to the structure of plants. Each of these dietary fiber components exert its own effect on bowel function and bulking of the stool.

THE EFFECTS OF DIETARY FIBER ON CARBOHYDRATE METABOLISM IN NORMAL AND DIABETIC SUBJECTS

Available carbohydrates are one of the principle sources of energy in the body. If carbohydrate utilization in the body is impaired, pathological conditions may occur. The most common pathological condition is diabetes mellitus. Research on the effects of dietary fiber on carbohydrate metabolism in normal and diabetic subjects has been conducted during the last decade. Dietary fiber may induce satiety and thus would be an effective measure in weight loss regimens. Several reports on these topics are reviewed in this section.

The Effect of Fiber on Carbohydrate Metabolism in Healthy Subjects

Southgate and Durnin (33) evaluated three diets differing in the content of unavailable carbohydrates. Four groups of individuals participated in the 1-month study. The first group consisted of 12 young men, ranging in age from 18 to 24 years and weighing from 63.4 to 78.9 kg. The second group consisted of 14 young women, aged 17 to 22 years and weighing 48.1 to 72.5 kg. The third group was composed of 11 elderly men 66 to 77 years of age and weighing 63.5 to 79.9 kg and the last group consisted of elderly women 67 to

78 years of age, weighing 53 to 89.8 kg. One diet contained no fruit or vegetables (except potato), another had fruit, vegetables and wholemeal bread and the third diet contained larger amounts of fruits and vegetables. In the first part of the experiemnt all subjects were fed the diet that was low in unavailable carbohydrates. There was a preliminary period of 2 to 3 days when the subjects ate the diet but no excreta were collected. This was followed by a 7-day balance period. As soon as fecal collections were completed during this period, the diet was changed for all subjects to the one containing more unavailable carbohydrate. On this diet, there was a 5-day preliminary period followed by a 7-day balance period. The last diet that was rich in unavailable carbohydrate was fed to 10 of the 14 women in the second group on a separate occasion with a 7-day preliminary period followed by a 7-day balance period. All subjects within each group were fed identical amounts of meals that provided about 1,600 to 2,000 kcal per day. When the diets containing increased amounts of unavailable carbohydrates were eaten, each subject was fed a ration of wholemeal bread. In addition, each subject was allowed as much white bread, butter, seedless jam, jelly marmalade, sugar and salt as desired. Each of these food items was weighed daily. Beer or soft drinks were available in measured amounts on request to both male groups while the women were restricted to a choice of soft drinks. Urine was collected over 24-hour periods beginning on the morning following the start of the balance period. The energy intake varied considerably within each group. However, no appreciable amounts of free sugars or starches (available carbohydrates) were detected in the feces of any subject in any of the treatments. Southgate and Durnin (33) concluded that there was no significant effect of sex or age on the digestibility of available carbohydrates in diets containing varying amounts of dietary fiber.

Jenkins et al. (34) evaluated the glucose response after the intake of various carbohydrate-containing meals to which guar flour and/or pectin were added. Thirteen healthy subjects (11 males and 2 females, aged 19 to 33 years and ranging 92 to 118% of ideal body weight) participated in one or more of three trials in random order and conducted in the morning after a 14-hour overnight fast. Venous blood samples were taken at 0, 15, 30, 45, 60, 90 and 120 minutes. In the first trial (4 subjects) the control meal was a homogenized liquid meal (containing 35 g Casilan, 35 g corn oil and 35 g glucose per 70 kg body weight). This was supplemented with 14.5 g guar flour during the experimental period. When guar flour was added to the liquid test meal (figure 1) no significant rise in the mean blood glucose level during the period was observed. The mean blood glucose level after the guar meal was significantly below the control at 30 minutes (4.77 and 6.33 mmoles per liter, respectively) and significantly above at 120 minutes (4.55 and 4.01 mmoles per liter, respectively). Each individual glucose curve was affected in the same manner. The mean insulin response followed a similar pattern to that of glucose (figure 1) with mean test insulin values at 15 minutes of 13 munits per liter compared with 22 munits in the control situation ($P<0.05$). At 30 minutes, mean insulin test values were 22 compared with 57 units per liter ($P<0.05$).

In the second trial with 8 subjects, Jenkins et al. (34) added 10 g of pectin to the marmalade in the control diet. The control consisted of 70 g sliced white bread with 16 g butter and 80 g marmalade and 300 ml tea containing 43 g milk but no sugar. It was observed that the addition of extra pectin resulted in blood glucose levels that were significantly below those of the control (figure 1) at 15 minutes (5.64 and 6.18 moles per liter,

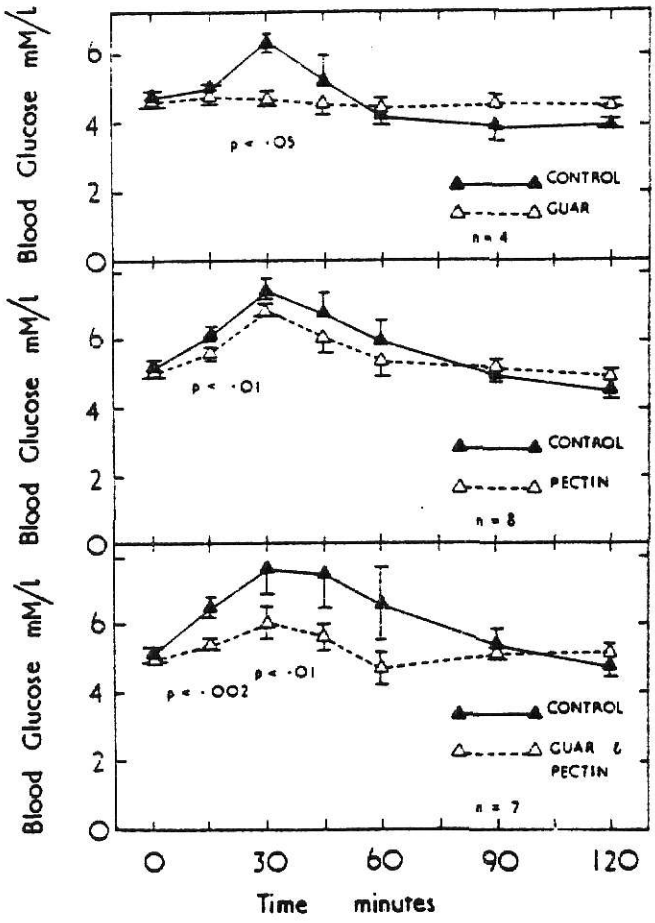

Fig. 1 Blood glucose levels (mean ±SEM) in four subjects after the test (guar) and control liquid test meal (upper panel), in eight subjects after the test (pectin) and control solid test meal (middle panel); in seven subjects after the test (guar and pectin) and control solid meal (lower panel). (34)

respectively). Although the values did not reach the 5% significance level, they remained below those of the control at 90 minutes. However, in 6 individuals in whom serum levels were measured, fiber-supplemented values were significantly lower than control values (figure 1) at 15 minutes by 14 munits per liter, at 30 minutes by 22 munits and at 45 minutes by 40 munits.

In the third trial, Jenkins et al. (34) fed the same diet used in the second trial to 7 subjects modified only in that the bread served at each meal contained 16 g guar flour. Results are depicted in figure 1. Means of blood glucose levels after the test meals were significantly reduced below those of the control meals at 15 minutes (5.39 and 6.49 mmoles per liter, respectively). Blood glucose levels in each individual subject were lower in the test situation than the control at 15 minutes though at 30 minutes this occured in only six of seven subjects. At 45 minutes, the blood glucose values obtained with the experimental diet remained below those of the control though the values were not significantly different (45 minutes, 5.62 and 7.50 mmoles per liter; 60 minutes, 4.71 and 6.59 mmoles per liter for test and control values, respectively). The mean test insulin response at 15, 30, 45, 60 and 90 minutes was significantly below those of the control with values of 26, 37, 34, 30 and 20 munits per liter, respectively (figure 2) in the 5 subjects tested for plasma insulin response. Jenkins et al. (34) postulated that the results obtained in the trial with guar flour and pectin may be due to their effect on glucose absorption rates, on the release of gastrointestinal hormones which in turn affect insulin secretion or directly modify glucose metabolism or the release of pancreatic hormones. It was concluded that unavailable carbohydrates may reduce the rise in blood glucose that follows a carbohydrate meal and that this effect

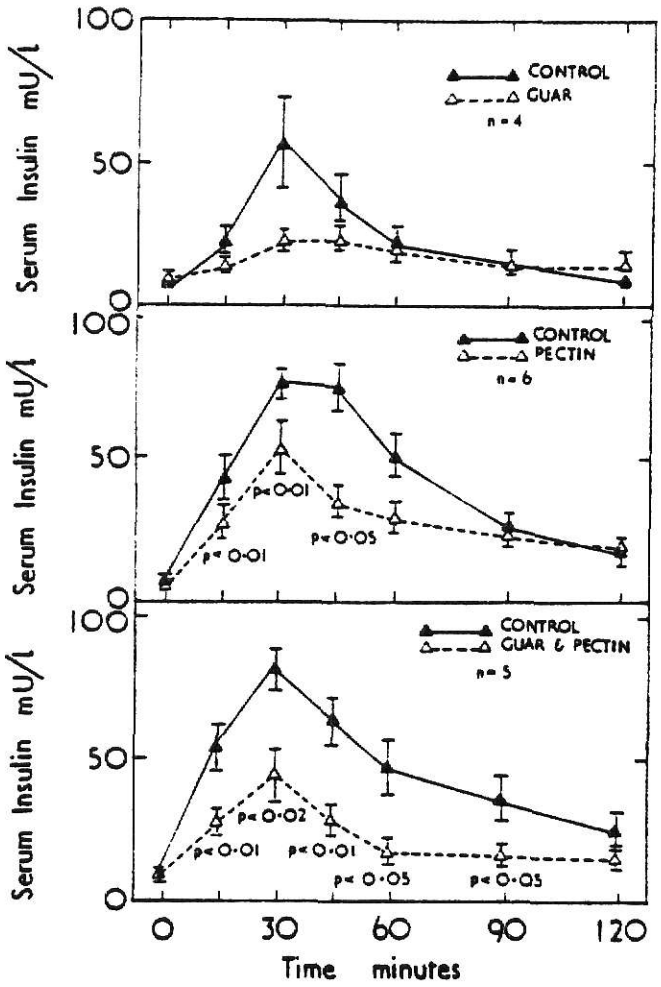

Fig. 2 Serum insulin levels (mean ±SEM) in four subjects after the test (guar) and control liquid test meal (middle panel); in five subjects after the test (guar and pectin) and control solid test meal (lower panel). (34)

may be possible with other unabsorbable noncarbohydrate gelling agents.

Jenkins et al.[1] evaluated the effect of eating standard carbohydrate portions of commonly eaten foods on postprandial blood glucose in 24 healthy volunteers divided into groups of four. The subjects were fed 50 g carbohydrate portions of over 40 foods as single meals on separate mornings after an overnight fast. Meals were made up to 600 ml and eaten over a standard 10- or 15-minute period. Capillary blood samples for glucose analysis were taken at intervals of 0, 15, 30, 45, 60, 90 and 120 minutes from the start of the meal. Foods tested included cereal products (white and wholemeal breads, Ryvita crispbread, white and brown rice, white and wholemeal pastas), breakfast cereals (cornflakes, Shredded Wheat, Weetabix, All Bran and muesli), biscuits (sweet wheatmeal, oatmeal, plain and water biscuits), leguminous seeds, fruits, vegetables and confectionery. After every 5 to 6 tests, the subjects took a 50 g glucose tolerance test for comparison as a standard. There were marked differences in the effects of different foods on the postprandial glycemia. When the areas under the 2-hour blood glucose curve were compared to all treatments, cereal products, fruits and vegetables were 80 to 100% of that for glucose, biscuits and breakfast cereals were 50 to 70%, while leguminous seeds raised the blood glucose to only 30 to 50%. No relationship to total fiber content was found. It was suggested that the effects of legumes on glycemia warranted further investigation but appeared promising in the lowering of blood glucose in those cases where carbohydrate metabolism was impaired.

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[1] Jenkins, D. J. A., Wolever, T. M. S., Taylor, R. H., Barker, H. M., Fielden, H., Baldwin, J. M., Newman, H. C., Bowling, H. C. & Goff, D. V. (1979) Bioavailability to man of carbohydrates in foods. Proc. Nutr. Soc. 39, 11A.

Jefferys[2] investigated the effect of different preparations of fiber on gut function as measured by the oral glucose tolerance test in 6 healthy subjects (4 males and 2 females), aged 20 to 25 years. After a 12-hour fast, the subjects were fed 1 g glucose syrup per kg body weight. Fiber preparations consisting of the glucose syrup with either unprocessed bran, bagasse or wood cellulose were fed randomly with a week between each experiment. The fiber (0.2 g per kg body weight) was soaked in water overnight and then added to the glucose solution. All the drinks were made up to 6 ml per kg body weight with water. Blood samples were taken at 30-minute intervals for 2 hours. It was observed that bran significantly improved the glucose tolerance at 60, 90 and 120 minutes compared to the control ($P<0.01$) and also significantly reduced the area under the curve ($P<0.01$). The bagasse (10% undigestible carbohydrate) and wood cellulose (95% undigestible carbohydrate) raised the glucose concentrations at 30 and 60 minutes ($P<0.01$) compared to the control value. It was concluded that the presence and the nature of dietary fiber in the diet modified the metabolic response to digestible carbohydrate in healthy subjects.

The Effect of Dietary Fiber on Satiety and Weight Loss

The effect of apples, apple juice and pureed apples were compared by Haber et al. (35) to investigate whether the physical state of fiber had any effect on satiety. Ten healthy volunteers (5 males and 5 females), aged 22 to 40 and within 6% of ideal body weight, participated in the study. The

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[2]Jefferys, D.B. (1973) The effect of dietary fibre on the response to orally administered glucose. Proc. Nutr. Soc. 33, 11A-12A.

apples used were "Golden Delicious" and each contained about 3.1% of the weight of the whole, intact apple. The apples were fed quartered and cored (482 g) or as juice (444 ml). In addition, 150 ml water was included in each meal because the apple puree could not be made without fluid. The subjects were fed the test meals on five occasions at least two days apart. As anticipated, juice was drunk more quickly than puree, which in turn could be swallowed at a faster rate than the cored apples. This indicated that natural fiber slowed the ingestion of nutrients and that the delaying effect was markedly reduced when the fiber was processed.

The satiating capacity of the test meals was assessed numerically using a scoring system graded from minus 10 to represent extreme hunger to plus 10 to represent satiety. A hunger to satiety score was recorded before and immediately after each meal, and at 60, 120 and 180 minutes after starting the meal. Whole apples and puree were significantly more satisfying than the juice. The satiety resulting from the whole apples and puree lasted above the fasting level for 2 hours whereas that for juice lasted for 1 hour. This indicated that the satiating effect of a whole apple was partly attributable to its fiber content. Haber et al. (35) concluded that the removal of fiber from food and its physical disruption resulted in faster and easier ingestion and decreased satiety.

In a study on the effect of wholemeal bread on satiety, Bryson et al. (36) fed unlimited amounts of bread, butter and jam for lunch on four consecutive Tuesdays. On two days the bread was white (made from 70% extraction flour) and on the other two days it was wholemeal (made from 100% extraction flour). After the meals, the amount consumed by each subject was calculated by weighing the uneaten bread, butter and jam. No significant

differences between the energy intake with the two types of bread were observed. The average intake with wholemeal bread was 1,117 kcal and with white bread it was 1,052 kcal. However, the composition of the meals was significantly different. The intakes of protein and fat were higher ($P<0.01$) with wholemeal bread than with white bread, 21.6 versus 17.2 g protein and 45.9 versus 36.9 g fat, respectively. This difference was almost balanced by a decrease in the carbohydrate intake with wholemeal bread (162.1 g) versus white bread (171.6 g) so the energy intake for the meals did not differ significantly. Those subjects who tended to eat a large or a small amount of bread, butter and jam at the beginning of the study continued to do so throughout the experiment on both types of bread. It was concluded that wholemeal bread and white bread did not differ in their effect on satiety.

The effects of regular enriched white bread and high fiber bread on weight loss in 16 overweight college males were compared by Mickelson et al. (37) over an 8-week period. The mean initial body weight of the subjects fed the regular bread (control group) was 89 kg and that for the high fiber bread group was 95 kg. All subjects ate the same kind and amounts of food in addition to 12 slices of regular (1.02 g crude fiber per day) or high fiber (25.5 g crude fiber per day) bread. The regular bread diet provided 12.84 g carbohydrate, 0.91 g fat and 2.2 g protein. The high fiber bread diet provided 9.10 g carbohydrate, 0.47 g fat and 2.5 g protein. To avoid excessive stress, subjects were permitted to snack between meals as desired with careful records of snacks being kept by each subject. Each subject was weighed at weekly intervals after voiding and before breakfast. Fasting blood samples were secured at the start of the study and at the

beginning of each of the three 3-day balance trials. The first balance trial began on the tenth day of study, the second on the twenty-second day, while the third encompassed the last 3 days of the study. The subjects fed the reduced-calorie bread lost more weight ($P<0.05$) than those fed regular bread (8.77 and 6.25 kg, respectively). Weight losses from week to week were more consistent for the subjects fed the high fiber bread than for the control subjects. Activity levels of the subjects were not significantly altered throughout the study. Fecal loss of energy was greater for the subjects fed the high fiber bread diet by an average of 71 kcal per day compared to the subjects eating regular bread. There was no significant difference in the loss of fecal fat and protein. Thus, the increased loss of energy in the feces along with a lower caloric intake on the high fiber diet resulted in an overall advantage of 446 kcal per day over the low fiber diet. No significant differences in urea nitrogen, plasma glucose and hemoglobin were observed for subjects on either diet. Mickelson et al. (37) stated that since there was no decrease in plasma glucose, it appeared that homeostasis was maintained in normal individuals. It was concluded that bread, especially reduced-calorie bread with a high fiber content, was beneficial in a weight loss regimen.

Kahaner et al. (38) investigated the effect of adding a high fiber food to the daily diet on eating patterns. Quantative and qualitative daily diet histories of 6 healthy subjects (4 males and 2 females), aged 22 to 47, were recorded for 8 weeks. An initial 3-week period was used as a control to determine the dietary patterns of each subject. During the following 3-week period, 3 oz of All Bran with approximately 5.4 g dietary fiber was included in the daily diet of each subject. During the final 2-week period, the

intake of All Bran was discontinued and subjects continued to keep diet histories. The most significant change in eating behavior attributable to fiber supplementation was a decrease in eating eggs, butter and breakfast meats. These foods were most often replaced because all six subjects chose to eat the major portion of All Bran during breakfast. An increase in milk and fruit also occurred during the supplemented feeding. These foods were added to make All Bran more palatable and served to increase carbohydrate and protein intake. Five subjects added the supplement to the between meal-time feeding and thus caused an increase in total daily caloric intake. At lunch and dinner few foods were altered with no particular pattern of substitution. None of the subjects modified his eating behavior to include a high fiber food daily after the experimental period. Thus, behavior modification by forced dietary intake of a high fiber breakfast food resulted in definite diet pattern changes, but they did not persist following the experimental period.

The Effect of Viscosity of Fiber on Glucose Absorption

Leeds et al.[3] studied the effect of viscosity of dietary fiber on gastric emptying and glucose absorption in the rat. Seventy-two rats (36 female rats, weighing 172 to 213 g and 36 male rats, weighing 180 to 260 g) were studied after 16-hour fasts. A meal composed of 500 mg glucose, 16 mg phenol red, 80 g of one of three guar gum preparations and 4 ml water were given by orogastric intubation. Animals were sacrificed after 0.5 and 1

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[3]Leeds, A.R., Bolster, N.R., Andrews, R. & Truswell, A. S. (1979) Meal viscosity, gastric emptying and glucose absorption in the rat. Proc. Nutr. Soc. 38, 44A.

hour (8 animals each), or 1.5 or 2 hours (4 animals each), and immediately after the abdominal cavity was opened. The gut was excised and segmented into the stomach, upper mid and lower thirds of the small gut, cecum and colon. These were analyzed for glucose and phenol red. Solutions of the three guar gum preparations had viscosity ranges at 37^{o} as follows: purified guar gum, 9,400 to 79,400 centipoises; and purified and depolymerized guar gum (two types) 360 to 470 centipoises and 10 to 20 centipoises, respectively. Glucose disappearance from the gut was significantly slower ($P<0.001$) after the most than after the least viscous meal, and the rate of disappearance of glucose was dependent upon the rate of gastric emptying. However, meal viscosity did not significantly affect disappearance of glucose from the small intestine when this was expressed as a proportion of glucose emptied from the stomach. It was concluded that increasing meal viscosity slowed glucose disappearance from the gut of the rat and this was attributable to a slowing of gastric emptying.

