Gastric Disappearance of Dietary Fiber by Adolescent Boys[1]

S. GRAMSTORFF FETZER, C. KIES, and H. M. FOX, Department of Food and Nutrition, University of Nebraska, Lincoln, NE 68583

ABSTRACT

This study examined apparent disappearance of three forms of purified dietary fibers as consumed by normal adolescent boys. During the four four-day randomly arranged experimental periods, the eight subjects consumed a basal diet alone or the basal diet plus 14.2 g per day supplements of cellulose, hemicellulose, or pectin. Complete feces collections were made by the subjects throughout the study. Feces were analyzed for fiber constituents by detergent methods, and the apparent disappearance of cellulose was 45–46%. Hemicellulose disappearance was 76–90%, depending on the method used for calculation. Pectin seemingly disappeared completely as defined by standard methods of pectin determination. Changes in stool characteristics as the result of pectin feeding indicated, however, that the pectin was modified only so as to be no longer detectable by standard chemical methods.

The role of fiber in nutrition and health has received much attention in recent years. Diets low in fiber content have been implicated in many disorders including coronary heart disease, varicose veins, hiatus hernia, tumors and cancer of the colon, and obesity (Burkitt et al 1974). Conversely, little research has been done on apparent digestibility of fiber and the role of digestibility in nutrition and health. Fiber must be defined before its role can be discussed, but unfortunately much confusion exists about what should be included in the definition. Consequently, there are many definitions of fiber.

Major sources of confusion are the terms "dietary fiber" and "crude fiber." Crude fiber is what remains of cell-wall constituents after treatment with acid, alkali, and alcohol. Dietary fiber, on the other hand, has been defined as plant materials that are not digested by human digestive secretions (Scala 1974, Van Soest and Robertson 1977). According to this definition, dietary fiber includes pectin, cellulose, hemicellulose, and lignin. Crude fiber, constituting only one-fifth to one-half of total dietary fiber, is mostly cellulose with some hemicellulose and lignin. Much of the lignin and hemicelluloses are lost in determining crude fiber; they are thus included with the more digestible carbohydrates (Van Soest and Robertson 1977, Van Soest and McQueen 1973). Dietary fiber, then, is perhaps a better term than crude fiber when discussing the role of fiber in nutrition and health and will be used in this article.

Dietary fiber, by definition, is not digested by the secretions of the human gastrointestinal tract. Microorganisms in the colon can, however, digest the components of dietary fiber. Large individual variation in the degree of degradation was noted by early workers (Hummel et al 1943, Macy et al 1943, Mangold 1934, Sealock et al 1941, Williams and Olmstead 1936).

The relationship between dietary fiber and metabolizable energy is just beginning to be explored. Universally acceptable definitions of dietary fiber, cellulose, hemicellulose, and lignin have yet to be found. Because of the heterogeneity of purified and nonpurified fiber sources, obtaining reproducible results from one laboratory to another is difficult. A method of determining total dietary fiber accurately has not been accepted.

Another basis of confusion in study of fiber is the lack of agreement on terms such as digestibility and utilization. Direct study of digestibility and utilization in human bioassays is impossible. The usual approach involves feeding weighed amounts of test materials and determining fecal output of the test materials. A better term for this might be gastric disappearance rather than apparent digestibility.

The objective of this research was to examine the apparent digestibility of three forms of purified dietary fibers by studying their disappearance when the fibers were supplemented in an experimental diet consumed by normal adolescent boys.

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MATERIALS AND METHODS

The 21-day study was divided into an introductory two-day depletion period, a three-day adjustment period, and four experimental periods of four days each, randomly arranged for each of the eight subjects. No subject received the experimental diets in exactly the same order as any other subject. This minimizes effects of order of diet presentation on results, and any carryover effects tend to promote negative rather than false positive results.

During the four experimental periods the subjects were fed a basal diet alone or the basal diet plus 14.2 g of hemicellulose, cellulose, or pectin (Table I). All subjects received all experimental diets. The basal diet alone was fed during the adjustment period and the basal diet minus milk was given during the depletion period. The two introductory periods were included 1) to hasten protein adjustment in later periods by feeding a relatively low protein diet, 2) to determine the caloric needs of the subjects, 3) to educate subjects in their duties and responsibilities, and 4) to allow general adjustment to the experimental regime.

The eight adolescent boys who were subjects for the study were also volunteers for a longitudinal study conducted by the Department of Food and Nutrition, University of Nebraska. Subject descriptions are given in Table II. Consent forms were obtained from each subject, his parents, and his personal physician. The project was approved for human subject participation by the University of Nebraska Institutional Committee on Investigations Involving Human Subjects.

The basal diet consisted of peanut butter, starch bread, applesauce, peaches, pears, milk, orange juice, jelly, soft drinks, and vitamin and mineral supplements. Foods were given in the amounts shown in Table I. Vitamin and mineral supplements were taken at the noon meal each day. Caloric adequacy of the diet was ascertained by weighing the subjects daily. Amounts of soft drinks, butter oil, and hard candies were varied to maintain each subject's weight. Subjects were allowed to have water, sugar-free soft drinks, and sugar-free gum as desired.

Cellulose, hemicellulose, and pectin supplements were added to the peanut butter. Approximately one-third of each day's allotment of peanut butter was eaten at each meal.

Complete feces collections were made by each subject throughout the study. A dye marker (brilliant blue) was given at the beginning of each experimental period. Capsules containing brilliant blue dye were given to subjects as part of the breakfast meal on the first day of each experimental period. Feces collected after that time were considered to be part of the composite for the period immediately prior until the dye marker was evident in a stool collection. That dyed stool collection was divided. The dyed portion marked the beginning of the new period composite. The

stool collections were added to this composite until the appearance of blue dye, indicating the start of a new period. (Hence, the dates of stool composite collection for each period corresponded not to calendar dates of feeding but to whatever period of time excretion of these diets occurred.) Stool separation into period lots was made easier in this study because the different fibers did affect stool appearance and consistency. Methyl blue marked the liquid phase, and the undigested fibers were part of the solid phase. Appearance of the dye and changes in consistency because of different fiber sources occurred practically at the same time suggesting that little mixing of stools occurred between periods. In other studies from this laboratory, glass beads were used, in addition to methyl blue, to differentiate between liquid phase and solid phase marking of stools. Unless the diets were such that severe constipation or diarrhea resulted, little difference was found in the use of these markers except that methyl blue was a more absolute indicator.

Fecal samples were refrigerated until fecal composites were made with water at the end of each period. Aliquots of each fecal composite were air dried in an evaporating dish on a sand bath.

Fiber constituents in the dried fecal composites were analyzed by the detergent method of Goering and Van Soest (1970) with slight modifications. The neutral detergent method for determining cell-wall constituents was used to determine total hemicellulose, cellulose, and lignin in the feces.

Two samples from each fecal composite were air dried in evaporating dishes on a sand bath. The samples were then fat-extracted. The dried, fat-extracted samples were ground to pass through a 1-mm screen. A sample of approximately 0.5 g was used for the neutral detergent analysis and another 0.5 g for the acid detergent determinations.

Pectin in the feces was analyzed by two methods. A modified gravimetric method as described by Pearson (1970) was used to determine the pectin content of the feces as calcium pectate. The second method was a modification of the official method of the AOAC (1970), which determines pectin content as a pectic acid precipitate.

Statistical analyses included analysis of variance and Duncan's multiple range test.

RESULTS AND DISCUSSION

Individual and mean fecal fiber data are given in Tables III–V.