Johnson and Gee[4] investigated in vitro the effect of guar gum at levels of 0.1, 0.25 and 0.5% on the intestinal absorption of glucose. Everted sacs were prepared from excised rat jejunum and alloted at random to a control incubation medium (with a viscosity of 1 centipoise) containing 28 mmoles glucose and three treatment media containing 0.1, 0.25 and 0.5% guar gum with viscosities of 3, 16 and 104 centipoises, respectively. After a 30-minute incubation period, the glucose transported into the serosal solution of each sac was measured by colorimetry and expressed in terms of tissue dry weight. A significant reduction in glucose absorption was

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[4]Johnson, I. T. & Gee, J. M. (1980) Inhibitory effect of guar gum on the intestinal absorption of glucose in vitro. Proc. Nutr. Soc. 39, 52A.

observed with increasing concentrations of guar gum. In separate experiments, a similar effect was obtained using high viscosity carleoxymethyl cellulose in place of guar gum. In both cases, there was a rapid decline in absorption as the apparent viscosity of the medium was increased from 1 to 10 centipoises. It was concluded that both guar gum and carboxymethyl cellulose inhibited glucose transport in vitro probably because of an increase in the thickness of the unstirred solvent layer at the mucosal surface brought about by the higher viscosity of media containing gel-forming polysaccharide gums.

Jenkins et al. (39) conducted a study using a range of substances to investigate the type of dietary fiber or fiber analogue that had the greatest potential use in diabetic treatment. Groups of 4 to 6 subjects who were selected from 11 subjects (aged 20 to 40 years and mean weight 103% of ideal) participated in two or more trials (one of which was a control) which were randomly allocated and at least 2 days apart from each other. The meals were taken over a 10-minute period in the morning after an overnight fast. The control diet consisted of 50 g glucose, 25 g xylose, 15 g lactulose and 40 g PLJ (Pure Lemon Juice) in 400 ml water. The control diet was supplemented with either 14.5 g of guar gum (6 subjects), tragacanth (6 subjects), pectin (6 subjects), methylcellulose (5 subjects), 4.5 g wheat bran (6 subjects) or 12 g cholestyramine (4 subjects) which amounted to nearly 12 g fiber per meal. Four of the six subjects who originally took guar gum also took 14.5 g partially hydrolized nonviscous guar with the control diet 6 weeks later. Blood samples were collected at fasting and 15, 30, 45, 60, 90 and 120 minutes after the start of the meal for glucose and insulin analysis. Urine was collected before and 2 hours

after the meal for xylose estimation. In the guar experiments urine was collected every 2 hours for 8 hours.

Guar was the only substance that significantly decreased the percentage maximum rise in blood glucose (by 50%). All substances, however, produced significantly lower test blood glucose values on one or more occasions during the glucose tolerance test (figure 3). During the first hour, the area under the blood glucose curve was significantly reduced by guar (68%; $P<0.05$), tragacanth (34%; $P<0.01$) and methylcellulose (29%; $P<0.05$) compared to the control curve. There was a significant correlation between viscosity of the individual substances and the mean percentage reduction of the maximum rise in blood glucose concentration ($r=0.926$) and mean percentage reduction of the area under the curve ($r=0.904$). The differences in serum insulin response with the different fibers followed the same pattern as the glucose concentrations. Guar was the only substance that significantly reduced the maximum rise in serum insulin by 51% although in general, the test insulin responses were below control values. As with glucose, the reduction in the area under the insulin curve correlated with viscosity. A significant decrease in 2-hour urinary xylose excretion was seen with guar ($P<0.02$), tragacanth ($P<0.02$) and bran ($P<0.01$) over control values. The reduction over control values with pectin and methylcellulose did not reach significance and cholestyramine values were almost identical with the control. Hydrolysed guar had no effect on the glucose and insulin outputs. Jenkins et al. (39) concluded that viscosity had a considerable effect on absorption in that guar, the most viscous susbstance tested, was the most effective in decreasing postprandial glucose and insulin concentrations. This was confirmed by the fact that hydrolysed guar, without a viscous

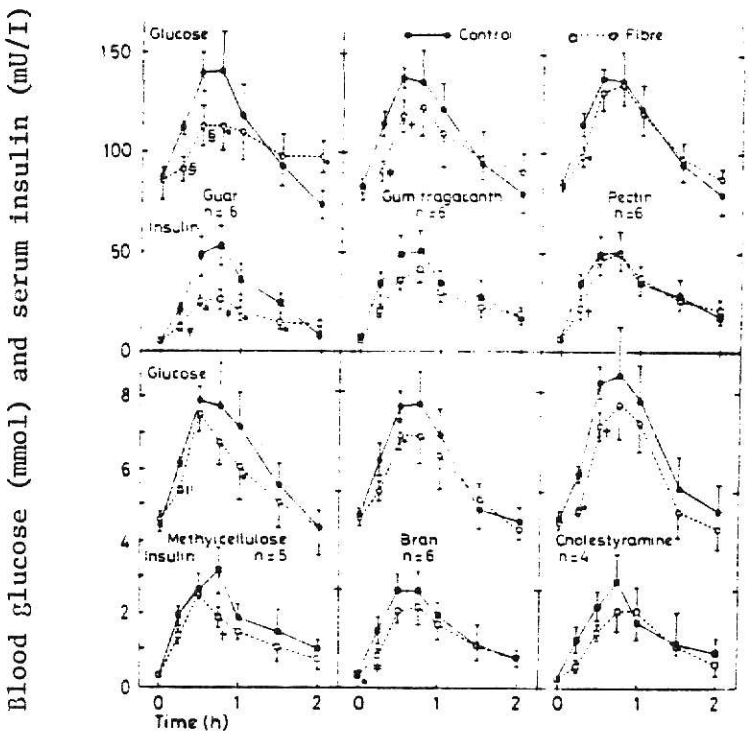

Fig. 3 Mean blood glucose and serum insulin concentrations of volunteers after taking control and fibre-containing test meals. Difference from control: *P<0.05; +P<0.02; ‡P<0.01; ∂ P<0.002; ‖P<0.001.
Conversion: SI to traditional units--
Glucose: 1 mmole/liter≈18 mg/100 ml. (39)

nature did not show the same effect on blood glucose and serum insulin. Agents that increase viscosity provide one possible approach to the treatment of diabetes.

The Effect of Dietary Fiber in Diabetes

Jenkins et al. (40) examined the effect on 24-hour urinary glucose excretion of adding 25 g guar gum to the diets of 7 diabetics (5 males and 2 females, ranging in age from 21 to 69 years and weighing 92 to 127% of ideal weight) both at home and in a metabolic ward of a hospital. Six of the subjects were on insulin therapy and one was following a controlled diet. Four subjects participated in the home-based studies of 3 weeks duration; two took guar gum in the second week while the other two took guar gum during weeks 1 and 3, respectively. The guar gum was divided among the meals and incorporated into weighed slices of bread, canned soup and fruit juice consumed at the beginning of the meal. During the control period, equal amounts of bread, soup and fruit juice without guar gum were consumed. Twenty-four-hour urinary collections were made for the 5 days from Monday to Friday during the 3 weeks of study. In the metabolic studies, 5 subjects were followed for 10-day periods on a 2-day rotating menu. During the second 5-day period, guar gum was fed in bread, soup and mashed potato distributed among the meals, as in the home study. Apart from the addition of guar gum, test and control diets were identical. Carbohydrate intakes were adjusted to be equivalent to the home diets of the subjects. Twenty-four-hour urine collections were made over the 10 days.

In the home studies, there was a significant reduction in mean urinary glucose output from 26 to 14.1 g glucose per day when guar gum was added to

the diet ($P<0.05$). In the metabolic ward studies, addition of guar to the diet produced a significant reduction in mean glucose output from 29.0 to 13.3 g glucose per day ($P<0.01$). Thus, the incorporation of 25 g of unabsorbable carbohydrate in the form of guar gum into the diet of diabetics decreased their mean urinary glucose excretion by 40 to 50%. This effect was independent of the dose of insulin. Jenkins et al. (40) concluded that gel-forming, unabsorbable carbohydrate may therefore be a useful adjunct in diabetic therapy irrespective of the type of treatment or insulin dosage used.

The effect of guar and pectin supplements on blood glucose level and serum insulin response to carbohydrate feeding in 11 diabetics after 14-hour overnight fasts was studied by Jenkins et al. (41). Eight of the subjects were insulin independent (4 males and 4 females, averaging 58 years of age and 120% of ideal body weight) and 3 insulin dependent diabetics (2 males and 1 female, averaging 21 years of age and 105% of ideal body weight). The volunteers took one of two test meals in the morning after a 14-hour overnight fast. In the fiber supplemented test meal, each portion of bread contained 16 g guar powder while 10 g of pectin were added to the marmalade. The two meals were fed in random order 1 to 2 weeks apart. Insulin-dependent diabetics injected their normal morning insulin dose 15 minutes before the meal. Venous blood samples were drawn at 0, 15, 30, 45, 60, 90, 120, 150 and 180 minutes. In insulin-independent diabetics, the mean blood glucose concentration after the meal containing guar and pectin was significantly below that of the control meal by 2.61, 3.45 and 3.06 mmoles per liter at 30, 45, 60 and 90 minutes, respectively. Serum insulin levels of the 8 insulin independent diabetics after the fiber supplemented meal were also significantly below the control meal values by 11, 19, 22, 24 and 19 munits

insulin per liter at 30, 45, 60, 90 and 120 minutes, respectively. When these meals were fed to the 3 insulin dependent diabetics, a similar flattening of the postprandial glucose rise ensued. It was concluded that the data obtained provided evidence that dietary fiber may reduce the glycemia following a carbohydrate test meal without increasing serum insulin levels in diabetics.

The manner in which the fiber content of meals affected diabetic controls was investigated by Miranda and Horwitz[5]. Eight diabetic subjects on insulin were fed randomly a low fiber diet containing 3 g crude fiber and a high fiber diet with 20 g crude fiber, each for 10 days. Diets were similar in terms of calories, carbohydrate, fat and protein. Insulin dose of each subject was kept constant. Plasma glucose was measured four times during each of 3 days during each feeding period. Mean plasma glucose on the low fiber diet was 169.4 mg per dl. This was significantly higher than the value of 120.8 on the high fiber diet. Although fasting plasma glucose was not significantly different on the two diets, significantly lower values on the high compared to the low fiber diets were observed at 1100 hours (122 versus 164 mg per dl); 1700 hours (100 versus 154 mg per dl); and 2100 hours (113 versus 204 mg per dl). Percentage decrease in mean plasma glucose on the high fiber diet was significantly correlated with the mean plasma glucose on the low fiber diet (r=0.84). Hypoglycemia reactions were more common in subjects fed the high fiber diet. It was concluded that substantial changes in fiber content of the diabetic diet may lead to marked changes in diabetic control, and that increasing dietary fiber may be a useful means of lowering plasma glucose in some diabetic patients.

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[5]Miranda, P. M. & Horwitz, D. L. (1977) The effect of dietary fiber content on plasma glucose levels in diabetics. Diabetes 26, Supplement, 13.

The utility of a 75% carbohydrate diet in treating diabetic patients requiring either insulin or oral hypoglycemic agents were evaluated by Kiehm et al. (42). Thirteen diabetic men, ranging in age from 34 to 63 years and with weights from 82 to 113% of the ideal, were included in the study. Five required insulin ranging from 18 to 28 units per day, another five required sulfonylureas and three required 40 to 55 units of insulin per day. All men were fed individualized, weight maintaining American Diabetic Association (ADA) diets for 1 week, then isocaloric, high carbohydrate diets for approximately 2 weeks. A representative 2,200 kcal ADA diet contained 4.7 g crude fiber, 234 g carbohydrate (43% of calories), 128 g protein (23%) and 83 g fat (34%). The 2,200 kcal high carbohydrate diet contained 14.2 g crude fiber, 4.4 g carbohydrate (75% of calories), 86 g protein (16%) and 23 g fat (9%). Plasma glucose values at fasting levels and at 1600 hours were obtained daily. After 2 weeks on the 75% carbohydrate diet, sulfonylureas were discontinued in all 5 men. Insulin was discontinued in 4 men and decreased from 28 to 15 units in the fifth subject in the group requiring less than 30 units per day. Fasting plasma glucose values were significantly lower ($P<0.001$) in all 10 men. However, insulin requirements and fasting plasma glucose values were not changed in the 3 men requiring 40 to 55 units of insulin. It was concluded that a high carbohydrate diet with generous amounts of dietary fiber may be the treatment of choice of diabetic patients requiring sulfonylureas or less than 30 units of insulin per day.

Bose (43) compared 20 normal and diabetic subjects over a 2-year period who were fed a typical Bengalee diet with another group of normal and diabetic individuals who were fed North Indian diets. Highly physically active and obese individuals were excluded from the study. The Bengalee

diet provided 2,000 kcal, 500 g carbohydrate, 75 g protein, 25 g fat and 15 g fiber and included many fiber-rich cereals, vegetables (high in water holding capacity), very little animal proteins and occasionally fruits. The North Indian diets provided 2,000 kcal, 250 g carbohydrates, 100 g protein, 75 g fat and 5 g fiber. Thus, the North Indian diet was rich in fat and animal protein. The inclination to diabetes was measured by the individual's capacity to tolerate an infusion of 50 g glucose. Blood samples were collected at fasting and 2 hours after the intake of diet and glucose load.

Fasting and postprandial values reported for blood glucose on the low fiber (North Indian) diets were 170 and 190 mg glucose per dl, respectively, in the diabetic subjects. On the high fiber (Bengalee) diet these were 145 and 150 mg glucose per dl at fasting and 2 hours, respectively. The hypoglycemic effect of the high fiber diet was significant ($P<0.005$) when compared to the low fiber diet. Bose (43) commented that subjects with maturity-onset diabetes who switched from the North Indian diet to the Bengalee diet were able to control the disease. Several other subjects who were taking sulfonylureas were able to discontinue therapy on the Bengalee diet. The results obtained for the glucose tolerance test indicated that in the nondiabetic condition, the hyperglycemic stage was more pronounced postprandially in subjects fed the North Indian diet compared to those fed the Bengalee diet. Fasting and postprandial values obtained were 88 and 92 mg glucose per dl, respectively, on the Bengalee diet and 95 and 102 mg glucose per dl, respectively, on the North Indian diet. The hyperglycemic effect of the low fiber diet was significant compared to the high fiber diet. A similar trend (that was significant) was observed in the diabetic subjects during the glucose tolerance test. Fasting and postprandial values for

blood glucose on the Bengalee diet were 130 and 145 mg glucose per dl, respectively, and on the North Indian diet 145 and 160 mg glucose per dl, respectively. Bose (43) concluded that normal individuals consuming a high fiber Bengalee diet were less prone to hyperglycemia than those on a low fiber diet and that the Bengalee diet also aided diabetic subjects to keep blood sugar levels under control.

Dietary fiber appears to reduce plasma glucose levels in both healthy and diabetic subjects. Thus, fiber may be a promising adjunct to insulin, oral hypoglycemic agents and/or controlled diets that are used in diabetic therapy. The effect of dietary fiber on weight loss is less clear cut, because conflicting results have been reported. The source of fiber included in weight loss regimens appears to affect the degree of weight reduction.

THE EFFECTS OF DIETARY FIBER ON THE METABOLISM OF LIPID, CHOLESTEROL AND BILE AND ITS ROLE IN VASCULAR DISEASES

This section reviews selected studies on the effects of dietary fiber on the metabolism of lipids, cholesterol and bile and also its role in essential hypertension and atherosclerosis. Lipids are a source of energy and constituent or precursor of components of the body such as membranes and prostaglandins. Cholesterol is a normal constituent of certain organs such as the brain. Conjugated bile salts facilitate lipid absorption from the small intestine. Bile is also implicated in cholesterol metabolism. Triglycerides are products of lipid degradation and along with cholesterol are components of lipoproteins.

Hypercholesterolemia and hyperlipoproteinemia are implicated in the development of atherosclerosis. Atherosclerosis of coronary arteries, in turn, has been associated with heart attacks. Essential hypertension or high blood pressure apparently is also a factor in atherosclerosis and heart disease. Most of the research on the effects of dietary fiber on coronary heart disease have been extrapolated from epidemiological studies linking the consumption of a Western-type diet, that is low in fiber, to the increased incidence of heart disease. These studies have been omitted in this report.

The Effect of Fiber on Bile Metabolism

According to Danielsson (44), the main endproducts of cholesterol metabolism are neutral steroids and bile acids. The composition of neutral sterol fraction of feces varies with diet and intestinal flora. Neutral sterols of endogenous origin from the feces of various species include cholesterol, cholestanol, coprostanol, epicoprostanol, cholestanone, coprostanone, lathosterol, delta-7-coprostenol, 7-dehydrocholesterol and methostenol. The conversion of cholesterol to bile acids occurs in the liver. The two main bile acids are cholate and chenodeoxycholate which may be conjugated with the amino acids, taurine or glycine. Bile acids that are excreted in feces constitute a complex mixture of compounds formed from the action of intestinal microflora. Microbial transformations begin in the cecum and include hydrolysis of the conjugates, dehydroxylations and different oxidation and reduction reactions leading to the formation of metabolites that are invariably less polar than the parent bilary bile acids. The effect of dietary fiber on bile metabolism is discussed since bile is an integral part of fat metabolism.

In Vitro Studies

Drasar and Hill (45) stated that deconjugated bile salts might profoundly alter fat absorption. Conjugated bile salts (present in the normal human small intestine) form micelles with products from the hydrolysis of fats in the jejunal lumen more efficiently than free bile acids. During an investigation (45) of intestinal microflora in healthy subjects and patients with various gastrointestinal disorders (including steatorrhea), 15 of 25 strains of the genus Bacteroides were isolated from the gut, and these strains deconjugated bile salts in vitro both aerobically and anaerobically. Escherichia coli, Pseudomonas species, enterococci and Streptococcus salivarius were unable to split the conjugates tested.

The binding of sodium taurocholate and sodium glycocholate by various samples of non-nutritive fiber was studied by Story and Kirtchevsky[6]. Substrate solutions of the bile salts were made by dissolving sodium taurocholate or glycocholate in 0.15 M sodium chloride. Tracer quantities of tritiated sodium taurocholate or glycocholate and the fiber sample being tested were included in the solutions. The solutions were incubated for 1 hour at 37° and the amount of bile salts bound to the fiber was calculated from the analysis of supernatant radioactivity. Cholestyramine and colestipol (bile salts sequestrants used to lower serum cholesterol levels) were used as controls. Only alfalfa (among a series of 8 types of non-nutritive fiber) bound an appreciable quantity of taurocholate (17%). When 100 mg of non-nutritive fiber was incubated with 240 μmoles of

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[6]Story, J. A. & Kritchevsky, D. (1974) Binding of bile salts by non-nutritive fiber. Fed. Proc. 33, 663.

taurocholate, appreciable amounts (3 to 5%) were bound by sugar cane pulp, sugar beet pulp, bran and oat hulls. Synthetic fiber (cellophane spangles and cellulose) failed to bind a significant quantity of taurocholate. When various quantities of binding substance were incubated with 100 μmoles of taurocholate or glycocholate, cholestyramine reached a plateau in which any amount over 40 mg bound 80 to 90% of taurocholate. However, alfalfa showed a linear response through 160 mg. It was concluded that non-nutritive fiber appeared to participate actively in cholesterol metabolism either by binding bile salts (which would decrease cholesterol absorption) or by some other mechanism.

Birkner and Kern (46) investigated the in vitro adsorption of bile salts to nondigestible food residues, hemicellulose and salicylazosulfapyridine. Cholestyramine, a known bile sequester, was included in some experiments for comparison. The bile salts used in the study were 24-^{14}C labeled cholate, chenodeoxycholate, deoxycholate and taurocholate as well as ^{3}H (glycine) glycocholate. Bile salt solutions were prepared in concentrations ranging from 0.2 to 10 mM in 0.2 M buffer solution of the desired pH. Chenodeoxycholate was tested at pH 6.5 and above, and deoxycholate at pH 8 and above because of their limited solubility at lower pH. The following weights of adsorbents were tested: 0.1 g each of cholestyramine powder and the residues of celery, lettuce and string beans; 0.125 g of hemicellulose; 0.25 g of the residues of apple, corn, kidney beans and potatoes and 0.5 g of salicylazosulfapyridine powder. The adsorbent and 5 ml buffered bile salt solution were incubated 2 hours at 25°. Adsorption was calculated from the decrease in bile salt radioactivity of the supernatant obtained from centrifugation.

Birkner and Kern (46) observed that the residues of celery, corn,

lettuce, potatoes and string beans adsorbed substantial amounts of chenodeoxycholate ranging from 19 to 60% of the amount adsorbed to cholestyramine. Hemicellulose, salicylazosulfapyridine and the residues of apple and kidney beans adsorbed negligible amounts of both chenodeoxycholate and glycocholate. The adsorption of bile salts to food residues was increased at lower pH and was greater for the less polar dihydroxy bile salts (chenodeoxycholate and deoxycholate) than the more polar trihydroxy bile salts (cholate and its conjugates). These observations indicated that bile salt adsorption to food residues was hydrophobic and the binding was responsible for micellar aggregation. Thus, dihydroxy bile salts formed micelles at lower concentrations than trihydroxy bile salts. Hemicellulose and salicylazosulfapyridine adsorbed only small amounts of bile salts. The adsorption of glycocholate and chenodeoxycholate to a number of adsorbents increased as their concentration in the incubation media increased. Birkner and Kern (46) suggested that bile salt adsorption to food residues may be an important factor in fat adsorption and bowel function in patients with decreased bile salt concentration in the intestine, especially after bacterial deconjugation and dehydroxylation of the bile salt.

The binding of ^{14}C-cholate, deoxycholate and chenodeoxycholate to pine wood and oats of various particle sizes was measured in vitro by Burczak and Kellogg (47). Fifty μmoles of the appropriate radioactive bile salt in 3 ml of 0.2 M potassium phosphate buffer at pH 7.0 was added to scintillation vials containing 50 mg of the fibrous sample to be tested. The vials were incubated 4.5 hours at 37°, then centrifuged. The supernatant radioactivity was a measure of unbound bile salt. Bound bile salt was calculated by subtraction of supernatant activity from control values. Binding of the three bile salts increased as wood particle size decreased and surface area

increased. The three oat particle sizes (coarse, medium and fine) bound specific bile salts to a higher percent than did similar size wood shavings. Cholate and deoxycholate (primary bile salts with a hydroxyl group attached at the 7-alpha position) bound to oats with no distinct pattern while deoxycholate (a secondary bile salt) binding increased as both particle size decreased and particle surface area increased. It was concluded that the effect of fiber on bile salt binding in vitro may be attributable to the specificity of the fiber for different bile salt structures in the case of oats and on particle size, with respect to wood shavings.

The binding in vitro of 50 μmoles radioactive sodium salts of cholate, chenodeoxycholate, deoxycholate, taurocholate, taurochenodeoxycholate, taurodeoxycholate, glycocholate, glycochenodeoxycholate and glycodeoxycholate by 50 mg of alfalfa, bran, cellulose, lignin and cholestyramine was measured by Story and Kritchevsky (48). The appropriate binding substance and bile acid in 5 ml phosphate buffer (pH 7.0) were incubated at 37° for 2 hours then centrifuged. Supernatant radioactivity was a measure of unbound substrate. Bound bile salts were calculated by subtraction. Cholestyramine bound an average of 81.3% of all the bile acids and salts tested. Story and Kritchevsky (48) stated that this occurred because cholestyramine was an ion exchange resin specifically designed to bind bile salts. Lignin, alfalfa and bran bound 29.2, 15.9 and 9.0%, respectively, while cellulose bound only negligible amounts of the bile acids and salts studied. It was concluded that binding of bile acids and salts vary with the type and source of fiber used and with the bile acids or salts tested.

In Vivo Studies

Pomare et al. (49) stated that the essential metabolic abnormality in the pathogenesis of cholesterol-rich gallstones is probably attributable to the secretion by the liver of bile supersaturated with cholesterol. The degree of cholesterol saturation of bile is influence by both the size (inversely proportional) and the composition of the circulating bile salt pool. The addition of fiber, such as bran, to the diet might expand the bile salt pool and increase the amount of detergent available to solubilize cholesterol in the gallbladder. Consequently, the effects of bran on the size and kinetics of the primary bile salt pools in 6 symptomless subjects and on the lipid composition of bile in 10 gallstone patients was studied.

In the first study, 3 men, aged 42 to 48 years, and 3 women, aged 49 to 56 years, were studied before and 4 to 6 weeks after adding at least 20 g coarse, flaky bran daily to their normal diets. The quantity and kinetics of the cholate and chenodeoxycholate were measured simultaneously by an isotope dilution technique. The labeled bile acids were administered to the subjects after an overnight fast. The total bile salt pool was taken as the sum of cholate, chenodeoxycholate and deoxycholate pools. Lithocholate was not measured. When the subjects added bran to their diets, the deoxycholate pool decreased 33% ($P<0.025$) and the chenodeoxycholate pool increased 27% ($P<0.05$) while no significant difference in pre- and postbran values occurred for the cholate nor for the total bile salt pool. During bran feeding, chenodeoxycholate synthesis increased by 25% ($P<0.025$) whereas, no such trend was apparent with cholate synthesis. Total bile salt synthesis averaged 1.24 before and 1.46 mmoles per day during bran feeding ($0.05<P<0.10$). The half-lives of cholate and chenodeoxycholate pools were not significantly affected by bran compared to no bran supplementation. If

there had been significant binding of bile salts in the small intestine, bran would have shortened the half-lives of both substances.

In the second study by Pomare et al. (49), the objective was to investigate whether bran supplements would reduce cholesterol saturation of bile. Ten female subjects, aged 33 to 53 years, with gallstones were chosen because such subjects usually have supersaturated bile. The experimental design was similar to the first study described above. Bran supplementation resulted in a decreased molar percentage of cholesterol (10.1 to 8.6%, $P<0.01$) whereas, there was no significant trend with the molar percentages of bile salts or phospholipids from baseline values. Initially, 9 of the 10 subjects had supersaturated bile and in these subjects bile became significantly less saturated in 8 subjects with bran compared to no bran supplementation. However, bile became unsaturated in only 2 subjects. Pomare et al. (49) stated that based on their short term results, it was doubtful if bran would be an effective agent for dissolving gallstones.

Pomare and Heaton[7] studied the effects of unprocessed wheat bran on bile salt metabolism. In 5 subjects with intact gallbladders, there was evidence of reduced dehydroxylation with bran. The proportion of deoxycholate in bile was halved and there was reduced transfer of radioactivity from ^{14}C-labeled taurocholate to its dehydroxylated derivatives in bile. Bran caused increased deconjugation of taurocholate. In 6 cholecystectomy subjects, bran failed to reduce dehydroxylation probably because in such subjects there was increased exposure of bile salts to intestinal bacteria. It was suggested that dietary fiber affected bile salt metabolism and provided a possible link between fiber-depleted diets

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[7]Pomare, E. W. & Heaton, K. W. (1973) Alteration of bile salt metabolism by dietary fibre (bran). Gut 14, 826.

and diseases attributable to bacterial metabolites.

The effects of a typical rural Guatemalan diet (high fiber and containing mostly black beans, tortillas, rice and vegetables with a small amount of egg and cheese) and an egg formula diet with (low fiber) and without (no fiber) oat bran (0.6 g per kg body weight toasted or untoasted) were compared by Kretsch et al. (50) in 6 healthy American men, 23 to 40 years of age. All diets were designed to provide constant amounts of the following per kg body weight: protein (0.875 g); energy (40 kcal); cholesterol (3.65 mg) and fat (0.8 g with 0.55 g as butter fat, 0.04 g as egg fat and 0.21 g as vegetable oil). The oat bran and Guatemalan diets provided about 12 and 93 g neutral-detergent fiber per day, respectively. Each diet was fed for a 15-day period (5 metabolic periods in all) with the fiber-free diets always preceding the oat bran or Guatemalan diets. Fasting blood samples were collected on the first day of the study and at the middle and end of each metabolic period.

Kretsch et al. (50) observed that serum cholesterol and triglyceride levels were not significantly different among dietary treatments. A significant two-fold increase in total bile acid excretion each day occurred when subjects were fed the Guatemalan and the oat bran diets in contrast to the fiber-free control diet. However, the concentration of total fecal bile acids (mg dry feces per g) decreased significantly only with the Guatemalan diet where it was about one-half the value compared to the other diets. No significant differences were found in the proportion of mono- and dihydroxy bile acids but the actual amount of monohydroxylated bile acids (principally lithocholate) excreted daily increased by nearly two-fold for all subjects consuming the Guatemalan and oat bran diets. There was a similar increase in the dihydroxylated bile acid excretion.

The Guatemalan diet was the only diet that showed a trend towards decreased fecal urobilinogen excretion. However, fecal urobilinogen concentration (mg dry feces per g) was significantly decreased with the Guatemalan (concentration about one-sixth that of the control) and the oat bran (concentration about one-half that of the control) diets. Urinary urobilinogen excretion was significantly lowered only when subjects were fed the Guatemalan diet. Kretsch et al. (50) postulated that increased urobilinogen excretion may have resulted from elevated metabolic activity of intestinal bacteria and/or a change in bacterial composition. It was concluded that the Guatemalan diet increased total bile acid excretion but lowered fecal bile acid concentration and urobilinogen excretion.

The Effect of Dietary Fiber on Lipid and Cholesterol Metabolism

Studies with Healthy Subjects

Prather (51) investigated the effect of cellulose on serum lipids levels in 5 female subjects, aged 18 to 23 years. The experimental period consisted of 8 consecutive weeks in which the basal diet with and without 13 g of cellulose was fed randomly for 4 weeks each. Each subject served as her own control. Blood samples were collected from each subject in the postabsorptive state, initially and weekly thereafter. It was observed that serum cholesterol, total lipid and the phospholipid levels of the subjects fed the two diets were not statistically different.

Kay and Truswell (52) studied the effect of isoenergetic substitution of bran and 100% wholemeal bread for white flour and white bread in 6 healthy subjects (3 men and 3 women, aged 22 to 37 years) in a metabolic unit. The control diet provided an average of 10.14 MJ, 90 g protein, 91 g

fat, 282 g carbohydrate, 18 g alcohol, 3.7 g crude fiber and 0.52 g cholesterol. Crude fiber intake on the high fiber diet was increased to 8.6 g. The 21-day high fiber experimental period was preceded and followed by a 14-day control period so that each experiment lasted 7 weeks. Blood samples were taken on each of the last 30 days and feces collected for the last 6 days of each diet period. Plasma cholesterol and triglycerides were not significantly altered by the addition of wheat fiber. However, wheat fiber caused an increase ($P<0.01$) in fecal bulk. Fecal steroid excretion was the same in the last week of the first control and the high fiber periods, but both total bile acid and neutral steroid excretions increased ($P<0.05$) in the second control period. It was concluded that the addition of wheat fiber to a controlled diet for a 3-week period does not lower plasma lipid levels in healthy young adults. The rebound phenomenon in bile acid excretion during the second control period indicated that some alteration in the enterohepatic circulation may have occurred as a result of bran consumption. However, the mechanism of this effect was unexplained. Finally, the significant increase in fecal bulk resulted in a dilution of fecal bile acids.

In an 11-week study, Connell et al. (53) investigated the effect of processed wheat bran fed in moderate amounts on serum lipid levels in healthy subjects randomly divided into a low fiber group and a high fiber group. The control group (23 subjects) consumed their normal diet alone with a breakfast cereal containing negligible amounts of dietary fiber. The average fiber intake of the control group was 3.5 g. The experimental group (22 subjects) added a fiber-containing breakfast cereal to their normal daily regimens so that the fiber intake of their diet was almost double that of the control group. The average fiber intake of the experimental group was approximately

8 g in the first 4 weeks and 6 g in the remaining weeks of the study. Blood samples were drawn at the start of the trial and at 4, 7 and 11 weeks for fasting serum cholesterol and triglyceride determinations. There were no significant differences in the serum cholesterol and triglycerides in either group after the double dose of the fiber at 4, 7 or 11 weeks. Thus, Connell et al. (53) concluded that the addition of a tolerable amount of dietary fiber to the diet had no effect on serum lipids.

Walters et al. (54) investigated the effects of bagasse (the residue from sugar cane) on the fecal excretions of acid, neutral steriods and lipids as well as plasma cholesterol and triglycerides. After initial control observations, 9 nuns were fed a supplement of 10.5 g bagasse (with a high proportion of cellulose and lignin) in biscuit form and 10 other nuns were fed control biscuits that were low in fiber. The biscuits were added to the normal diets of the nuns and provided an increased fiber content of 9 g per day. After 12 weeks, the dietary regimens were crossed over for an equal period, after which final control observations were made while the nuns consumed their normal diets without any supplements. Blood samples were collected every 2 weeks for plasma cholesterol while two consecutive 3-day stool collections were obtained during the latter half of each dietary period. The bagasse had a moderate bulking effect. The total fecal loss of neutral steroids was unaltered by the bagasse whereas, there was an increased daily loss of acid steroids ($P<0.001$) and fatty acids ($P<0.005$). The increased excretion of bile and fatty acids did not cause lowering of plasma cholesterol and triglyceride levels, even after 12 weeks.

In another 12 week study, Walters et al. (54) fed 5 different volunteers metabolically controlled low fiber diets with either low fiber biscuits or 39 g wheat bran biscuits. The control diet provided 14 g dietary fiber which

was increased to 27 g with the addition of the bran biscuits. After a 4- to 5-day adjustment period, stools were collected weekly. Bran had no significant effect on the excretion of bile acids. Fecal fat excretion was increased on the bran diet compared to the control but not significantly. Walters et al (54) stated that although both bagasse and bran produced bulking effects and increased the excretion of fatty acids, their effects on steroid excretion were different, probably owing to differences in their chemical compostion.

The effect of citrus pectin on blood lipids and fecal steroids in 9 subjects (4 men and 5 women, aged 21 to 28 years) was studied by Kay and Truswell (55). The experimental design consisted of a 21-day pectin period preceded and followed by a 14-day control period, thus the study lasted a total of 7 weeks. A 7-day rotating menu was used with individual fat, cholesterol and fiber content similar to usual intakes. The control diet provided an average of 2,350 calories, 275 g carbohydrate, 86 g fat, 90 g protein, 17 g alcohol, 7.3 g crude fiber and 425 mg cholesterol. Pectin (15 g per day) was consumed with fruit and sugar as a gel in divided doses with meals. Fasting blood samples were taken before breakfast on the last 3 days of each dietary period and 6-day fecal collections were made at the end of each dietary period. Plasma cholesterol concentrations were reduced by a mean of 13% ($P<0.001$), fecal fat excretion increased increased by 44% ($P<0.001$), neutral steroids increased by 17% ($P<0.001$), fecal bile acids increased by 33% ($P<0.02$) while plasma triglyceride levels did not change over from baseline values. It was concluded that pectin exerted a hypocholesterolemic action in man. Kay and Truswell (55) suggested that the presence of a gel in the lumen of the small intestine could interfere with the equilibrium between the micellar phase and the molecular phase that

passes into the unstirred layer on the brush border and in this way might reduce lipid absorption.

Van Berge-Henegouwen et al. (56) studied the effect of a standardized coarse wheat bran product on serum lipids in a group of 7 young healthy males, aged 18 to 24 years, over a 5-week period. Serum lipids were analyzed before and after 2 weeks of treatment. The subjects added the wheat bran (0.5 g per kg body weight) to their normal meals after the control period and during a period of 4 weeks. Thus, the total intake of the bran supplement varied from 33.5 to 37.9 g per day in the subjects. Serum samples were collected after an overnight fast of at least 12 hours. The dietary intake of carbohydrate, protein and lipid did not change significantly during the study. In all but one subject, serum cholesterol was reduced significantly over a period of 4 weeks with a mean of 10.1%. The reduction in low density lipoprotein- and very low density lipoprotein-cholesterol did not reach statistical significance and high density lipoprotein-cholesterol was significantly reduced after 2 to 4 weeks of bran feeding. The reduction in the high density lipoprotein fraction accounted for almost 40% of the lowering of total serum cholesterol after 4 weeks. Total serum triglycerides decreased significantly after 4 weeks (mean of 23.8%), and serum very low density lipoprotein decreased at the same rate as total triglycerides. It was concluded that the results could have therapeutic consequences for the dietary management of hyperlipidemia. However, the lowering of high density lipoprotein-cholesterol could almost be interpreted as unfavorable since an inverse relationship between high density lipoprotein-cholesterol levels and the occurrence of coronary heart disease has been established.

Stasse-Wolthuis et al. (57) studied the effects of citrus pectin, pectic substances contained naturally in fruits and vegetables and wheat bran on cholesterol metabolism. The 40 male and 22 female subjects, aged 18 to 28 years, were fed a relatively low fiber diet for 2.5 weeks after which they were divided into four groups. During the following 5 weeks of the study, one group was fed the low fiber diet; a second group was fed a high fiber diet rich in vegetables and fruits, while the diets of the third and fourth groups were supplemented with citrus bran and wheat bran, respectively. The four groups consumed an average of 18, 43, 28 and 37 g dietary fiber per day, respectively. Differences in the consumption of type and amount of fat, cholesterol, protein and carbohydrates within the groups were negligible. Before the start of the study and at the end of the control and experimental period, fasting blood samples were drawn at 1-day intervals. In addition, blood samples were taken once during the second, third and fourth weeks of the experimental period. Fecal collections were obtained during the last 7 days of both periods.

The concentration of serum total cholesterol decreased in those subjects fed the diet containing citrus pectin and the diet with vegetables and fruits (compared with the low fiber diet) by 13 and 7 mg per dl, respectively, but this effect was not significant. The addition of bran to the low fiber diet resulted in a significant increase of 13 mg serum cholesterol per dl over the value of the low fiber diet with no fiber supplementation. The amount and type of dietary fiber had no significant effect on the concentration of serum high density lipoprotein-cholesterol. With respect to fecal lipids, the high fiber diet with vegetables and fruits as well as the diet with bran significantly decreased the intestinal transit time by 13 and 19 hours, respectively, compared to the low fiber diet. Both

these diets, compared with the low fiber diet, also significantly increased fecal excretion by 49 and 77 g wet weight per day, respectively. Pectin had no significant effect on fecal lipid. Stasse-Wolthuis et al. (57) concluded that some of the components of dietary fiber of fruits and vegetables apparently lower serum cholesterol whereas, bran incrased serum cholesterol in the short term.

Studies with Subjects with Hyperlipidemia and Diabetes Mellitus

Jenkins et al. (58) reported the effects of guar gum on the serum lipids of 10 subjects (4 men and 6 women with an average age of 57 years) with type IIa or b hyperlipidemia during a 2-week study. Three of the subjects had been taking 12 to 16 g cholestyramine per day for over 2 years and a fourth patient had been taking 1,000 mg of clofibrate per day. These treatments continued throughout the study. Serum cholesterol levels of all 10 patients had been stable for 6 to 18 months before the start of the trial. Guar gum was added in three doses of 5 g to the normal diets of the subjects either in a specially prepared soup or as a powder mixed with fruit juice or milk. Fasting blood samples were drawn at the beginning and end of the 2-week period. At the end of the 2-week period, mean serum cholesterol level decreased 10.6% ($P<0.01$). Serum triglyceride was not altered significantly. Jenkins et al (58) suggested that guar gum, which could be incorporated into foods, merited further study as a potential hypercholesterolemic agent.

Jenkins et al.[8] investigated the effects of guar crispbread containing 1 g guar gum, 2.4 g starch and 2.6 g gluten per slice on blood lipids in

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[8] Jenkins, D. J. A., Reynolds, K., Slavin, B., Leeds, A. R., Waller, A & Jepson, L. M. (1979) Reduction of blood lipids by guar crispbread. Proc. Nutr. Soc. 38, 86A.

11 type II or IV hyperlipidemic subjects (4 men and 7 women with an average age of 56 years). The subjects were fed an average of 13 g guar gum in crispbread form over 2 to 8 week periods. Eight weeks of treatment (7 subjects) reduced total serum cholesterol by 13% ($P<0.02$) while high density lipoprotein-cholesterol was unchanged. A 13% nonsignificant reduction was observed in serum triglycerides. Guar crispbread was as effective as guar gum fed in hydrated fruit juice, skim milk and soup, 8 subjects) or semi-hydrated form (50% in soup and 50% in white bread, 4 subjects) in decreasing blood lipid levels over 2-week periods. It was concluded that guar crispbread would probably be a useful hypocholesterolemic agent.