Neutral detergent fiber (NDF) data, given in Table III, are expressed both in terms of percent of total fecal excretion (dry weight basis) as NDF and in terms of grams of NDF excreted per subject per period. When subjects received no added fiber, hemicellulose, cellulose, or pectin, mean percentages of dry feces excreted as NDF were 27.2, 30.3, 42.3, and 25.9%, respectively. Cellulose supplementation resulted in significantly higher percentages of NDF in feces than did other fiber supplements. Pectin supplements resulted in a significantly lower percentage of NDF in feces.

When data were recalculated in terms of grams of NDF excreted per period, directionally similar results were obtained. Mean values of subjects while receiving no fiber supplement, hemicellulose, cellulose, or pectin were 26.0, 39.6, 57.2, and 27.2 g per subject per period. Because NDF is composed of hemicellulose, cellulose, and lignin, an increase in NDF with cellulose and hemicellulose supplementation would be expected. Because NDF figures increased less with hemicellulose supplements than with cellulose supplements, hemicellulose could be assumed to be more digestible than cellulose. Supplements consisted of 56 g of fiber per period. Because subjects excreted 26.0 g of NDF during the control period, the recoveries of NDF attributable to added cellulose or hemicellulose during these periods were only 31.3 and 13.6 g, respectively, indicating disappearances of these fibers of 45% (cellulose) and 76% (hemicellulose).

Hemicellulose in feces was calculated as shown in Table IV. As would be expected, the hemicellulose figures were highest when hemicellulose supplements were given. This was true both when data were expressed in terms of percentage dry weight of feces as hemicellulose and in terms of grams of hemicillulose excreted in feces per period. During the control period, a mean of 11.4 g of hemicellulose was excreted, whereas during the hemicellulose period this figure rose to 17.1 g, a statistically significant change. This suggests a 90% disappearance for hemicellulose rather than 76% as suggested by the NDF method. Hemicellulose was estimated by subtracting the percent acid detergent fiber (ADF) from the percent NDF. In theory, hemicellulose is destroyed in the acid detergent process. If this does not really occur, hemicellulose figures are falsely low.

The purified fibers were analyzed by the procedures used for fecal analyses. When the ADF procedure was applied to hemicellulose, an average of 96% of the sample weight disappeared. This does not account for the 14% difference found in fecal analyses but does suggest that this particular source is not completely destroyed by the ADF procedure.

Similarly, in theory, cellulose should be almost completely recovered in the ADF procedure. An average of 95% of the cellulose source was recovered by ADF analysis. These results of analyzing the fiber sources suggest the possibility of error in the method or in its application or in the purity of the fiber sources.

The percent cellulose in feces was determined by subtracting acid detergent lignin (ADL) weights from ADF values. As expected, cellulose contents of feces when cellulose supplements were given were significantly higher than when the control diet was fed, whether expressed as percent cellulose in dry feces or as grams of cellulose excreted per period. During the control period, a value of

TABLE I
Experimental Plan

Period[a]	No. of Days	Fiber Supplement	Amount of Supplement	Total Dietary Fiber
Depletion	2	None	0	6.8 g/day[b]
Adjustment	3	None	0	6.8 g/day
Exp. 1	4	Hemicellulose[c]	14.2 g/day	21.0 g/day
Exp. 2	4	Cellulose[d]	14.2 g/day	21.0 g/day
Exp. 3	4	Pectin[e]	14.2 g/day	21.0 g/day
Exp. 4	4	None	14.2 g/day	6.8 g/day

[a]Experimental periods 1–4 were randomly arranged for subjects.
[b]The basal diet containing 6.8 g of fiber per day was composed of: 100 g of peanut butter, 300 g of starch bread, 100 g of applesauce, 100 g of peaches, 100 g of pears, 100 g of orange juice, and 50 g of nonfat dry skim milk; to meet energy requirements of subjects, varying amounts of soft drinks, hard candy, jelly, and butter oil; and vitamin and mineral supplements.
[c]Hemicellulose as mucilose flakes containing pentosans, hexosans, and galactans from psyllium. Winthrope Laboratories, Division of Sterling Drug Inc., New York, NY 10016.
[d]α-Cellulose fiber as a fine powder approximately 99.5%. Sigma Chemical Corporation, P.O. Box 14508, St. Louis, MO 63178.
[e]Pectin-polygalacturonic acid methyl ester from citrus fruits as a fine powder. Grade I. Sigma Chemical Corporation, P.O. Box 14508, St. Louis, MO 63178.