Anderson[9] studied the trigylceride response of 21 diabetic men to 75% carbohydrate diets containing varying amounts of sucrose, oligosaccharides and polysaccharides. The subjects were fed a weight-maintaining 44% carbohydrate diet (control) for 1 week, then one of the three isocaloric, 75% carbohydrate diets for 7 to 14 days. The oligosaccharide and polysaccharide contents of the three diets were, respectively: 19 and 53%; 47 and 53%; and 13 and 87%. Only the first diet contained sucrose (28%). Thus, the first two diets were low, while the third diet was high in fiber content. Fasting triglycerides on the low fiber diets were 178% of values on the control. Thus, the presence or absence of sucrose did not affect the fasting triglyceride response. No change in fasting triglyceride levels was observed with the high fiber diet and values were 98% of those of the control diet. The data indicated that high carbohydrate diets that are low in oligosaccharides and high in polysaccharides with generous amounts of fiber are not associated with hypertriglyceridemia.

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[9]Anderson, J. W. (1976) Influence of type of carbohydrate on the triglyceride response to high carbohydrate diets in diabetic men. Am. J. Clin. Nutr. 29, 471.

The Effect of Dietary Fiber on Hypertension

Animal Studies

Gardey et al.[10] investigated the effects of dietary fiber on blood pressure in 20 rabbits. The rabbits were weaned onto a control diet containing approximately (per kg), 30 g fat (as naturally occurring fats in barley meal and soybean meal and 1% added corn oil), 200 g wheat bran and 100 g cellulose (solka-floc). The animals were fed the diets for 5 weeks before the start of the experiment, then divided into four groups of 5 animals each. The first group was fed the control diet plus 200 g coconut oil per kg; the second, the control plus 200 g cellulose and 200 g coconut oil per kg; the third, the control diet; and the last, the control diet plus 200 g cellulose per kg. The protein and carbohydrate contents of the diets were adjusted to maintain a constant ratio of protein:metabolizable energy (1.5 g protein:100 kJ energy). The experimental period lasted 7 weeks. Arterial blood pressure was measured daily during the final two weeks of the control period and weekly during the experimental period. It was observed that the fat-enriched diet significantly increased blood pressure of the first group by the end of two weeks. The addition of cellulose in the absence of added dietary fat had no effect upon blood pressure in the third and fourth groups.

Kennedy et al.[11] studied the effects of fats containing high levels of linoleic acid (safflower oil) and palmitic and oleic acid (palm oil) on

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[10]Gardey, T. Burstyn, P. G. & Taylor, T. G. (1978) Fat induced hypertension in rabbits. 1. The effects of fibre on the blood pressure increase induced by coconut oil. Proc. Nutr. Soc. 37, 97A.

[11]Kennedy, M. Burstyn, P. G. & Husbands, D. R. (1978) Fat induced hypertension in rabbits. 2. The effect of feeding diets containing high concentrations of safflower oil and palm oil. Proc. Nutr. Soc. 37, 98A.

blood pressure in rabbits. The growing rabbits were fed a low fat control diet for 2 weeks then the experimental diets for 8 weeks. The first group of 4 rabbits were fed a diet containing 200 g safflower oil per kg; the second group of five, a diet with 200 g palm oil per kg, and the last group, 200 g palm oil and 200 g cellulose (solka-floc) per kg. The protein and energy contents were adjusted to allow for these additions. Blood pressure was measured daily during the control and experimental periods. Serum samples were collected after overnight fasting. Feeding palm oil (second and third groups) compared to safflower oil increased plasma cholesterol concentration during the first 3 weeks ($P<0.01$) but after 7 weeks plasma cholesterol levels were raised in all groups. Triglycerides fell in all groups but least in that fed cellulose ($P<0.05$). The three high fat diets caused an increase in blood pressure compared to the low fat diet but the increase was greater with palm oil with no fiber supplement ($P<0.05$) than with safflower oil. The addition of cellulose with the palm oil lessened the rise. The greatest change in serum lipid values resulted in the greatest change in blood pressure.

During the investigation of the effect of feeding diets containing 200 g per kg palm oil and safflower oil on the blood pressure of rabbits conducted by Kennedy et al.[11], Goulding et al.[12] measured the fragility of erythrocytes to assess changes in membrane properties. When cellulose was added to the palm oil diet, the fragility of the erythrocytes was increased. This effect was also studied in two groups each with 5 growing male rates. One group was fed a stock diet containing (g per kg): soya flour (500),

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[12]Goulding, N. J., Husbands, D. R. Burstyn, P. G. R., & Taylor, T. G. (1978) The effect of feeding cellulose to rats and rabbits on the fragility of the erythrocyte membrane. Proc. Nutr. Soc. 38, 31A.

barley (2.3), palm oil (150), dried yeast (73) and a vitamin mix. The other group was fed the stock diet diluted with cellulose (solka-floc to provide 140 g cellulose per kg diet. The diets were fed to the rats for 14 days. Blood samples were collected and erythrocytes were obtained by centrifugation. Erythrocyte fragility was measured by determination of the amount of hemoglobin released into solution at various concentrations of sodium chloride. The molarity of sodium chloride producing 50% hemolysis was calculated. Feeding cellulose increased erythrocyte fragility in rats as with the rabbits. The fatty acid composition of the erythrocyte membrane lipids was not significantly altered between the two groups of rats. It is unclear how the changes in blood chemistry in rabbits fed palm oil diets with differing levels of fiber are related to the fragility of erythrocyte membranes.

Human Studies

The effect of dietary fiber on blood pressures of humans was investigated by Wright et al.[13] in four studies. Blood pressures of the subjects were measured three times weekly throughout the 2-week control period and 4-week experimental period. Three-day weighed diet records were collected during both periods. In the first study, 17 individuals, whose usual diet was relatively low in fiber (2.36 g per MJ), increased their intake of fiber to 3.47 g per MJ. Their mean systolic pressure decreased from 121.2 to 117.3 mm mercury ($P<0.01$) and diastolic pressure from 78.5 to 74.8 mm mercury ($P<0.001$). In the second study, 14 subjects, whose usual diet was relatively low in fiber, were fed specially baked wholemeal bread

[13]Wright, A., Burstyn, P. G. & Gibney, M. J. (1970) Dietary fiber and blood pressure. Proc. Nutr. Soc. 39, 3A.

with 10% added bran (providing 110 g per kg) to replace all of their white bread, and were asked to consume 5 g bran daily with their food. Dietary fiber intake in this group increased from 1.61 to 3.47 g per MJ ($P<0.001$). Their mean systolic pressure decreased from 119.9 to 118.2 mm mercury and diastolic pressure from 79.5 to 76.8 mm mercury ($P<0.01$). In the third study, 11 subjects, whose usual diet was high in fiber, were fed white bread to replace all of their wholemeal bread and asked to avoid very high fiber breakfast cereals. Dietary fiber intake decreased from 3.93 to 1.78 g per MJ ($P<0.001$). Mean systolic pressure increased from 113.8 to 121.5 mm mercury ($P<0.02$) and diastolic pressure from 74.2 to 77.0 mm mercury. In the fourth study, three-day dietary records were kept on 94 individuals divided into high (45 subjects) and low fiber (48 subjects) groups based on normal fiber intake (average of 3.44 and 1.64 g per MJ, respectively). Both the systolic and diastolic pressures of the high fiber group were significantly lower than those of the low fiber group. It was suggested that the dietary intake data obtained from the studies could account for much of the difference in blood pressures between vegetarians and meat eaters.

Sacks et al. (59) measured blood pressure levels in 176 members of a commune in Boston, who consumed a macrobiotic diet low in animal products, and 24 individuals, who were non-vegetarians and consumed a diet similar to a Western-type diet. In all, 85 female and 127 male subjects participated in the study. Systolic blood pressure adjusted for age, weight and consumption of animal protein was higher ($P<0.01$) in males than in females by 3.3 mm mercury. The adjusted diastolic blood pressure scores were the same in both sexes. Of the dietary variables considered, only the percentage of animal food in a meal related significantly to both systolic and diastolic pressures. Overall, blood pressure levels were lower in vegetarians than

non-vegetarians. It was concluded that blood pressure levels and consumption of food from animal sources were related.

The Effects of Dietary Fiber on Atherosclerosis

Story et al.[14] studied the effect of cholesterol-free diets containing 25% protein as casein or soya protein, and 15% fiber as wheat straw, alfalfa and cellulose on atherosclerosis in rabbits. All diets contained 40% sucrose and 14% hydrogenated coconut oil in addition to the protein and fiber. Levels for atheromata (arch plus thoracic) and serum cholesterol and triglycerides (mg per dl) in rabbits fed the experimental diets were, respectively: casein-wheat straw, 2.05, 375 and 94; casein-alfalfa, 1.25, 193 and 60; casein-cellulose, 3.0, 402 and 164; soya-wheat straw, 1.81, 254 and 66; soya-alfalfa, 1.46, 159 and 62; and soya-cellulose, 2.50, 248 and 41. Liver cholesterol and triglyceride levels were comparable for all groups. When wheat straw or cellulose was fed, soya protein was less atherogenic and lipidemic than casein. Alfalfa was the least atherogenic and lipidemic of the fibers tested and its presence in the diet negated any differences between the proteins.

Fisher et al. (60) studied the effect of pectin on atherogenesis in two groups of 2-year old cockerels (30 per group). Both groups were fed a corn-soybean diet containing 15% protein and supplemented with either 5% pectin (first group) or 5% cellulose (second group). The animals were fed the diets and water ad libitum for 18 months. Blood samples were collected toward the end of the experimental period. The birds were sacrificed at the

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[14] Story, J. A., Tepper, S. A. & Kritchevsky, D. (1976) Atherosclerosis in rabbits fed cholesterol-free diets: Effect of protein and fiber. Fed. Proc. 35, 294.

end of this period, and aortas from the heart to the iliac bifurcation and livers were removed. The pectin-fed birds had fewer ($P<0.001$) atherosclerotic plaques in the abdominal aorta but significantly higher concentrations of cholesterol in the plasma and liver than cellulose-fed birds. In a separate study, analyses were made of the excreta of 10-week-old chickens fed pectin or cellulose supplemented to diets containing 10% fat and 0.5% cholesterol. The pectin-fed birds lost three times as much lipid and almost twice as much cholesterol per gram of excreta compared to the cellulose-fed birds. It was concluded that pectin apparently was effective in retarding spontaneous avian atherogenesis.

Moore et al. (61) investigated the relationships between dietary components and atherosclerotic lesions on 114 white and 139 black male cadavers, ranging in age from 20 to 60 years at the time of death. The subjects were a subsample of cases in the International Atherosclerosis Project. A 28-day pattern of food intake of the subjects during the terminal year of life was determined from a detailed questionnaire filled out by female respondents who shared the household for an average of 18 years. Higher intakes of protein from vegetables, total carbohydrate, starch and crude fiber were associated with a decreased incidence of atherosclerotic lesions. The other components (total calories, total protein, animal protein, total fat, animal or vegetal fat, saturated or unsaturated fatty acids, total sugars and cholesterol) were not related to the occurrence of atherosclerotic lesions. When the diet-lesion relationships were examined on the basis of nutrient-to-calorie ratios, starch and vegetable protein were associated with less atherosclerotic lesion involvement in the coronaries, while animal protein and fat, regardless of source, were associated with greater atherosclerotic lesion involvement. Moore et al. (61) stated that

their results indicated that the consumption of more foods of vegetal origin may be related to a decreased incidence of atherosclerosis.

Schwarz (62) analyzed 26 sources of dietary fiber for silicon content. It was hypothesized that a lack of silicon may be an important etiological factor in atherosclerosis. Large amounts of silicate-silicon (1,000 to 25,000 ppm) was present in sources of fiber of greatly varying origin and chemical composition which were implicated in decreasing cholesterol and lipid levels thereby preventing experimental atherosclerosis or binding bile acids in vitro. Conversely, various kinds of purified cellulose, which do not produce these effects, were very low in silicon. Cotton, considered the purest natural form of cellulose, contained only 120 ppm silicon. Industrial refinement may greatly reduce silicon content in foods. Two of the samples tested, bran and wheat flour, were prepared by carefully controlled milling of a specific type of wheat. Flour of 65% extraction rate contained less than 10% of the silicon found in bran. Soybean meal, a source of fiber that reduced blood lipids and experimental atherosclerosis, was high in silicon, but two refined soybean preparations for human consumption contained very little of the element. Samples of wheat bran of different origin varied significantly in silicon content, two of the three having low values. Schwarz (62) postulated that this difference may be related to the kind and origin of the grain and to the differences in milling process. These could account for discrepancies in the results of blood lipids obtained with bran by different investigators. The same reasoning was suggested for inconsistencies in the reported effects of cellulose.

Some of the evidence presented in this section is conflicting, but a few conclusions may be drawn. Depending on the source and particle size, fiber may bind bile salts in vitro to different degrees. In vivo experiments

indicate that there are disparities in the effect of fiber on lipid and cholesterol metabolism. However, pectin and guar gum have consistently exerted a hypocholesterolemic effect and may have some therapeutic value. Lastly, a vegetarian diet may be a positive factor in the retardation of hypertension and atherosclerosis.

THE EFFECT OF FIBER ON NITROGEN METABOLISM

Many populations in developing countries subsist on a diet that is high in cereals and/or vegetables. Since cereals and vegetables contribute fiber to the diet, it is important to note if their inclusion affects the bioavailability of nitrogen. Such studies are few and the available data are conflicting. Apparently, various sources of fiber affect nitrogen balance differently.

Protein Digestibility, Availability and Balance Following The Intake of Dietary Fiber

Animal Studies

A 28-day study was conducted by Kiem and Kies (63) to examine the influence of graded levels of cellulose, hemicellulose and lignin on the nutritional status of nine groups of 8 male weanling mice. The semipurified, casein-based diet used in the trials consisted of 10% casein, 8% sucrose, 10% corn oil, 5% each of mineral and vitamin mixes and varying amounts of wheat starch added to make 100 g of ration. Dietary fiber at levels of 5, 10 or 20% was added to the stock diet at the expense of starch. All diets and water were fed ad libitum. An adjustment period lasting one week in

which a standard 5% hemicellulose, 10% casein laboratory ration was fed, preceded the start of the 28-day experiment.

Feed consumption for cellulose, hemicellulose and lignin at levels of 5, 10 and 20% were 135.8, 123.1 and 118.3; 101.0, 123.1 and 103.6; 119.3, 114.4 and 92.3 g, respectively. Energy intakes for these groups were 546.0, 470.1 and 404.6; 406.1, 470.1 and 354.4; 479.5, 437.0 and 315.6 kcal, respectively. Finally, weight gains for the respective groups were 16.7, 13.9 and 11.5; 7.2, 14.1 and 8.8; 10.2, 8.9 and 3.4 g. No significant differences were found in feed consumption except between the mice fed 20% lignin and those fed 5% cellulose ($P<0.05$). The mice tended to consume less ration as the percent of cellulose and lignin increased. Thus, both dilution and lower intake of the rations decreased energy intake. The mice fed 20% lignin consumed significantly less ration and thus gained considerably less weight. The mice fed hemicellulose did not follow the same trend as mice fed cellulose and lignin. The 10% hemicellulose group tended to consume more ration and thus tended to gain more weight than did the 5 or 20% groups. The 20% group consumed less ration than the 10% group. The mice tended to scatter the ration more as the percent of fiber increased, an activity associated with decreased acceptance. Even so, the 20% group gained slightly more weight than did the mice fed 5% hemicellulose. Kiem and Kies (63) concluded that in general, as the level of fiber increased, feed consumption and weight gain decreased.

Meyer (64) investigated the effect of dietary fiber on nitrogen balance in 48 male weanling rats over a 7-day period. The 0.52% nitrogen stock diet that was used in the study had the following constituents (g): sucrose, 86.8; defatted whole egg protein, 4.0; cottonseed oil, 5.0; salt mixture, 4.0; vitamin mix, 0.1; and choline, 0.1. The stock diet was fed alone or

with cellulose (added at the expense of the diet) at levels of 5, 15 and 30%. The four dietary groups of animals consumed about the same amount of ration. Hence, the nitrogen intake of the groups were about the same. Fecal nitrogen increased with increased levels of cellulose compared to the control and this effect was significant. There was no significant influence of fiber intake on endogenous urinary nitrogen excretion. Thus, any change in nitrogen balance from the control by cellulose-fed rats was attributed to increases in fecal nitrogen loss.

Narayana Rao et al. (65) investigated the effect of microcrystalline cellulose with a particle size of 40 μ added at the expense of cornstarch in the diets of six groups of 6 male rats. The groups were fed either a nitrogen-free diet or a 12% casein diet alone or with cellulose added at a level of 10 or 20%. In order to determine net protein utilization with varying amounts of cellulose, the rats were fed a stock diet for 7 days after which they were fed ad libitum one of the nitrogen-free or casein diets for 10 days. At the end of the feeding trial, the animals were sacrificed and the carcasses were dried to a constant weight for analysis. Inclusion of 10 or 20% microcrystalline cellulose added to casein diets did not significantly influence the utilization of nitrogen in balance and protein utilization studies. Narayana Rao et al. (65) suggested that it was possible to incorporate microcrystalline cellulose in the diets of rats to increase dietary bulk without significantly affecting the utilization of protein.

Human Studies

The utilization of nitrogen in low and high fiber diets was among the variables studied by Kelsay et al. (66). Twelve male subjects, 37 to 58

years of age participated in a 26-day experiment with a cross-over design. The high fiber diet included fruits and vegetables and the low fiber diet included fruit and vegetable juices. Neither diet contained whole grain cereals nor nuts. The low fiber diet was supplemented with iron, magnesium, copper and vitamin A so that it would be equivalent to the high fiber diets in these respects. Caloric intake was adjusted by increasing or decreasing all foods the appropriate percentage so that the subjects maintained their weight throughout the experiment. The subjects fed the high fiber diet consumed about 285 mg neutral-detergent fiber per kg of body weight (compared to 50 mg in subjects fed the low fiber diet). Fecal nitrogen excretions were greater ($P<0.001$) on the high than on the low fiber diets. Fecal nitrogen excretions were 18.03 and 9.45 g over a 7-day period on the high and low fiber diets, respectively. Urinary excretions of nitrogen were not significantly different between the high and low fiber diets. Apparent digestibilities of nitrogen were significantly lower on the high fiber than on the low fiber diet and were 81.1 and 90.4% on the high and low fiber diets, respectively. Kelsay et al. (66) suggested that the depression of apparent digestibility of nitrogen may be of particular concern to those on a reducing regimen who include large amounts of fiber in the diet. Consequently, such persons should maintain an adequate protein intake.

Kies and Fox (67) investigated the effect of graded additions of hemicellulose on the protein nutritional status of 12 adult men, aged 18 to 25. The 50-day study was divided into a 2-day depletion period, a 3-day pre-adjustment period, three experimental periods of 14 days each and a 3-day post-adjustment period. During the depletion period, subjects were fed a diet that provided 0.8 g nitrogen per day. During adjustment and all experimental periods subjects were fed the same diet plus 130 ground peanuts.

This basal diet provided 6.8 g nitrogen but was adjusted in calories so that body weight could be maintained. Hemicellulose was added to the diets to provide 4.2 g during depletion, adjustment and one experimental period, 14.2 g during a second experimental period and 24.2 g during a third period. All subjects were fed all diets randomly.

Mean balances for all subjects fed diets containing 4.2, 14.2 and 24.2 g of added hemicellulose per day for the first 7 days of each period were 0.62, 0.00 and 0.11 g nitrogen and for the second 7-day period were 0.56, 1.04 and 0.10 g nitrogen per day, respectively. Regardless of whether values for the first or last seven days of each period were used, subjects retained significantly less nitrogen when fed the two higher levels of hemicellulose than 4.2 g hemicellulose. Subjects who were in strongest positive nitrogen balance showed the least change in nitrogen balance as a result of dietary hemicellulose addition. As levels of hemicellulose were increased, both urinary and fecal nitrogen values also increased. However, these differences were not statistically significant at all levels of intake. Kies and Fox (67) stated that the increased fecal nitrogen indicated that the poorer nitrogen balances achieved with higher hemicellulose intake were due primarily to interference with protein absorption. Blood urea nitrogen levels of subjects were lower while subjects were fed the experimental diets compared to levels on the basal diet. No consistent differences in blood urea nitrogen levels as a result of hemicellulose additions were noted. The researchers concluded that changes in the level of dietary hemicellulose resulted in changes in the apparent protein nutritional status. Thus, recommendations for radical changes in dietary fiber intake should be avoided unless the total effects on the physical well-being of human beings are considered.