TABLE II
Physical Data for Subjects[a]

Subject No.	Height (cm)	Weight (kg)	Age
556	176	70	16
558[b]	181	63	17
559[b,c]	178	73	15
921[b,c]	174	66	15
926[d]	169	57	15
927[d]	163	50	14
928	171	57	14
930	...	74	15

[a]The ethnic-racial classification was American/white for all eight boys.
[b]558, 559, and 921 were brothers.
[c]559 and 921 were twins.
[d]926 and 927 were brothers.

TABLE III
Neutral Detergent Fiber Data

Subject No.	Percent of Total Dry Feces Excreted as Neutral Detergent Fiber[a]				Grams of Dry Feces Excreted as Neutral Detergent Fiber[b] (grams/period)			
	Diet				Diet			
	Control	Hemicellulose	Cellulose	Pectin	Control	Hemicellulose	Cellulose	Pectin
556	34.0	32.4	44.1	26.2	12.7	21.0	73.9	10.4
558	32.8	29.6	46.9	19.9	27.7	32.2	90.4	23.7
559	20.1	29.1	40.8	22.7	21.4	33.7	52.6	23.8
921	27.4	19.3	46.8	31.2	39.8	56.7	50.9	30.4
926	23.0	28.5	35.4	28.5	19.6	40.9	56.2	38.9
927	37.6	36.7	42.1	32.2	56.7	56.5	51.9	44.4
928	22.4	27.1	42.5	21.8	13.3	35.4	54.1	21.9
930	20.8	39.6	39.5	24.9	17.1	40.3	27.8	23.9
Mean[c]	27.2a,b	30.3b	42.3a	25.9a	26.0a	39.6a	57.2b	27.2a

[a]Percent of total dry feces excreted as neutral detergent fiber was calculated as follows: (Weight of neutral detergent fiber-ash weight/Sample weight) × 100 = percent NDF.
[b]Grams of dry feces excreted as neutral detergent was calculated as follows: Percent NDF × calculated dry fecal weight = grams NDF per subject per period.
[c]Mean values with different letters are significantly different from one another ($p < 0.05$).

TABLE IV
Hemicellulose Data

Subject No.	Percent of Total Dry Feces Excreted as Hemicellulose[a]				Grams of Dry Feces Excreted as Hemicellulose[b] (grams/period)			
	Diet				Diet			
	Control	Hemicellulose	Cellulose	Pectin	Control	Hemicellulose	Cellulose	Pectin
556	11.9	14.5	9.9	8.3	4.4	9.4	16.6	3.3
558	16.0	15.5	9.5	10.5	13.5	16.8	18.3	12.5
559	12.0	14.4	7.5	12.7	12.8	16.7	9.7	13.4
921	10.5	9.0	10.5	11.4	15.2	26.4	11.4	11.1
926	13.6	11.9	7.9	9.9	11.6	17.1	12.6	13.4
927	13.2	13.8	10.1	8.9	19.8	21.2	13.1	12.3
928	13.5	13.8	7.6	12.2	8.0	18.0	9.6	12.3
930	7.6	11.4	9.7	10.2	6.3	11.5	6.8	19.8
Mean[c]	12.3b	13.0b	9.2a	10.5a	11.4a	17.1b	12.3a	11.0a

[a]Percent of total dry feces excreted as hemicellulose was calculated as follows: Percent NDF − (percent cellulose + percent lignin) = percent hemicellulose.
[b]Grams of dry feces excreted as hemicellulose was calculated as follows: Percent hemicellulose × calculated dry feces weight = grams hemicellulose per subject per period.
[c]Mean values with different letters are significantly different from one another ($p < 0.05$).

TABLE V
Cellulose Data

Subject No.	Percent of Total Dry Feces Excreted as Cellulose[a]				Grams of Dry Feces Excreted as Cellulose[b] (grams/period)			
	Diet				Diet			
	Control	Hemicellulose	Cellulose	Pectin	Control	Hemicellulose	Cellulose	Pectin
556	15.0	13.4	32.1	14.9	5.6	8.7	53.8	5.9
558	11.4	8.1	32.7	5.9	9.6	8.8	63.0	7.0
559	4.0	6.9	29.8	5.5	4.2	8.0	38.4	5.8
921	13.1	7.5	33.1	17.4	19.0	22.1	36.0	17.0
926	7.5	14.4	25.8	12.3	6.4	20.7	41.0	16.8
927	21.2	19.6	29.6	20.6	32.0	30.8	36.5	28.4
928	4.2	9.8	33.3	6.5	2.5	12.8	42.3	6.5
930	9.7	24.8	27.8	11.3	7.9	25.2	19.6	10.9
Mean[c]	10.7a	13.0a	30.5a	11.8a	10.9a	17.1a	41.3b	12.3a

[a]Percent of total dry feces excreted as cellulose was calculated as follows: (Weight of acid detergent fiber-weight of acid detergent lignin/Sample weight) × 100 = percent cellulose.
[b]Grams of dry feces excreted as cellulose was calculated as follows: Percent cellulose × calculated dry fecal weight = grams cellulose per subject per period.
[c]Mean values with different letters are significantly different from one another ($p < 0.001$).

10.9 g of cellulose was excreted per subject per period. This rose to 41.3 g when 56 g of cellulose was given as a supplement. By this method, the apparent disappearance of cellulose is 46%, a figure nearly identical to that determined by NDF alone. The apparent cellulose excretion rose to 17.1 g, however, during the hemicellulose supplemented period. Although this was not significantly greater than that excreted during the control period, it suggests that all hemicellulose is not destroyed during the ADF determination. If the apparent cellulose values are added to the hemicellulose figures, the disappearance of hemicellulose is 80%, a value somewhat closer to the 76% figure obtained by the NDF method.

Some variation in excretion of lignin was found when values were expressed as percent lignin in dry feces, but no significant differences were found when data were expressed as grams of lignin excreted per subject per period. Because lignin was fed in constant amounts, variation in fecal lignin figures was not expected.

Pectin in feces was analyzed by two methods. Neither method detected pectin in feces whether pectin supplements had been given or not. This supports the contention that pectin is almost completely digestible by humans (Werch and Ivy 1941, Werch et al 1942). The physical appearance of the feces during the pectin-supplemented period was generally claylike and well formed. This markedly contrasted the stool characteristics of the other periods. During the control period, the feces were generally well formed but lacked the claylike appearance of feces during the pectin-supplemented period. The feces during the cellulose and hemicellulose periods generally were not well formed and the stools of the hemicellulose-supplemented period had a shiny, glossy appearance.

Increases in dietary fiber might be expected to result in decreased fecal transit time and increased total dry fecal weight. These effects were not demonstrated in this study, however. The mean weights of the dried four-day fecal composites were 93.8 g in the control period, 139.3 g in the hemicellulose-supplemented period, 134.8 g in the cellulose-supplemented period, and 104.1 g in the pectin-supplemented period. Differences between means of fecal weights were not statistically significant.

In conclusion, studies with adolescent boys of gastric disappearance of dietary fibers indicate cellulose to be less digestible than hemicellulose. Pectin appeared to be completely digestible. Other researchers have found that both hemicellulose and pectin have greater influences than cellulose on fecal sterols, zinc, copper, magnesium, and nitrogen excretion. Thus, qualities other than digestibility may be responsible in part for the assumed beneficial or negative attributes of dietary fiber.

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