Kies and Fox (68) also investigated the effects of cellulose, hemicellulose and pectin on protein utilization in healthy adults and adolescents in three studies of similar design. The first study (with 8 female subjects, aged 20 to 22) was 25 days in length and included an introductory 2-day nitrogen depletion period, a 3-day adjustment period and four experimental periods of 4 days each. In the second study, there were 10 subjects (8 females and 2 males, aged 10 to 52). This study was 33 days in length and included an introductory 2-day nitrogen depletion period, a 3-day nitrogen adjustment and four experimental periods of 7 days each. The third study was identical to the second study except that 8 male adolescents, aged 14 to 17, were used as the subjects. During the four randomly arranged experimental periods in each of the three studies, all subjects were fed the following dietary variations in separate periods: basal diet, basal diet plus 14.4 g hemicellulose, cellulose or pectin per day. The same basal diet was fed during the adjustment periods in the three studies and provided 6.8 g dietary fiber and 7.8 g nitrogen per day. Caloric intake was varied to meet the energy requirements of the subjects.

The results (table 5) indicated that nitrogen balances were significantly poorer in all three studies when cellulose or hemicellulose was added to the diets in comparison to the values obtained when either no supplement or pectin were added. No significant differences were found in values for the first and second studies when the adults were fed the three types of fiber supplements over no fiber supplement in the 4- and 7-day periods. Nitrogen balances of the adolescent boys were significantly more positive, regardless of dietary alterations than were balances for the adult subjects in the first and second studies. No significant changes were found in blood serum protein, blood serum albumin, blood hemoglobin, blood

TABLE 5

Comparative effects of cellulose, hemicellulose and pectin on various parameters of protein nutritional or protein utilization (68)

Parameter[a]	Mean values of subjects while receiving[b]			
	No supplement	Cellulose	Hemicellulose	Pectin
Nitrogen balance (g N/day)				
Study A	+1.10[2]	+0.82[3]	+0.74[3]	+1.09[2]
Study B	+1.22[2]	+0.97[3]	+0.86[3]	+1.31[2]
Study C	+1.91[1]	+1.36[2]	+1.38[2]	+1.83[1]
Fecal nitrogen (g N/day)				
Study A	0.97[2]	0.14[3]	1.18[3]	1.09[2,3]
Study B	0.91[1,2]	1.17[3]	1.29[3]	1.06[2,3]
Study C	0.86[1]	0.92[1,2]	1.10[2]	1.10[1,2]
Fecal nitrogen (g N/day fecal weight)				
Study A	0.0091[1]	0.0093[1]	0.0115[1]	0.0098[1]
Study B	0.0089[1]	0.0065[2]	0.067[2]	0.0072[1,2]
Study C	0.0092[1]	0.0066[2]	0.0082[1,2]	0.0097[1]
Fecal nitrogen (g N/g wet fecal weight)				
Study A	0.0025[1]	0.0026[1]	0.0022[1]	0.0026[1]
Study B	0.0021[1]	0.0030[1]	0.0013[2]	0.0018[1,2]
Study C	-	-	-	-
Urinary nitrogen (g N/g wet fecal weight)				
Study A	5.84[1]	5.95[1]	5.99[1]	5.73[1]
Study B	5.75[1]	5.74[1]	5.73[1]	5.51[1,3]
Study C	5.08[2]	5.57[1,2]	5.37[2]	5.01[1]

"cont'd.-TABLE 5"

Blood serum uric acid				
Study A	4.50[1]	4.41[1]	4.47[1]	4.49[1]
Study B	4.34[1]	4.31[1]	4.32[1]	4.36[1]
Study C	5.82[2]	5.65[2,3]	5.55[3]	5.72[2]
Blood urea nitrogen				
Study A	9.0[1]	8.2[1]	8.1[1]	7.9[1]
Study B	8.5[1]	8.8[1]	8.3[1]	7.9[1]
Study C	7.4[1]	7.9[1]	8.1[1]	7.0[1]
Blood serum total protein				
Study A	6.83[1]	6.88[1]	6.84[1]	6.81[1]
Study B	6.88[1]	6.79[1]	6.86[1]	6.99[1]
Study C	6.82[1]	6.83[1]	6.81[1]	6.80[1]
Blood serum albumin				
Study A	4.78[1]	4.76[1]	4.81[1]	4.78[1]
Study B	4.82[1]	4.85[1]	4.88[1]	4.92[1]
Study C	4.99[1]	5.03[1]	5.02[1]	4.95[1]
Blood hemoglobin				
Study A	13.4[1]	13.5[1]	13.6[1]	13.4[1]
Study B	13.0[1]	13.2[2]	13.3[1]	13.3[1]
Study C	15.2[2]	15.3[2]	15.3[2]	15.4[2]
Blood hematocrit				
Study A	39.0[1]	39.5[1]	39.5[1]	38.7[7]
Study B	38.2[1]	38.6[1]	39.2[1]	38.9[1]
Study C	44.2[2]	44.5[2]	44.3[2]	45.2[2]

[a]Values for study A are the mean value for eight adult subjects receiving experimental diets for four days; for study B they are for ten adult subjects receiving diets for seven days; and for study C they are for eight adolescent boys receiving diets for four days.

[b]Values within each parameter grouping with different superscripts are significantly different from one another at the 5% level.

hematocrit or blood urea nitrogen among the treatments in all studies. Trends towards lowered blood serum uric acid levels were found with cellulose and hemicellulose in comparison to when pectin or no supplements were used. Kies and Fox (68) stated that lowered uric acid levels may have indicated malabsorption of purines and nucleoproteins that may or may not have an adverse effect. It was concluded that both cellulose and hemicellulose tended to inhibit protein absorption which resulted in apparently poorer nitrogen balances of subjects even when consuming adequate amounts of protein. Since Americans generally consume excess amounts of protein, the possibilities of the development of protein deficiences as a result of increasing dietary fiber were slim.

The Effect of Dietary Fiber on Growth

The growth response with the addition of a purified source of cellulose to a stock diet was studied by Davis and Briggs (69) in day-old chicks over a period of 4 weeks. The chicks were fed water and feed ad libitum. The stock diet contained 64% glucose, 18% crude casein, 10% gelatin, 4% soybean oil, 6% unspecified salts, 0.3% l-cysteine and vitamins. Cellulose at levels of 0, 5, 10, 15, 20, 30, 40 and 50% were added to the stock diet at the expense of glucose. The average weight gains at those levels were 308, 354, 340, 340, 288, 268, 200 and 140 g, respectively. The addition of 5, 10 and 15% cellulose to the stock diets resulted in significantly increased growth rates compared to the other cellulose levels. Additions of cellulose at levels ranging from 20 to 50% resulted in retarded growth compared to the response on the stock ration. It was concluded that it was important to include a limited amount of cellulose in purified laboratory rations to obtain maximum growth.

Protein utilization in diets prepared from different legumes as a sole source of carbohydrates was investigated by Shurpalekar et al. (70). Forty male weanling rats, weighing 30 to 40 g, were allotted to five groups randomly and were fed the experimental diets ad libitum for 6 weeks. The diets were made adequate in all respects and contained 18% casein, 2% salt mixture, 1% vitamin mix, 10% peanut oil and 69% of either corn starch or the carbohydrate fractions of the various legumes (Bengal gram, Green gram, Red gram and Black gram). No significant differences in the growth rates of the rats fed diets containing the various leguminous carbohydrates or corn starch were observed. It was concluded that when leguminous polysaccharides were utilized as the sole source of carbohydrates in the diets of rats, a growth rate comparable to that of corn starch may occur.

Meyer (71) designed a 28-day study to investigate the effect of cellulose on protein utilization by weanling male rats fed ad libitum a stock diet supplemented with different levels of casein. The stock rations consisted of 90% sucrose, 5% cottonseed oil, 4% minerals and 1% vitamin mix. Crude casein replaced sucrose in the rations when added at levels of 6, 10, 14, 18, 22, 26, 30 and 34%. Cellulose (30% was added at the expense of the ration so that the ratio of calories to protein and other nutrients) was the same as in the control rations. The rats were divided into 16 lots. Eight lots, each containing 7 rats, were fed the stock diets. The other eight, each with 6 to 7 rats, were fed the cellulose-supplemented rations.

Average weight gains of rats fed the stock diets were 3, 31, 68, 101, 136, 140, 139 and 141 g at casein levels of 6, 10, 14, 18, 22, 26, 30 and 34% respectively. On the stock diets, the weight gains at the various levels increased up to the casein level of 22% then became constant. With 30% cellulose, the weight gains did not achieve a maximum until the 26%

casein-supplemented diet was fed. Moreover, of the diets fed, the weight gains of the rats fed the control and cellulose-supplemented rations with 6 and 10% casein were not significantly different. At all higher casein levels, the rats fed 30% cellulose gained significantly less weight than those fed the control rations. The average gains in carcass lean body mass of rats fed the control rations were 0.2, 21.3, 50.2, 79.1, 103.3, 103.1, 101.0 and 100.3 g at casein levels of 6, 10, 14, 18, 22, 26, 30 and 34%, respectively. The average gains in carcass lean body mass on cellulose-supplemented rations were -4.4, 18.2, 42.4, 55.8, 72.5, 87.5, 81.4 and 88.1 g at the respective casein levels. The data indicated that 26% casein was needed in the cellulose-supplemented rations to obtain maximum fat-free body gains while 22% casein was required on the stock diets. At casein levels from 6 to 22%, the rats fed the cellulose-supplemented rations gained significantly less lean body mass per unit of casein fed compared to the control groups, while at the higher casein levels, both groups achieved the same fat-free body gain per unit of casein consumed. Finally, average weight gains in carcass fat on the stock diets were 2.8, 6.2, 11.4, 11.9, 22.5, 27.8, 26.1 and 33.0 g at casein levels of 6, 10, 14, 18, 22, 26, 30 and 34%, respectively. Average weight gains in carcass fat on the cellulose-supplemented rations at the respective casein levels were 1.2, 6.3, 8.8, 10.1, 14.2, 19.7, 17.5 and 19.2 g. There was no significant difference in carcass fat gain for control and cellulose-supplemented rations when casein levels varied from 6 to 18%, but the rats fed the higher casein levels with cellulose had significantly less gain in carcass fat than those fed the stock diets. Meyer (71) concluded that cellulose added at the expense of the stock ration, which left the ratio of available calories to protein and other nutrients unchanged, exerted an influence other than adding

bulk to the diet. At low casein levels, decreases in fat-free body gain occurred. With cellulose in the diet, larger amounts of casein were required to obtain maximum gains of fat-free body gain allowed by the particular energy concentration.

The effect of dietary fiber on protein utilization varies among animals including man. However, many of the studies that have been conducted in this area are short term studies. More long term studies are necessary to elucidate the true effects of dietary fiber on nitrogen metabolism.

THE EFFECT OF FIBER ON MINERAL AND VITAMIN METABOLISM

Minerals are not only components of the body but their presence is required in various biochemical reactions. Certain vitamins also participate in metabolic processes, and a lack of these nutrients induce vitamin deficiency diseases. Minerals and vitamins may function synergistically in the body, for example, the roles of vitamin D, calcium and phosphorus in bone formation. Hence, it is important that there should be no interference with the absorption of these nutrients in the body. During the last decade an increase of fiber in the diet has been recommended. Selected studies on the effects of fiber on the utilization of minerals and vitamins are reviewed in the following section.

Mineral Studies

Animal Studies

Ranhotra (72) fed weanling male rats a low iron, sucrose-based diet for 5 weeks. The low iron diet was composed of 30% dried skim milk, 2.2%

vitamins, 4% corn oil, 1% sodium chloride, 1% calcium carbonate, 1% sodium phosphate, 1% trace minerals and 59.8% sucrose. The iron content was 2.5 ppm. After hemoglobin values had lowered to 6 g per dl or less, the depleted rats were divided into 12 groups. Five groups were used to establish a reference curve and were fed the low iron diet supplemented with 0, 6, 12, 15 and 24 ppm iron as ferrous sulfate. The remaining seven groups were fed the low iron diet with finely ground breads replacing sucrose to obtain 15 ppm iron. Purified alpha-cellulose or microcrystalline cellulose were added to the bread at levels of 10, 20 and 30%. A cellulose-free, iron-fortified bread diet was also included as the control. The hemoglobin repletion phase was 2 weeks. Repletion was significantly higher on the low iron, sucrose-based diet than on the bread-based diets, even though the iron content of this diet was significantly lower than the bread-based diets. Ranhotra et al. (72) stated that hemoglobin repletion on the low iron diet was most rapid because ferrous sulfate, which is high in available iron, furnished all the dietary iron. In bread-based diets, only 41 to 70% of the dietary iron originated from ferrous sulfate that was originally added to the bread. The remaining dietary iron represented naturally occurring iron in flour and in alpha-cellulose. No iron was detected in microcrystalline cellulose. Iron intake, hemoglobin and hematocrit repletion on the control diet did not differ significantly from that observed on cellulose-containing bread diets, irrespective of the level of cellulose used.

Using the depletion-repletion technique described above (72), Ranhotra (73) examined the effect of breads containing added fiber (table 6) on iron absorption in several groups of rats over a 2-week period. The relative bioavailability of iron in bread varied significantly among the breads tested and was lower for the two diet breads H and I (table 6) than the other

TABLE 6

Product Description (73)

Bread		Iron added, ppm[a]
A	Wheat flour	Ferrous sulfate, 33.1
B	Wheat flour, powdered cellulose	Ferrous sulfate, 40.6
C	Wheat flour, powdered cellulose, wheat bran, whole wheat and soy flours	Ferrous sulfate, 48.8
D	Wheat flour, powdered cellulose, wheat bran and soy flour	Not specified, 27.4
E	Wheat flour, powdered cellulose, wheat bran and soy flour	Ferrous sulfate, 51.5
F	Wheat flour, wheat bran, whole wheat flour, whole rye, flaxseed meal, soy flour	Ferrous sulfate, 37.1
G	Wheat flour, cracked wheat, wheat bran, wheat germ	Reduced, 39.1
H	Wheat, rye barley and vegetable flours	Not added, 39.8
I	Wheat and whole wheat flours; cracked wheat, rye oatmeal, soy barley and vegetable flours	Not added, 43.1
J	Whole wheat flour	Not added, 40.7

[a]In air-dried samples

breads. The magnitude of the interference was unrelated to the amount of dietary fiber in bread. Ranhotra (73) suggested that ingredients other than cellulose interfered with the availability of iron in bread.

Harmuth-Hoene and Schelenz (74) supplemented the semisynthetic diets of five groups of 12 weanling male rats with a 10% level of either guar gum, carob bean gum, sodium-alginate, agar-agar or carrageenan substituted for an equal weight of cornstarch. A control group of 12 rats were included in the study for comparison. The experiment was carried out over a period of 8 days to study the effect of these supplements on the metabolism of certain minerals. The semisynthetic diet consisted of 9% casein, 22% sucrose, 56% cornstarch, 4% corn oil, 4% cellulose, 1% vitamin mixture and 4% salt mixture. The control and experimental diets contained 5,821 to 5,388 ppm calcium, 127 to 144 ppm iron, 8.11 to 10.6 ppm zinc, 1.72 to 2.10 ppm chromium, 1.12 to 1.25 ppm copper (copper concentration of the sodium-alginate diet was 4 to 20 ppm), and 0.021 to 0.026 ppm cobalt. Dietary calcium intake was between 64 to 74 mg per day in all groups. In the control animals and those fed guar gum, carob bean gum and sodium-alginate calcium absorption was close to 60% of the intake. Agar-agar reduced calcium absorption to 50%, whereas carrageenan reduced calcium absorption to 6% of calcium intake. Consumption of sodium-alginate, agar-agar and carrageenan significantly reduced the absorption of iron from the diet compared to the other treatments. At a constant zinc intake of 100 to 107 mg per day in all six groups, guar gum, carob bean gum, agar-agar and carrageenan reduced zinc absorption significantly. Absorption of chromium in the control animals was 92% of chromium intake. The addition of indigestible polysaccharides decreased chromium absorption significantly in all groups compared to the control group. The effect was most pronounced in the animals supplemented with

sodium-alginate, agar-agar and carrageenan. The copper intake in the sodium-alginate group was not compared with the other groups because the intake on this diet was high. Copper absorption was significantly reduced from 16% in the control group to practically zero by guar gum, carob bean gum, agar-agar and carrageenan. Absorption of cobalt was reduced significantly by all five supplements compared to the control. The effect was most pronounced in agar-agar and carrageenan.

Harmuth-Hoene and Schelenz (74) conducted a longer study (21 weeks) on 24 weanling male rats fed a standard diet (Altromin No. 1320) for 10 days after which the rats were divided into a control and two experimental groups of 8 animals each. The control group was fed the semi-synthetic basal diet described previously. Guar gum or agar-agar at the 10% level was substituted for cornstarch in the experimental diets. During weeks 1, 5 and 21, 7-day balance studies were conducted. The proportion of calcium absorbed from the diet declined with increasing age of the animals in all three dietary groups. Absorption was not changed by guar gum but was slightly lowered by agar-agar compared to the control during weeks 1 and 5 and significantly reduced during the last balance period. Iron absorption was also reduced with age in all animals irrespective of dietary treatment. Compared with the control, the ingestion of agar-agar and guar gum resulted in a significant drop in iron absorption during the first balance period. During weeks 5 and 21, iron absorbed from agar-agar diets was lower than from the control or the guar gum diets. Copper absorption was marginal in the control group compared to the other groups throughout the feeding trial and never exceeded 5% of dietary intake. Supplementation with guar gum or agar-agar caused pronounced fecal losses of copper during the first balance period compared to the control. In the two following balance periods, copper intake and fecal

losses were nearly balanced in all three animal groups. Zinc absorption was markedly reduced by the ingestion of agar-agar and less by guar gum compared to the control group. Absorption of chromium was never below 77% of dietary intake in all animals. Fecal chromium excretion was increased somewhat by guar gum and more pronounced by agar-agar compared to the control indicating a lowered chromium absorption in both groups. A significant interference with cobalt absorption by agar-agar and guar gum compared to the control was observed. In the control group cobalt absorption ranged from 64 to 76%, in the guar gum group from 25 to 42% and in the agar-agar group from 40 to 55% of intake. Adaptation apparently occurred upon the continuous feeding of agar-agar and guar gum and protected the rat against massive losses of minerals and trace elements. Harmuth-Hoene and Schelenz (74) suggested that mineral supplements should be added to diets high in fiber especially for children and pregnant or lactating women since it is still not yet known whether man possesses an adaptive mechanism similar to the rat.

Gruden et al. (75) studied the effect of cellulose and zinc on ^{65}Zn absorption in infant rats. Six-day-old infant rats were divided into four experimental groups and fed artificially with 0.47 ml of the following diets marked with 2.5 µCi ^{65}Zn: normal pasteurized cow's milk containing 3 µg zinc per ml; cow's milk plus 6% cellulose; cow's milk plus 6% cellulose and 12.5 µg zinc per ml; and cow's milk plus 12.5 µg zinc per ml. After 8 hours of artificial feeding the baby rats were returned to the lactating female rats. Three and six days later the whole body activity of ^{65}Zn was determined in all animals. Compared to controls, the addition of 6% cellulose to cow's milk influenced neither the whole body nor carcass retention of ^{65}Zn. The addition of 12.5 µg zinc per ml to the milk significantly decreased both parameters by 5 to 6%. The effect was even greater (11 to 13%) in rats fed

cow's milk plus 6% cellulose and 12.5 μg zinc per ml of milk. The latter group of animals had significantly lower retentions of ^{65}Zn in liver, kidney, femur and brain than the controls. Although addition of cellulose influenced neither the whole body nor the carcass activity of zinc, it appeared to decrease tissue retention of radiozinc, the effect being significant even in the liver.

Davies et al. (76) conducted two experiments using a repletion technique to compare zinc availability from diets containing 18.5 mg zinc per kg and supplemented with bran, bran fiber or phytate. In the first experiment, 40 male rats weighing 55 to 60 g were fed a basal zinc-deficient diet for 17 days then divided randomly into five groups and fed one of the following diets ad libitum: a basal zinc-deficient diet; the basal diet supplemented with 150 g bran per kg (containing 50 g fiber, 18.5 mg zinc and 5.3 g phytate per kg of diet); the basal diet supplemented with 50 g bran fiber per kg of diet (extracted by neutral-detergent and containing most of the cellulose and hemicellulose and 18.5 mg zinc per kg); and the basal diet with 5.3 g phytate and 18.5 mg zinc per kg of diet. All dietary supplements were added at the expense of an equal weight of sucrose. After 12 days on these diets, each group was divided into two equal subgroups. One of each subgroup was offered drinking water containing 25 μg zinc per ml for a further 8 days while the remaining subgroups were maintained on distilled water. The inclusion of bran reduced growth rates by 84% compared with those of control rats fed the basal diet supplemented with zinc. These reduced growth rates were similar to those of the rats fed the zinc-deficient diets. Similarly, phytate caused a 70% reduction in growth rates compared with the controls. The growth rates of the rats fed the fiber diet were the same as those of the zinc-supplemented controls indicating that the phytate content of the bran

rather than fiber limited zinc availability.

In the second experiment, Davies et al. (76) divided 10 male rats, weighing 49 to 56 g, into two groups of 5 rats. The control group was offered the basal semi-synthetic diet supplemented with 12 mg zinc per kg. The experimental group were fed a similar diet except that pectin was added to give a dietary content of 50 g pectin per kg. Since the pectin from bran was removed by neutral-detergent extraction, the second experiment was conducted to study the effect of pectin on zinc availability. Pectin had no effect on the growth rate of the rats. Thus, none of the components of bran had any effect on the growth rate. According to Davies et al. (76) this provided further evidence that the phytate content of the bran rather than fiber limited zinc availability.

Human Studies

During a 21-day study, McHale et al (77) studied the effect of cellulose or hemicellulose on calcium and magnesium metabolism in 12 healthy subjects, aged 10 to 22 years old. The study was divided into an introductory 1-day nitrogen depletion period, a 2-day nitrogen adjustment period and three experimental periods of 6 days each. During the three experimental periods, the subjects were fed a basal diet alone or the basal diet plus cellulose or hemicellulose supplements (10 or 20 g per day). Calcium intake from supplementation and food in the diet averaged 1,562.64 mg per day during all experimental periods. Mean magnesium intake was 329.68 mg per day for all subjects. During the study, vitamins and minerals were provided to meet the daily requirements. Energy intake was adjusted to meet the individual needs of each subject.

Fecal calcium excretions of subjects fed the basal diet or the basal diet plus 10 or 20 g hemicellulose were 761.38, 1,035.73 and 798.62 mg per day,

respectively. Although not statistically significant, there was a trend toward increased fecal calcium excretion when 20 g of cellulose and 10 g of hemicellulose were fed in comparison to values when no fiber and 10 g cellulose supplements were fed. The greatest increase in fecal calcium excretion occurred with 10 g hemicellulose. There was a significantly higher urinary calcium excretion ($P<0.05$) when the subjects were fed 10 g cellulose and 20 g hemicellulose in comparison to the other fiber supplements or no supplements. Mean urinary calcium excretion on the diets with no supplement, 10 and 20 g cellulose were 75.14, 83.14 and 76.33 mg per day, respectively. Mean urinary calcium excretion with no fiber supplement, 10 or 20 g hemicellulose were 70.48, 66.44 and 87.58 mg per day, respectively. No statistically significant differences were found in calcium serum levels of the subjects as a result of variation in dietary fiber. Mean calcium serum values during the pre-study and with no supplement, 10 or 20 g cellulose were 1.097, 1.102, 1.072 and 1.065 mcg per dl, respectively. Mean calcium values during the pre-study and on no fiber supplement, 10 or 20 g hemicellulose were 1.052, 1.090, 1.058 and 1.057 mcg per dl, respectively. All subjects were in positive calcium balance during the experimental periods.

Fecal magnesium excretions of subjects fed no supplement, 10 or 20 g cellulose were 211.64, 224.46 and 264.82 mg per day, respectively. Fecal magnesium excretions while receiving no supplement, 10 or 20 g hemicellulose were 172.34, 266.47 and 224.0 mg per day, respectively. Although not significant, a trend toward increased fecal magnesium excretion occurred when 20 g cellulose and 10 g hemicellulose were fed in comparison to the other experimental diets. Fecal magnesium excretion was lowest with no supplement and highest when 10 g of hemicellulose was fed. Mean urinary magnesium

excretion on the diet with no supplement, 10 or 20 g cellulose were 136.12, 136.57 and 140.14 mg per day, respectively. There was a trend toward increased magnesium excretion with the cellulose supplements in comparison to no supplement but the increase was not significant. Compared to no supplement, there was a significantly lower magnesium excretion during supplementation with hemicellulose, the greatest effect being with 20 g hemicellulose ($P<0.01$). The mean urinary magnesium excretion values during no fiber supplement, 10 or 20 g hemicellulose were 114.91, 120.66 and 102.36 mg per day, respectively. Magnesium serum values were significantly lower ($P<0.001$) with 10 g cellulose and 10 g hemicellulose in comparison to the pre-study period, no fiber supplement, 20 g cellulose or 20 g hemicellulose supplements. Mean magnesium serum values during the pre-study, no fiber, 10 and 20 g cellulose supplementation periods were 2.045, 1.938, 1.906 and 1.940 mcg per dl respectively. Mean magnesium serum values during the pre-study, no fiber, 10 and 20 g hemicellulose supplementation periods were 1.995, 1.976, 1.879 and 1.922 mcg per dl, respectively. All but one subject was in negative magnesium balance with no fiber supplement. All subjects were in negative balance with 20 g cellulose. All but two subjects were in negative balance with 10 g cellulose. Mean magnesium balances were negative however, throughout the cellulose experimental period. Mean magnesium balances were positive with no fiber supplementation and negative with 10 and 20 g hemicellulose supplementation. All subjects except one were in negative magnesium balance with 10 g hemicellulose. McHale et al. (77) concluded that hemicellulose and cellulose supplements in the diets inhibited the absorption of calcium and magnesium. The monitoring of the intake of nutrients when fiber was included in the diet was recommended.

Seventeen lacto-ovo vegetarian adolescents who were pair-matched with 17 omnivores by age, sex and hair-type were studied by Treuherz[15]. The zinc nutritional status of both groups were compared using zinc content of hair as an index. The volunteers also completed a 3-day detailed, weighed food intake record, answered a question about food habits and provided a hair sample for analysis of zinc content. Results of hair analysis revealed that vegetarians had significantly lower levels of zinc in their hair than the omnivores ($P<0.01$). There was a significant positive correlation between hair zinc and fiber intake in the omnivores ($P<0.05$). There was slight inverse correlation between hair zinc and fiber intakes of the vegetarians.

Kelsay et al. (78) studied the effects of fiber from fruits and vegetables on calcium, magnesium, iron and silicon balances in 12 men, aged 37 to 58 years. Diets containing fruits and vegetables (high fiber diet) or fruit and vegetable juices (low fiber diet) were fed for 26 days in a cross-over design study. Both diets were virtually free of phytates. Neither diet contained whole grain cereals or nuts. Caloric intake was adjusted by increasing or decreasing all foods the appropriate percentage so that the subjects maintained their weight throughout the study. The diets contained 50% of the calories from carbohydrates, 37% from fats, and 13% from proteins. Magnesium and iron were added to the low fiber diet to make it equivalent to magnesium and iron content of the high fiber diet. The low fiber diet consisted of 4.6 g neutral-detergent fiber and 4.6 hemicellulose whereas, the high fiber diet was composed of 23.8 g neutral-detergent fiber, 11.6 g acid-detergent fiber, 4.3 g lignin, 12.3 g hemicellulose and 7.3 g cellulose.

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[15]Treuherz, J. (1980) Zinc and dietary fibre: observations on a group of vegetarian adolescents. Proc. Nutr. Soc. 39, 10A.

The mean calcium balance was positive on the low and negative on the high fiber diets. The difference between the balances was significant ($P<0.01$). Mean loss on the high fiber diet was 122 mg calcium per day, whereas on the low fiber diet the mean retention was 72 mg calcium per day. The greater loss of calcium on the high fiber diet was attributed to a significantly higher fecal calcium output (1138 compared to 827 mg calcium per day on the low fiber diet). Urinary calcium excretion did not differ significantly on the two diets. Although urinary and fecal excretions of magnesium did not differ significantly, the amount excreted was enough to result in a positive magnesium balance on the low fiber diet and a negative balance on the high fiber diet. The difference between the balances was significant ($P<0.01$). Urinary iron excretion was significantly greater on the high fiber diet ($P<0.05$), but was less than 1% of the intake on both diets. Neither fecal iron excretion nor iron balance differed significantly between the diets. Urinary silicon excretion did not differ significantly between the diets, but fecal silicon excretion was significantly higher on the high fiber diet (44.4 mg silicon per day) than the low fiber diet (12.3 mg silicon per day). Mean silicon balance was negative on both diets but significantly more negative on the high than the low fiber diet ($P<0.01$). Kelsay et al. (78) concluded that the negative mineral balances observed in their study indicated that extremely high fiber intakes are not advisable or that mineral intakes should be increased when high fiber diets are consumed.

In another study, Kelsay et al. (79) determined the intakes and excretions of zinc, copper and phosphorus for 12 men, 37 to 58 years of age, when they consumed the low and high fiber diets mentioned previously (78). In this study, copper, iron and carotene were added to the low fiber diet to make it equivalent to the high fiber diet in those nutrients. Zinc intakes

of the subjects fed the two diets did not differ significantly. The mean zinc balance was positive on the low fiber and negative on the high fiber diet. These balances differed significantly from each other ($P<0.001$). The mean retention of zinc on the low fiber diet was 3.5 mg per day. The mean loss on the high fiber diet was 0.9 mg per day attributable to a significantly higher fecal loss of 13.0 mg zinc per day. Fecal zinc loss on the low fiber diet was 9.3 mg per day. Urinary zinc losses on both diets did not differ significantly and amounted to about 3% of zinc intake. Copper intakes on the two diets were not significantly different. The mean copper balance was positive on the low fiber and negative on the high fiber diet. These balances differed significantly from each other ($P<0.005$). The mean retention of copper on the low fiber diet was 0.2 mg per day. The mean loss of copper on the high fiber diet was 0.4 mg per day. Urinary copper excretions were about 4% of intake on both diets and did not differ significantly. Fecal copper excretions were 84 and 122% of the intake on the low and high fiber diets, respectively, and the differences were significant ($P<0.005$). Phosphorus intakes were not significantly different on the two diets. Fecal excretions of phosphorus were 39 and 44% of the intake on the low and high fiber diets, respectively. The subjects had mean retentions of 361 and 292 mg per day on the low and high fiber diets, respectively. Excretions and balances for phosphorus were not significantly different between the diets. Persistence of balances of minerals due to fruit and vegetable fiber in the diet for more than 26 days was not determined. The need for controlled studies conducted for longer periods of time to determine the long-term effects of fiber on mineral balances was suggested by the researchers.

Drews et al. (80) studied the effect of dietary fiber on copper, zinc and magnesium utilization by 8 healthy adolescent boys, who participated in a 21-day study, divided into an introductory 2-day nitrogen depletion period, a 3-day nitrogen adjustment period and four experimental periods of 4 days each. During the experimental periods, the subjects were fed a basal diet or the basal diet plus 14.2 g hemicellulose, cellulose or pectin. All subjects were fed all experimental diets. Hemicellulose additions resulted in significantly higher fecal zinc excretions compared to the other fiber supplements. There was a trend toward increased fecal zinc when cellulose supplements were fed in comparison to values when no supplements were fed, but this effect was not significant. Pectin had no apparent effect on fecal zinc excretion. There was a trend toward greater urinary zinc excretion on the hemicellulose supplement but this was not significant. There was a significant decrease in zinc retention in response to the hemicellulose diet when compared to the other fiber supplements or no fiber supplement. All but one subject was in negative zinc balances on the hemicellulose diet. Mean zinc balances of subjects fed cellulose were somewhat higher than those fed hemicellulose but still were poorer compared to the period when no fiber supplements were fed. Pectin had essentially no effect on zinc retention in comparison to retention when no fiber supplements were fed. No significant differences in serum zinc values were observed among the treatments. Fecal copper excretions of the subjects were significantly higher when hemicellulose was fed in comparison to the other diets. Fiber supplementation had no apparent effect upon urinary copper excretions when compared with no fiber supplementation. Copper balances were significantly lower with hemicellulose in comparison to the other treatments. Pectin slightly lowered fecal magnesium excretion in six subjects, but this

was not significant. Fiber supplementation had no apparent effect upon urinary magnesium excretion compared with no fiber supplementation. Magnesium retention was significantly lower with hemicellulose compared to the other treatments. Cellulose had an intermediate effect compared to the other treatments but this was not significant. Highest magnesium balances were noted with pectin compared with the other treatments. No significant differences in serum magnesium values were noted among the treatments. Drews et al. (80) concluded that under the conditions of the study, hemicellulose induced significantly increased fecal zinc, copper and magnesium excretions and significantly lowered zinc, copper and magnesium retentions compared to other fibers; cellulose had a directionally similar effect, but to a lesser degree; and pectin had the least effect on mineral utilization and retention.

Heaton and Pomare (81) studied the effect of bran on blood calcium in 14 subjects, aged 36 to 63 years, 6 of which were healthy (3 males and 3 females), 2 had asymptomatic gallstones (both females) and 6 had undergone cholecystectomy at least 6 months previously and were in good health (all females). The subjects consumed their normal diets plus 18 to 100 g (median 38 g) unprocessed wheat bran per day for 4 to 9 weeks (median 5 weeks). Blood samples were taken from all subjects after an overnight fast before and after the experiment to analyze for plasma calcium and phosphate. Plasma calcium fell significantly during bran feeding (10.1 to 9.8 mg per dl). There was no appreciable change in plasma phosphate (3.3 to 3.2 mg per dl) before and after bran intake, nor in alkaline phosphatase. It was concluded that the hypocalcemic action of bran was probably attributable to interference with the intestinal absorption of calcium.

Heaton et al (82) studied the effect of changing from white to wholemeal bread on plasma calcium concentrations of 19 healthy male volunteers, aged 19 to 23 years. The subjects were fed 231 g white bread per day for 2 or 3 weeks, then the white bread was replaced with the wholemeal bread made from 100% extraction wholemeal flour for a period of 19 weeks. The intake of wholemeal bread averaged 181 g per day. The wholemeal flour contained 102 to 112 g dietary fiber per kg, expressed as unavailable carbohydrate and lignin, compared with 32 g per kg in the white flour. A control group of 16 subjects, aged 19 to 26 years, were included in the study. No significant difference between the experimental and control groups was found with respect to fasting plasma calcium. Values were 2.56 and 2.54 mmol per liter for the experimental and control subjects, respectively. Failure of a moderate intake of wholemeal bread to affect plasma calcium levels after 19 weeks suggested that calcium depletion may occur only with abnormally large intakes of wholemeal bread.

Persson et al. (83) added unprocessed wheat bran to the breakfasts of 27 healthy volunteers, ranging in age from 60 to 89 years. The 27 subjects were divided into two groups. The first group (13 subjects) were fed 10 g bran per day for 6 weeks in their normal diet. The other group (14 subjects) were fed 20 g bran per day for the same length of time. The bran contained 2.43% nitrogen, 15.19% protein, 5.26% lipid, 53.66% nitrogen-free extra substances, 8.69% crude fiber, 5.84% ash, 12.36% water, with 319 calories and 12.9 mg iron per 100 g. Although the serum calcium level was unaltered by the different bran regimens, the serum levels of ionized calcium and iron showed a significant decrease in both groups. Persson et al. (83) suggested that since the serum levels of iron and ionized calcium are often abnormally low in the elderly, the amount of bran in their diets should be monitored.

In Vitro Studies

Thompson and Weber (84) examined the binding of endogenous copper, zinc and iron in six fiber sources (wheat bran, corn bran, soy bran, oat hulls, rice bran and cellulose) via incubation under three pH conditions: pH 0.65, pH 6.8 and a sequential treatment of pH 0.65, neutralization then pH 6.8. After incubation, the samples were centrifuged at 15,000 rpm for 15 minutes. An aliquot of the supernatant was taken from each sample for mineral analysis. The pH treatments had significant effects on the binding of the endogenous minerals to the fiber sources. Most of the minerals were still bound after the pH 6.8 incubation but were released into solution after the pH 0.65 incubation. After the sequential treatment the residues had mineral contents close to those from the pH 6.8 incubation. This indicated that while the endogenous minerals were not bound at the very acidic pH, they were rebound when the pH was raised. The sequential treatment showed that the three minerals were bound differently to the various fiber sources. The very low copper and zinc levels in cellulose led to a large magnitude of error and were not included in the analysis of data. The relative amounts of each mineral remaining in the residues were as follows from lowest to highest: for copper, soy bran-oat hulls wheat bran-rice bran corn bran; for zinc, soy bran-corn bran oat hulls wheat bran-rice bran; for iron, oat hulls corn bran soy bran wheat bran-cellulose rice bran. Of the three minerals, only zinc correlated positively to protein and phytate contents. Consequently, titrations using cellulose as a non-buffering control (cellulose and no protein) were conducted.

The six crude fiber sources were first titrated and then were titrated again after an enzymatic treatment. The enzymatic treatment was a pepsin-pancreatin method which digested protein and other digestible

constituents. The fiber samples were titrated with hydrochloric acid to an endpoint of pH 2.0, and with sodium hydroxide to an endpoint of pH 10.0. The slope of the titration curves indicated buffering capacity, with the greater buffering capacity resulting in a less vertical slope. The untreated rice bran had the greatest ability to buffer the hydrogen ions and had the highest protein level of all the fiber sources. Wheat bran and soybean had protein contents similar to each other and had similar abilities to buffer hydrogen ions. All treated fiber sources had decreased 76% or more in buffering capabilities with the exception of the cellulose control which did not change. The results indicated that when protein was reduced in the fiber sources, other physiochemical properties appeared to influence the buffering capacity. Thompson and Weber (84) concluded that the binding of trace minerals by fiber sources was a complex mechanism and was not yet understood.

Ismail-Beigi et al. (85) conducted an in vitro study to investigate some of the factors determining zinc and iron binding to wholemeal bread and its constituents. In the first experiment, the effect of pH on binding of zinc by powdered Tanok and phytate-free Tanok at pH 5.0 to 7.5 was studied. Tanok is an unleavened bread made from wholemeal flour of nearly total extraction rate and is a dietary staple in rural Iran. Binding of zinc was pH-dependent in both types of bread and reached a maximum of pH 6.5 to 7.5. At pH 6.5, 54 and 88% of the zinc was bound to Tanok and phytate-free Tanok, respectively. Ismail-Beigi et al. (85) attributed the higher binding by phytate-free Tanok to its higher fiber concentration.

The effect of pH on the binding of zinc by cellulose was studied in the second experiment. Binding of zinc by cellulose was pH-dependent with maximum binding (43.8%) occurring at the highest pH value (7.5) studied.

In the third experiment, the effect of binding of zinc by various celluloses and dextrans was studied using 50 mg of various celluloses, modified celluloses and dextrans. Solutions with stable zinc concentrations of 0.13 µg per ml at pH 6.8 were used. Binding of zinc varied from 14.5% for methylcellulose to 42.7% for carboxymethyl cellulose.

In order to study the binding of zinc by various wheat bran fractions, Ismail-Beigi et al. (85) carried out a fractionation step to obtain hemicellulose A, B, and C and lignin. Samples (50 mg) of these fractions and washed bran were tested for their capacity to bind zinc at pH 6.8. The concentration of stable zinc was 1.43 µg per ml. Washed bran and the bran components, lignin and hemicellulose fractions A and C had high binding capacities, while hemicellulose fraction B had the lowest affinity of the fractions studied.

The last experiment was a study of the binding of ferrous iron by bran and hemicellulose fraction A. Samples (50 mg) were incubated in solutions containing 0.5, 1.0 and 2.0 µg ferrous sulfate per ml. Ascorbic acid (0.1 ml of 1.0% solution) was added to each solution to maintain the iron in the ferrous state. Various control tubes containing the same iron concentrations without solids were included. Both bran and hemicellulose fraction A exhibited high iron-binding capacity. The percentage bound decreased as the iron concentrations were raised. Ismail-Beigi et al. (85) stated that it was difficult to assess the interference of bran on intestinal absorption of divalent metal ions based on their in vitro data. However, the binding of a portion of dietary zinc, iron and calcium by wheat fiber may help explain why deficiencies of these minerals were prevalent in rural areas of Iran and other Middle Eastern countries.

Vitamin Studies

Vitamin A

Phillips et al. (86) studied the effects of dietary pectin on the utilization of vitamin A and carotene in the rat. Weanling male rats were fed ad libitum either a ground cube diet with 3% added corn oil or a vitamin A-free, semipurified casein-sucrose diet. Three experiments were conducted. In the first experiment, weanling rats were fed the casein-sucrose diet containing supplemental vitamin A (3,000 µg vitamin A alcohol per kg diet) with 1% cholesterol, 3% pectin or both incorporated for 18 days. Liver storage of vitamin A was significantly reduced by dietary cholesterol. Pectin, however, did not significantly influence liver vitamin A levels regardless of cholesterol intake.

In the second experiment, 3% pectin was incorporated into the ground cube diet in which vitamin A activity was derived from both carotenoids (4,000 ug beta-carotene per kg) and preformed vitamin A (2,000 µg per kg). This diet or the control ground cube diet without pectin was fed for 21 days. Total liver vitamin A was not significantly influenced by pectin.

In the third experiment, male weanling rats were divided into two groups and fed the vitamin A-free, casein-sucrose basal diet or the basal diet with 2% pectin. After 20 days feeding, 10 animals in each group were dosed by stomach tube with 537 µg vitamin A acetate in 0.5 ml of cottonseed oil, while an additional 10 animals in each group were dosed with 5.4 mg beta-carotene in 0.5 ml cottonseed oil. Forty-eight hours after dosing, the animals were sacrificed and liver vitamin A was determined to study the effect of pectin on the utilization of vitamin A or beta-carotene from a single oral dose. The 20-day predosing feeding period reduced liver stores of vitamin A to negligible amounts. The oral administration of either

vitamin A or carotene produced significant liver stores of vitamin A. The feeding of 2% pectin did not affect the resulting liver stores. Thus, there was no effect on the utilization of either vitamin A or beta-carotene. Phillips and Brien (86) concluded that the mucilaginous polysaccharides had hypocholesterolemic activity in the rat without the adverse effect of limiting absorption of vitamin A or the utilization of the provitamin, beta-carotene.

Kaspar et al. (87) studied the effects of various sources of dietary fiber on vitamin A metabolism in 11 normal female subjects, aged 19 to 22 years. Serum vitamin A concentration in each subject was determined. Postprandial serum A concentration was measured 3, 5, 7 and 9 hours after the oral administration of 300,000 IU vitamin A-palmitate dissolved in 2 ml peanut oil. The vitamin A was given with a formula diet containing 30 g protein, 19 g fat and 75.4 g carbohydrate. The diet provided approximately 615 kcal. The formula diet was prepared from milk protein, corn oil, an oligosaccharide and water, and contained additional orange juice to improve the taste. The volume of the test diet totaled 375 ml. During the experimental period, the subjects were not permitted any further intake of food or fluid. The experiments were repeated 8 times at intervals of 10 days using the same subjects each time. Each experiment was conducted twice under otherwise constant conditions, without the addition of fiber to the formula diet (controls) and once with the addition of, respectively, 40 g wheat bran, 40 g microcrystalline cellulose, 15 g apple pectin, 15 g guar flour, 15 g carob bean flour and 20 g carrageenan.

When vitamin A was fed together with one of the fiber preparations (figure 4) all concentrations of vitamin A exceeded or equaled those obtained in the two control trials. The data obtained (figure 6) indicated

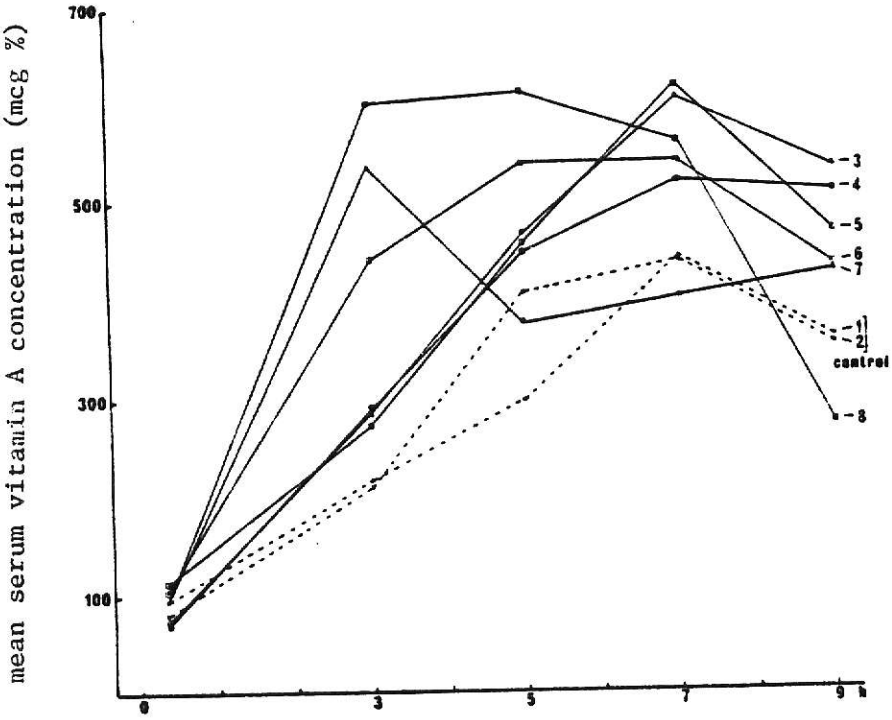

Fig. 4 Mean postprandial serum vitamin A concentration curves; 1 and 2 = controls, 3 = wheat bran, 4 = microcrystalline cellulose, 5 = carrageenan, 6 = carob bean flour, 7 = pectin, 8 = guar flour. (87)

that when the vitamin was administered with the dietary fiber preparations, the mean postprandial vitamin A concentrations equaled those obtained in two control tests or were significantly higher. When vitamin A was administered with guar flour and apple pectin 3 hours after starting the experiment, the mean serum vitamin A concentration was significantly higher than in the controls. Figure 5 depicts the area under the serum vitamin concentration curve which was taken as a measure of the amount of vitamin A absorbed. The area under the serum vitamin A concentration curve was significantly increased in all dietary fiber preparations studied, as compared to the controls. Kaspar et al. (87) concluded that under the experimental conditions, dietary fiber promoted the absorption of vitamin A in man.

Barnard and Heaton (88) measured serum vitamin A levels in 14 healthy volunteers of both sexes, aged 19 to 28 years, who acted as his or her own control during an experiment of vitamin A absorption. Fourteen subjects were fed a control diet containing 5,000 IU vitamin A per kg body weight, 0.5 g per kg Casilan, 0.5 g per kg glucose and 5 g per kg water. These subjects also were fed the same diet with 12 g cholestyramine (a resin). Twelve of the subjects also were fed the control diet with 12 g lignin.

In most subjects fed a control test meal the peak serum vitamin A level was observed at 5 hours, but in a few cases this occurred at 4 or 6 hours after ingestion of the meal. The timing of the peak was unchanged when lignin or cholestyramine was added to the test meal. The mean increase in serum vitamin A concentration after an intake of the control diet with cholestyramine in the 14 subjects was 40.7% of the increase for the control diet without cholestyramine ($P<0.001$). Thus, cholestyramine markedly reduced vitamin A absorption as assessed by the vitamin A tolerance test. It acted presumably by removing bile acid from solution and so prevented the

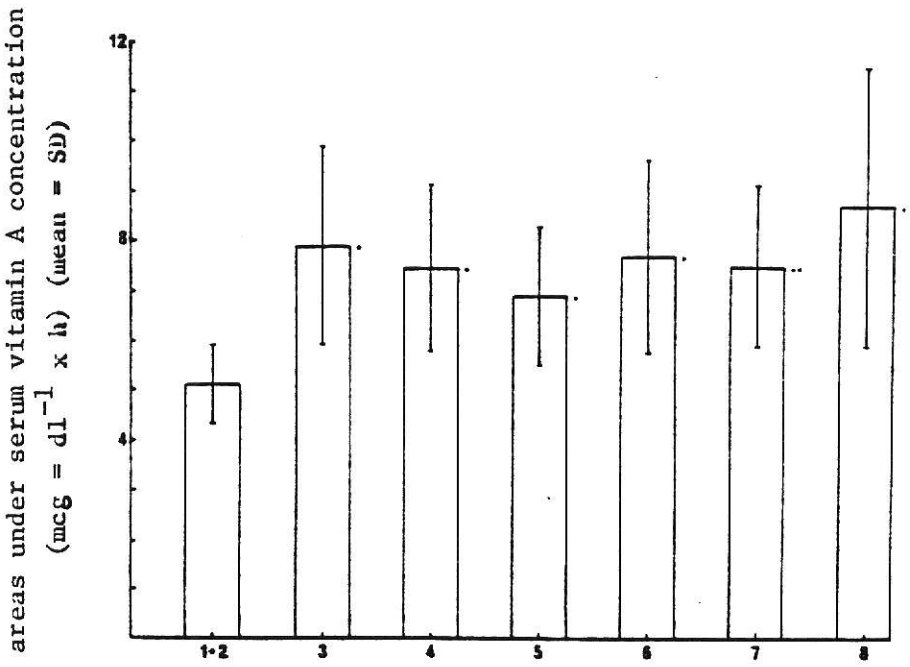

Fig. 5 Area under serum vitamin A concentration curves (mean$\pm$SD); 1 and 2 = controls, 3 = wheat bran, 4 = microcrystalline cellulose, 5 = carrageenan, 6 = carob bean flour, 7 = pectin, 8 = guar flour. *P<0.05; **P<0.025. (87)

formation of a micellar phase in the lumen of the small intestine. Barnard and Heaton (88) postulated that cholestyramine also impaired the absorption of the other fat-soluble vitamins D, E and K. The mean increase in serum vitamin A concentration after an intake of the control diet with lignin in the 12 subjects was 93.2% of the control test increase. This was not significantly different. Thus, lignin had no significant effect on the rise in serum vitamin A concentration. Barnard and Heaton (88) concluded that lignin did not bind conjugated bile acids in vivo to an important extent.

The Vitamin B Complex

Leklem et al (89) studied the bioavailability of vitamin B-6 in diets containing either 570 g whole wheat bread, 600 g white bread or 600 g vitamin B-6 enriched white bread in 9 healthy college men, aged 21 to 32 years of age. The experiment was based on a 3x3 Latin square design. The three experimental periods of 1-week each were preceded by 6 days of adjustment. Bread was gradually increased in the diet and meat and cheese eliminated during the 6-day adjustment period. The vitamin B-6 content of the three types of bread was 1.20, 1.18 and 0.35 mg in whole wheat, enriched white and white bread, respectively. The level of vitamin B-6 in the basal diet used throughout the study was 0.38 mg. An oral dose of the vitamin that was fed with the unenriched white bread provided 0.81 mg vitamin B-6. The total daily intake of vitamin B-6 was 1.5 mg. Although the dietary fiber content of the bread and basal diet were not measured by chemical analyses, Leklem et al. (89) estimated that the whole wheat bread contributed 48 g of dietary fiber per day as compared to 16 g per day for the white bread. Pyridoxine was found to be the predominant form of vitamin B-6 in the total diet, followed by pyridoxal and a small amount of pyridoxamine. All three diets were generally comparable with respect to the proportion of the

three forms of vitamin B-6.

Fecal vitamin B-6 excretion was significantly higher ($P<0.01$) when whole wheat bread was fed compared to when the other two breads were fed. Fecal vitamin B-6 values were 28.4, 18.3 and 17.7 mmoles fecal vitamin B-6 per week. No significant difference was noted between the urinary excretion values for total vitamin B-6 when the three breads were fed. Values of 0.74, 0.76 and 0.74 moles urinary total vitamin B-6 per week were observed. With the exception of two subjects, all subjects excreted a lower level of urinary 4-pyridoxic acid when they were fed whole wheat bread than when enriched white or white bread was fed. This difference was not significant. Values observed were 3.40, 3.89 and 3.91 μmoles urinary 4-pyridoxic acid per day on the whole wheat, vitamin enriched and white breads, respectively. There was only a slight difference in the overall means of the plasma vitamin B-6 and pyridoxal phosphate values for the 9 subjects fed the various types of breads. The means for whole wheat bread were slightly lower as compared to the means of the other two breads. These differences were not significant. Values observed were 3.07, 3.36 and 3.55 nmoles plasma pyridoxal phosphate per dl and 4.37, 4.72 and 4.70 nmoles plasma total vitamin B-6 for the whole wheat, enriched white and white breads, respectively. Leklem et al. (90) concluded that the bioavailability of vitamin B-6 from whole wheat bread was less than that from unenriched or pyridoxine-enriched white bread and oral pyridoxine.

Folate deficiency is a relatively uncommon disorder in central Iran. Russell et al. (90) conducted in vivo and in vitro studies using three Iranian breads because breads are staple foods in Iran to explain this observation. Four normal volunteers underwent serial folic acid absorption tests using 12.5 μCi tritiated pteroylmonoglutaminic acid (^{3}H-PGA) per

200 μg in the fasting state or with ^{3}H-PGA given orally halfway through low and high fiber meals. The low fiber meal contained 2.3 g acid-detergent fiber and was composed of 175 g white bread with 150 g peeled orange, 240 g milk and 10 g sucrose. The high fiber meal contained 8.2 g acid-detergent fiber and was composed of 175 g Tanok, substituted for white bread in the low fiber diet. No changes in folate absorption between the low and high fiber bread meals were observed. Although PGA absorption was lower in all subjects when tested with meals as compared to the fasting state, the changes were not significantly different.

The ability of Tanok and Bazari to remove folic acid solution in vitro was investigated by Russell et al. (90) by placing pulverized bread in each of 6 tubes containing 5 ml of 0.1 M sodium phosphate buffer, pH 7.4. Tritiated pteroylmonoglutaminic acid, ^{3}H-PGA (0.00g μg) was placed in the first tube and the amount was doubled in each subsequent tube, so that the sixth tube contained 0.16 μg of ^{3}H-PGA. Control tubes containing buffer and ^{3}H-PGA without bread were used for comparison. After centrifugation, 1 ml of supernatant was removed and counted in 15 ml of Bray's solution. A difference in radioactivity between the supernatants of control tubes and bread-containing tubes was taken as evidence of adsorption of folic acid by precipitated bread. Virtually 100% of the added radioactivity was recovered in the supernatant of all experimental samples compared to the control. Thus, there was no evidence of removal of PGA from solution by Bazari and Tanok in vitro and there was no decrease in folic acid absorption in vivo when ^{3}H-PGA was administered with breakfasts of increasing fiber content.

Cullen and Oace[16] studied the rate of B-12 depletion in groups of 6

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[16]Cullen, R. W. & Oace, S. M. (1977) Cellulose and pectin enhance B-12 depletion in rats. Fed. Proc. 36, 1118.

rats assigned to B-12 deficient diets containing no fiber or diluted to contain 10 to 50% cellulose or 5 to 30% pectin. Body weight, food intake and methylmalonic acid (MMA) excretion were monitored throughout the study. After 10 weeks, MMA excretion was increased slightly among cellulose groups and dramatically among pectin groups. Average excretions in μmoles MMA per mg creatinine for representative groups were approximately 15 (no fiber); 21 (40% cellulose), 31 (50% cellulose); 122 (5% pectin); 165 (10% pectin); and 300 (15% pectin). Rats fed 30% pectin suffered inanition and were changed to no fiber diets at 3 weeks. At 10 weeks, this group excreted 117 μmoles MMA per mg creatinine indicating that pectin was elevating MMA by a direct precursor effect. MMA excretion of 40% and 50% cellulose groups continued to increase and was not depressed by 0.5 μg B-12 to the extent that this dose suppressed MMA in no fiber rats. After intraperitonel injection of 1 μCi of ^{57}Co B-12, pectin rats excreted over twice as much isotope in their feces as no fiber rats in 3 days). Thus, pectin appeared to interfere with enterohepatic recycling of B-12. Both cellulose and pectin enhanced the rate of B-12 depletion but to different degrees.

The studies reviewed in this section indicate that mineral balances as well as serum and plasma levels of minerals may be sensitive to intakes of dietary fiber. Few studies have been conducted on the effects of dietary fiber on vitamin metabolism. Not all of the vitamins have been studied, and results are conflicting in the studies that have been reported. More research is necessary in this area. Until such research is completed, the intake of excess dietary fiber should be avoided or monitored closely.

THE EFFECT OF DIETARY FIBER IN BOWEL DISEASES

Many studies suggest that the consumption of Western-type diets characterized by a high percentage of animal fat and protein are responsible for the etiology of noninfectious bowel diseases primarily the irritable bowel syndrome, diverticular disease and colon cancer. Diverticular disease has been treated successfully using high residue diets. However, the effect of dietary fiber on the irritable bowel syndrome and intestinal carcinoma has not been established. This section is a review of selected studies conducted in this area.

The Effect of Dietary Fiber on The Irritable Bowel Syndrome

The effects of wheat bran on symptoms of irritable bowel syndrome were investigated by Søltoft et al. (91) in 59 outpatients with the disorder. The 38 female and 21 male subjects ranged in age from 18 to 73 years and were assigned randomly to an experimental or a control group. The patients in the experimental group were fed 3 biscuits daily each containing 10 g wheat bran, whereas the patients in the control group were fed wheat biscuits of a similar appearance. The treatment period was 6 weeks. Only 52 patients participated in the entire study. Of these, 19 women and 10 men were in the treatment group and 5 women and 8 men belonged to the placebo group. Fiber supplementation compared to the control had no demonstrable effect on the number of bowel movements, the consistency of the stools and the occurrence of borborygmi and abdominal distension. It was concluded that the results of the trial did not support the routine use of bran in the irritable bowel syndrome.

Manning et al.[17] compared the effects of two diets one low (14 subjects) and the other high (12 subjects) in cereal fiber on the irritable bowel syndrome for 6 weeks. Symptoms were consistently affected by the high fiber diet only. The number of days that the subjects suffered from abdominal pain was reduced from 46.8 to 34.9 ($P<0.05$) on the high fiber diet. Colonic motility was significantly reduced only on the high fiber diet. Passage of radioopaque pellets was accelerated by the high fiber diet but only in those with initially slow transit times. It was concluded that a high cereal fiber diet was of therapeutic value in the irritable bowel syndrome.

Fielding and Melvin (92) assessed the dietary fiber intake of 25 patients (16 females and 9 males) with the irritable bowel syndrome before onset of symptoms; between onset of symptoms and diagnosis; and over the 6 months following diagnosis. The dietary intake at diagnosis was compared with that of 25 controls matched for age, sex and eating habits. Dietary assessment was based on recall of intake over 1 week. Before the onset of symptoms, the female patients had a mean intake of 18.7 and the male patients consumed 22.8 g dietary fiber per day. Following the onset of symptoms, fiber consumption fell for the group (for the females, to 15.8 g and for the males 21.4 g) but this decrease was not statistically significant. Six months after treatment began, the dietary fiber intake of the patients was not significantly different from the controls. The 20 patients who had improved by 6 months had significantly increased their intake of dietary fiber to at least 15 g daily. Of 5 patients who had not improved, 4 were taking less than 15 g dietary fiber per day and had not

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[17]Manning, A. P., Heaton, K. W., Harvey, R. F. & Uglow, P. (1976) Cereal Fibre and the irritable bowel--a controlled trial. Gut 17, 822-833.

altered their intake significantly. The study indicated that after onset of symptoms, patients with the irritable bowel syndrome ingested less dietary fiber than healthy controls even though no association between any one food and symptoms were found. Following a diagnosis a significantly greater increase in the intake of dietary fiber was achieved by those who improved compared with those who did not.

The Effect of Dietary Fiber on Diverticular Disease

Brodribb (93) assessed the therapeutic value of increasing the daily dietary fiber intake on symptomatic diverticular disease in a 3-month double-blind controlled study. The 18 subjects with the disorder who were included in the study were told to eat 9 slices of crispbread daily instead of bread in addition to their normal diet. The subjects then were fed either wheat or bran crispbread. Nine slices of wheat crispbread supplied 0.6 g dietary fiber while the same amount of bran crispbread supplied about 6.7 g dietary fiber per day. None of the patients found the crispbread unacceptable. Assessment was undertaken via interviews and questionnaires. Significantly greater symptomatic relief occurred in those subjects fed the high fiber regimen than the control. The effectiveness of the high fiber diet also increased over the 3-month period. It was concluded that increasing fiber intake had therapeutic value in the treatment of diverticular disease.

Taylor and Duthie (94) compared the effectiveness of three dietary treatments in 20 subjects with symptomatic diverticular disease. The treatments consisted of a high roughage diet with bran supplements, a bulk laxative (Normacol plus an antispasmodic) and regular quantities of bran in the form of bran tablets. Each bran tablet contained 2 g bran and 9 tablets

were prescribed each day in divided doses. All patients were allocated randomly to a treatment; half were fed either the high roughage diet or Normacol and the other half, the bran tablets for a period of 1 month. Treatments were crossed over for another month. All patients experienced some improvement in symptoms with each treatment. After the high roughage diet 20% were entirely symptom-free, 40% after Normacol and 60% after bran tablets. Mean stool weight before treatment was 79 g. On both Normacol and bran tablets, stool weight increased significantly (105 and 121 g, respectively, compared to the control value) after 1 month. Stool weight also increased on the high roughage diet but this was not significantly different from the control value. Mean transit time was 96.6 hours which decreased significantly by all three treatments (76.4 hours on the high roughage diet, 71.7 hours on Normacol and 56.1 hours on bran tablets). Bran tablets proved more effective than either Normacol ($P<0.05$) or the high roughage diet ($P<0.001$). The mean percentage motility (the percentage of recording time that pressure waves were present in the colon) before treatment was 14.2%. Bran tablets reduced the intracolonic pressure activity to within normal limits (6.5%) whereas, neither the high roughage diet nor Normacol had any statistically significant effect in reducing intracolonic pressure. An abnormal rapid electrical rhythm in colonic smooth muscle was found initially in 80% of the patients but the incidence was reduced after each treatment. The electrical activity occurred in 50% of the patients consuming the high roughage diet, 60% on Normacol and 40% on the bran tablets. It was concluded that bran proved to be the most effective treatment of the three tested. Moreover, Taylor and Duthie (94) stated that their results indicated that all indices of colonic pathophysiology in diverticular disease could be restored to normal.

Consequently, their study supported the theory that diverticular disease resulted from a normal colon being subjected to abnormal dietary stress rather than from a primary or constitutional colonic abnormality.

Brodribb and Humphreys (95) compared the actual fiber intake of 40 subjects (10 men and 30 women, ranging in age from 25 to 85) with diverticular disease with that of 80 age- and sex-matched controls. Dietary assessment was based on the eating habits of the subjects. The mean crude fiber intake for the patients with diverticular disease and the controls were 2.6 and 5.2 g per day, respectively, the difference being statistically significant. The incidence of hemorrhoids, varicose veins, haitus hernias, gallstones and abdominal hernias was significantly higher in the experimental than in the control group. It was concluded that the results obtained support the hypothesis that a fiber-depleted diet was a causative factor in diverticular disease and was also associated with several other conditions.

In a second study, Brodribb and Humphreys (96) investigated the effect of bran on diverticular disease in the 40 patients described above. The patients consumed about 24 g wheat bran per day in addition to their normal diets for at least 6 months. It was observed that all subjects tolerated the bran. The symptoms of diverticular disease were improved with bran supplementation in 33 patients, slightly improved in 2 patients while 5 still had troublesome symptoms. Most of the subjects initially complained of many symptoms (averaging nearly 10%) before bran supplementation. After the intake of additional bran, 60% of all symptoms were abolished and a further 28% was relieved. All types of abdominal pain were relieved. Nausea, vomiting and flatulence were much improved after treatment. After treatment, the intestinal transit times decreased in patients whose initial times were

slower than 60 hours and decreased in those whose transit times were faster than 36 hours. Stool weight increased significantly with bran compared to no fiber supplementation. The number of intracolonic high pressure waves decreased especially during and after eating. Barium enema studies showed less spasm in 8 patients and no diverticula in 3 after bran was added to the normal diets. It was postulated that a high fiber diet might protect against the development of diverticular disease as well as relieving the symptoms associated with the disorder.

The Effect of Dietary Fiber on Colon Cancer

Intestinal Microflora

Drasar et al. (97) stated that colon cancer occurs primarily in industrialized countries especially Western Europe and North America. On the other hand, the incidence of sigmoidal and rectal carcinomas is low in Africa, Asia and most of South America. A Western diet, high in animal protein and saturated fat has been implicated in the etiology of these diseases. Microflora are thought to produce carcinogens or co-carcinogens in the intestine by using bile salts as a substrate. The issue of whether or not intestinal bacteria and/or a lack of dietary fiber are the primary cause(s) of the pathology of intestinal carcinoma has yet to be resolved.

Animal Studies

Araujo and Norden (98) measured the response of aerobic microflora in the gut of mice to dietary sucrose, starch and cellulose. Mice, 8 weeks of age, were distributed among the various dietary groups (4 mice per group) in such a manner that litter mates were not fed the same diet. The mice were fed stock diets containing 77% starch or 77% sucrose. Cellulose at a level

of 10% was added to the diets of 2 mice in each group. After a 3-week feeding period, the mice were sacrificed and the microflora of the intestinal tracts was sampled. Counts obtained from mice on either the sucrose or starch diets were not significantly different from each other. The addition of cellulose to these diets resulted in a greater drop in the number of bacteria found in the intestines of the animals fed the sucrose diet compared to those fed the starch diets. These differences were less noticeable with tests for coliform and streptoccal bacteria. It was concluded that several organisms apparently did not thrive in the environment produced by the addition of fiber in the diet.

The bacterial enzymes azoreductase, nitroreductase and beta-glucuronidase are implicated in the etiology of colon cancer. The effect of a high beef diet and advanced age on these enzymes produced by intestinal microflora were investigated by Goldin et al. (99). Ten to twenty male rats, weighing 120 to 150 g, were used in each experiment. The rats were fed a grain diet for 3 to 5 weeks then a high beef diet for about the same length of time. The grain diet contained the following components (percent by weight); casein (5.0), lactoalbumin (10.5), whole wheat flour (31.0), ground corn powder (31.5), alfalfa leaf meal (2.0) and vitamin and mineral salts (5.5). The beef diet contained beef with 15 to 20% fat (72.0), dextrose (11.0), sucrose (11.0) and vitamin and mineral salts (6.0). After each feeding trial, the activities of the bacterial enzymes were measured in the feces of these animals. Enzyme levels remained relatively constant during the period the animals were fed the grain diet. When the animals were fed the beef diet, there was a rapid increase within 20 days in the levels of the enzymes. The magnitude of the increase was approximately 2.5 times the level on the grain diet for beta-glucuronidase, 2.0 for nitroreductase and

1.5 for azoreductase. These differences for the enzyme levels on the enzyme levels on the high beef diet were statistically significant.

Another group of rats was studied by Goldin et al. (99) in order to investigate the effect of age on the enzyme activities of fecal flora. The rats were fed either the grain or beef diet continuously for an extended period. The beta-glucuronidase activity of grain-fed rats was followed for 13 months. The activity of this enzyme remained relatively constant for the first 22 weeks then increased by 1.5 from 8 to 13 months of age. The levels of nitroreductase was dramatically increased with advancing age in grain-fed animals. Beta-glucuronidase activity in the rats fed the meat diet was considerably higher in older rats compared to younger rats, and remained two-fold higher in the older animals throughout the remainder of the feeding trial. Nitroreductase and azoreductase activities were relatively constant in the rats fed the beef diet throughout the experiment. When the grain-fed and beef-fed rats were compared with each other, nitroreductase activity was higher and azoreductase activity was slightly higher in the older animals fed the grain diet. It was concluded that the metabolic activity of the intestinal microflora in rats was influenced by diet and age. The increased risk of developing cancer in the beef-fed rats (compared to the grain-fed rats) was related to the elevated levels of the enzymes early in life of these animals.

Human Studies

The effect of bran and wheat germ supplementations on the activities of beta-glucuronidase, nitroreductase and azoreductase on the fecal flora of 9 adult subjects was investigated by Goldin et al (99). The 16-week study was divided into 5-week pre- and posttrial periods in which no additional fiber

was added to the normal diets and a 6-week experimental period in which 30 g of either wheat germ (5 subjects) or wheat bran (4 subjects) were added to the diets. Fecal specimens were collected weekly throughout the experiment and were analyzed for beta-glucuronidase, nitroreductase and azoreductase. No significant difference in beta-glucuronidase activity was observed in the presupplemental fiber and postfiber periods, nor did subjects consuming bran as opposed to wheat germ show significant differences in enzyme levels. No significant differences were noted in fecal nitroreductase and azoreductase activities after the introduction of supplements of either bran or wheat germ to the normal diets. It was concluded that wheat bran and wheat germ had no effect on the three enzymes studied. However, Goldin et al. (99) cautioned that their subjects ate significantly less beef than the general American population (360 versus 750 to 960 g red meat, respectively). Thus, the data obtained may be a result of initial low levels of beef consumption.

Drasar et al. (97) investigated the effect of bran on the fecal flora of 4 healthy male subjects, aged 22 to 25 years. During the 3-week pretest period, the subjects were fed a basal low fiber diet providing 2,902 kcal and containing 351 g carbohydrate, 122 g fat and 88 g protein. The fiber content of the basal diet was increased by 36 g dietary fiber during a subsequent 3-week period by substituting an equal weight of wholemeal bread for white bread (120 g), All Bran for cornflakes (25 g), bran biscuits for Nice biscuits (52 g) and by adding 30 g bran (Allison's Bran Plus). The high fiber diet provided 2,775 kcal as 330 g carbohydrate, 115 g fat and 97 g protein. Stool specimens were collected throughout the study and for an additional week thereafter for bacteriological analysis. When feces from the high and low fiber periods were compared, there were no significant changes in the concentration of bacteria in the bacterial groups even though

there was a slight increase in total output of bacteria associated with increased fecal weight. Non-spore-forming anaerobic bacteria were the predominant microorganisms isolated from the feces of the subjects. The concentration of fecal beta-glucuronidase was assayed in 2 subjects and was observed to be unaffected by the change in fiber levels. It was concluded that a brief change in fiber levels of the diet had little effect on the homeostasis of the bowel.

The effects of various dietary supplements on fecal bacteria were studied by Drasar et al. (100) in 10 healthy male students, aged 22 to 25 years. All subjects were fed their normal diets. Various supplements were added randomly one at a time, to the normal diets of the subjects. All subjects did not eat all the diets. Instead, the subjects were divided into two groups. The first group consisted of 4 subjects. All four were fed 35 g pectin; three were fed 35 g guar gum and 1,000 g plantains; and two were fed 1,000 g bananas per day. The second group was composed of 6 subjects, all of whom were fed 60 g each of medium chain triglycerides and olive oil; and two were fed 1,000 g each plantains and bananas per day. All stools passed during the last week of each 2-week dietary period were collected for bacterial assay. Compared with the control values, the addition of guar gum, pectin, medium chain triglycerides, olive oil, bananas and plantains had no significant effect on the concentration of the groups of bacteria in the feces. It was concluded that the data obtained tended to confirm the hypothesis that bowel cancer is caused by carcinogens produced by intestinal bacteria from bile acids. This process was thought to be under dietary control.

Gastrointestinal Carcinoma

The relationship between gastrointestinal cancer and nutrition was investigated by Gregor et al. (101). They examined standardized rates for cancer of the stomach and intestine and data on the intake of nutrients in 28 countries including the United States. There were significant correlations between the intake of animal protein and the mortality rates for gastric and intestinal cancer. The higher the food intake, the lower the gastric cancer mortality rate but the higher the intestinal cancer rate. It was cautioned that the data could not be interpreted as indicating that food intake had a direct effect on the development of gastrointestinal cancer.

Lyon and Sorenson (102) examined the data on colon mortality in Utah, a state whose population is predominantly Mormon. Utah state law requires that all cancer cases, except skin cancer other than melanoma, should be reported to the Utah Cancer registry. Mormon doctrine prohibits the use of alcohol, tobacco, coffee and tea, and recommends moderate consumption of meats. For the years 1950 to 1969, the state population had 34% fewer deaths from colon cancer compared to the average United States population. The 1970 population of Utah was 1,059,273, 72% of whom were Mormons. Colon cancer incidence during 1966 to 1970 both for the state and for a large subgroup of Mormons (10,605) who abstained from tobacco were also compared with the United States population. The incidence of colon cancer of Mormons was 36 to 38% below the average of the United States while that of non-Mormon males was 28% and non-Mormon females was 8% below the United States average. The rural areas of Utah had lower rates of colon cancer than urban areas. However, while non-Mormons had higher rates of colon cancer in the urban areas, Mormons did not. A preliminary dietary survey

found no significant differences in meat, fat and fiber consumption between the population of Utah and that of the United States as a whole. It was concluded that the results obtained did not support the hypothesis relating these dietary components to colon cancer.

The International Agency for Research on Cancer Intestinal Microecology Group (103) conducted a survey on population samples from two areas of Denmark and Finland (Copenhagen and rural Kuopio, respectively) with a four-fold variation in the incidence of colon cancer. The surveys were done in the spring and autumn of 1975 in each population. In both Copenhagen and Kuopio, registers of the population were used for random selection in each season of approximately 30 males, aged 55 to 64 years, who had been residents for at least 10 years. Diet, transit time, fecal bacteria and fecal steroids were studied in both seasons, while consumption of dietary fiber was measured in the autumn study only. It was found that the Danish subjects consumed more ($P<0.05$) white bread, meat (mainly pork), beer, wine and spirits and less potatoes and milk than Finns. The diets of the Finns was composed of more fat, protein and energy than the diets of the Danes. The differences for protein and energy were significant ($P<0.001$). The higher energy intake in Kuopio was consistent with greater physical activity. Moreover, the sources of fat and protein were different, a greater proportion coming from meat in Copenhagen. The intake of dietary fiber was higher ($P<0.001$) in Kuopio (30.9 g) compared with Copenhagen (17.2 g). There were no significant differences in the use of laxatives or frequency of defecation although constipation was more of a problem in the Danish sample compared to the Finnish sample (27 and 12%, respectively). There were no significant differences in transit times of the stools between the two populations. Mean stool weights in Copenhagen were 157 g in the spring and

146 g in autumn while those in Kuopio were higher, 175 g in the spring and 211 g in the autumn. The difference in the autumn stool weights of the two samples was significant. The Danish population had a significantly higher count of Bacteroides and a lower count of Eubacteria in the feces than the Finnish population. The Finnish population had significantly higher counts of Enterococci and Streptococci in the feces than the Danish population. There were no significant differences in fecal steroid concentrations. Steroids are thought to be implicated in the production of carcinogens by nuclear dehydrogenating clostridia. It was concluded that the etiology of colon cancer may be multifactorial and not associated in a simple manner with fecal steroids.

The beneficiary role of dietary fiber in diverticular disease has been established whereas, in the irritable bowel syndrome it is still debatable. On the other hand, the etiology of colon cancer may be multifactorial and may not be related solely to a lack of dietary fiber in the diet.

SUMMARY

Dietary fiber includes various components of plant cell walls. Determination of fiber content of food by extraction and fractionation methods underestimate the total fiber content. Recently, acid- and neutral-detergents have been developed for use in fiber analysis. Enzymatic methods have been proposed but have not yet gained acceptance for routine use.

Each type of fiber has its own water holding capacity and effect when passing through the gut. Intake of dietary fiber results in decreased transit time and increased fecal bulk, both desirable laxative effects.

Consequently, dietary fiber has been used in the treatment of constipation. Dietary fiber also increases the excretion of fecal volatile fatty acids, thereby lowering stool pH. In addition to these effects however, dietary fiber influences the metabolism of nutrients and the incidence of certain gastrointestinal diseases.

Dietary fiber reduces plasma glucose levels in healthy and diabetic subjects and is a promising adjunct to insulin, oral hypoglycemic agents and controlled diets that are used in diabetic therapy. Conflicting results have been reported for the effect of dietary fiber on weight loss. Apparently, the source of fiber included in reducing regimens affects the degree of weight reduction.

Depending on the source, dietary fiber binds bile salts in vitro to various degrees, but binding in vivo has not been observed. However, an increased fecal excretion of bile acids occurs with increased intakes of dietary fiber.

Research has indicated that most sources of dietary fiber do not affect blood levels of lipids, triglycerides and cholesterol significantly. However, pectin and guar gum are hypocholesterolemic and are suggested as therapeutic agents in the management of hyperlipidemia. An increased intake of fiber is associated also with a lower incidence of hypertension and atherosclerosis.

The effect of dietary fiber on protein retention and utilization varies among animals including man. Some studies indicated that dietary fiber increases nitrogen excretion and decreases nitrogen availability while others reported no apparent effect. Similarly, both increased and decreased growth rates have been reported with fiber supplementation.

Studies on the effects of dietary fiber on mineral metabolism indicated that most of the components of dietary fiber induce negative balances of calcium, iron, copper, magnesium, chromium silicon and cobalt. Decreased retention of zinc also has been reported, but in the case of cereals, lowered zinc retention was attributed to phytate rather than fiber content. High intakes of dietary fiber have been shown to decrease blood levels of iron and calcium in man, but copper and magnesium levels were unaffected.

Vitamin A absorption usually is not affected by dietary fiber. However, dietary fiber increases vitamin A absorption at excessive levels of intake of the vitamin. Dietary fiber tends to decrease the absorption of vitamins B-6 and B-12 but apparently does not affect folate absorption.

Low intakes of dietary fiber have been associated with increased incidence of diverticular disease, irritable bowel syndrome and gastrointestinal carcinoma. An increased intake of dietary fiber results in the relief of symptoms of diverticular disease, but not always irritable bowel syndrome. Increased consumption of refined foods, animal protein and saturated fat are believed to be more related to the incidence of gastrointestinal cancer than decreased dietary fiber.

Many of the physiological mechanisms of dietary fiber still have not been substantiated. A major change in the intake of dietary fiber is unwarranted until the roles of dietary fiber in health and disease are clearly defined.

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DIETARY FIBER

by

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AN ABSTRACT OF A MASTER'S REPORT

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Dietary fiber includes various components of plant cell walls. Determination of fiber content of food by extraction and fractionation methods underestimate the total fiber content. Recently, acid- and neutral-detergents have been developed for use in fiber analysis. Enzymatic methods have been proposed but have not yet gained acceptance for routine use.

Each type of fiber has its own water holding capacity and effect when passing through the gut. Intake of dietary fiber results in decreased transit time and increased fecal bulk, both desirable laxative effects. Consequently, dietary fiber has been used in the treatment of constipation. Dietary fiber also increases the excretion of fecal volatile fatty acids, thereby lowering stool pH. In addition to these effects however, dietary fiber influences the metabolism of nutrients and the incidence of certain gastrointestinal diseases.

Dietary fiber reduces plasma glucose levels in healthy and diabetic subjects and is a promising adjunct to insulin, oral hypoglycemic agents and controlled diets that are used in diabetic therapy. Conflicting results have been reported for the effect of dietary fiber on weight loss. Apparently, the source of fiber included in reducing regimens affects the degree of weight reduction.

Depending on the source, dietary fiber binds bile salts in vitro to various degrees, but binding in vivo has not been observed. However, an increased fecal excretion of bile acids occurs with increased intakes of dietary fiber.

Research has indicated that most sources of dietary fiber do not affect blood levels of lipids, triglycerides and cholesterol significantly.

However, pectin and guar gum are hypocholesterolemic and are suggested as therapeutic agents in the management of hyperlipidemia. An increased intake of fiber also is associated with a lower incidence of hypertension and atherosclerosis.

The effect of dietary fiber on protein retention and utilization varies among animals including man. Some studies indicated that dietary fiber increases nitrogen excretion and decreases nitrogen availability while others reported no apparent effect. Similarly, both increased and decreased growth rates have been reported with fiber supplementation.

Studies on the effects of dietary fiber on mineral metabolism indicated that most of the components of dietary fiber induce negative balances of calcium, iron, copper, magnesium, chromium, silicon and cobalt. Decreased retention of zinc also has been reported, but in the case of cereals, lowered zinc retention was attributed to phytate rather than fiber content. High intakes of dietary fiber have been shown to decrease blood levels of iron and calcium in man, but copper and magnesium levels were unaffected.

Vitamin A absorption usually is not affected by dietary fiber. However, dietary fiber increases vitamin A absorption at excessive levels of intake of the vitamin. Dietary fiber tends to decrease the absorption of vitamins B-6 and B-12 but apparently does not affect folate absorption.

Low intakes of dietary fiber have been associated with increased incidence of diverticular disease, irritable bowel syndrome and gastrointestinal carcinoma. An increased intake of dietary fiber results in the relief of symptoms of diverticular disease, but not always irritable bowel syndrome. Increased consumption of refined foods, animal protein and saturated fat are believed to be more related to the incidence of gastrointestinal cancer than decreased dietary fiber.

Many of the physiological mechanisms of dietary fiber still have not been substantiated. A major change in the intake of dietary fiber is unwarranted until the role of dietary fiber in health and disease is clearly defined.