Effect of Various Levels of Dietary Hemicellulose on Zinc Nutritional Status of Men[1]

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ABSTRACT

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The effect of feeding various levels of hemicellulose on zinc nutritional status of adult men was studied. During three periods of 14 days each, subjects received daily supplements of 4.2, 14.2, and 24.2 g of hemicellulose and an otherwise constant diet. All 12 men received all experimental treatments. Order was randomized for each subject. Zinc intake was held constant at 11.3 g/day (1.3 mg from $ZnCl_2$ supplement and the rest from the basal diet). Mean zinc balances for subjects while receiving 4.2, 14.2, and 24.2 g hemicellulose for days 1–7 of each period were +0.89, +0.54, and −1.09 mg/day and for days 8–14 were +0.97, +0.27, and −0.91 mg/day. Results indicated a statistically significant effect on zinc balance as a result of change in dietary hemicellulose. No statistically significant differences between results from days 1 through 7 or from 8 through 14 were found, indicating that shorter term periods for balance studies of this type are valid.

Dietary fiber is a topic of current interest in human nutrition. Reduction of serum cholesterol levels and lowered incidence of hyperlipidemia and ischemic heart disease have been attributed to the gastrointestinal binding of cholesterol, bile salts, and fat by fiber (Eastwood 1969, Tribble and Scoular 1954, Trowell 1972). Fiber also has been suggested to aid in the removal of irritants and carcinogens from the gastrointestinal tract and possibly prevention of ulcerative colitis, colonic cancer, diverticulitis, duodenal ulcer, and appendicitis (Burkitt 1971a, Burkitt 1971b, Burkitt et al 1972, Vallee et al 1959). Fiber can have a beneficial role in the chelation of lithocholate in the gut (Pomare and Heaton 1973). Lithocholate is a potentially toxic degraded bile salt that, in unbound form, may be a factor in the etiology of gall-bladder disease. In the presence of a high residue diet, however, it may remain bound to fiber and is excreted in the feces.

Fiber intake varies among various population groups; a decrease in intake is typical as groups industrialize and adopt Western dietary customs (Burkitt et al 1972). Scala (1974) estimated that during the last century Americans decreased by 20% their intake of fiber from fruits and vegetables and by 50% their intake of cereal fiber. Results of most surveys defining fiber intakes of humans consuming self-selected diets are expressed in terms of "crude" that is only one-fifth to one-half of the total dietary fiber (Scala 1974). Lack of consistency in term definition and usage has led to confusion (Kelsay 1978). Kelsay (1978), as part of a comprehensive review of research on effects of fiber intake in humans, presented a list of kinds and levels of fiber found in 55 reports and attempted to interpret these in terms of recommended intakes. In terms of total dietary fiber, these recommended intakes ranged from approximately 5 to 35 g per day, depending on the author.

The possible role of fiber as a chelating agent binding dietary zinc was considered in previous studies (Bremner 1970, Reinhold et al 1976a). Studies involving zinc/fiber interactions tended to stress either bran or effects of cellulose (Halsted et al 1972, O'Dell 1969, Reinhold, et al 1976a, Reinhold et al 1974). Zinc/hemicellulose interactions have not been investigated in humans. Zinc deficiencies in humans were once thought nonexistent, but marginal zinc deficiencies may exist in many populations throughout the world (Halsted et al 1972, Hambridge 1974, Kies and Fox 1977, Moyer and Irwin 1967, Murphy et al 1971, Prasad 1966, Prasad et al 1963b, Price et al 1970, Reinhold et al 1976a, Reinhold et al 1975, Reinhold et al 1973, Ronaghy 1974, Ronaghy et al 1968, Ronaghy et al 1969, Sandstead 1973, Smith et al 1962, Walker 1974, White 1969). The object of our study was to investigate effects of one class of dietary fiber, hemicellulose, on zinc utilization by adult men.

MATERIALS AND METHODS

The experimental plan for the study is shown in Table I. The 50-day study was divided into a two-day depletion period, a three-day preadjustment period, three experimental periods of 14 days each, and a three-day postadjustment period. For each of the 12 subjects who participated in the study, the order of the three experimental periods was randomly arranged to minimize the effects of time and order of diet presentation.

During the depletion period, subjects received the basal diet shown in Table II from which the peanut butter component was omitted. With this omission, the diet provided 0.8 g of nitrogen and 8.40 mg of zinc per day. Initial feeding of a very low level of nitrogen (protein) speeded adjustment of subjects to the relatively low levels of protein fed in nitrogen balance studies. Other purposes were to introduce subjects to their duties and responsibilities and to establish the level of caloric intake necessary for each individual to maintain body weight.

During the adjustment and all experimental periods, subjects received a standardized diet shown in Table II that provided 7.5 g of fiber, 11.3 g of zinc, and 6.8 g of nitrogen. Hemicellulose was added to the diet to provide 4.2 g during depletion, adjustment, and one experimental period, 14.2 g during the second, and 24.2 g during the third. All subjects received all experimental variables in relation to hemicellulose intake, including other fiber sources. Total dietary fiber intake varied from 11.7 to 21.7 to 31.7 g per day during the three experimental periods.

Diets were supplemented with vitamins and minerals so that adequate intake of essential nutrients was assured (Table II). By varying the amount of starch bread, sucrose, hard candy, jelly, and soft drinks among individuals, total caloric intake of subjects was adjusted to the level necessary for weight maintenance. Subjects were weighed daily, and all maintained relatively the same weight from beginning to end of study (±2.0 kg). After the level of energy intake was established for each individual, caloric intake was maintained constant.

Hemicellulose supplements were added to the ground peanuts, and approximately one-third of each day's allotment was served at each of the three meals. The fruits and vegetables used as part of the basal diet were purchased from the same lots at the beginning of the study.

Descriptions of the 12 adult men who were volunteers for this study appear in Table III. All were inmates of the Nebraska Penal and Correctional Complex for Men—Reformatory Unit; they continued usual institutional assignments of work or study except for consumption of special meals and for collections of excreta. The

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TABLE I
Experiment Plan

Period[a]	Number of Days[b]	Hemicellulose Supplement[c] (g/day)	Total Dietary Fiber[d] (g/day)	Zinc Intake (mg/day)
Depletion	2	4.2	11.7	11.3
Adjustment	3	4.2	11.7	11.3
Randomized experiment				
1	14	4.2	11.7	11.3
2	14	14.2	21.7	11.3
3	14	24.2	31.7	11.3

[a] Experimental periods randomly arranged for each subject.
[b] Each 14-day experiment divided into two 7-day periods for separate analyses of data.
[c] Hemicellulose containing pentosans, hexosans, and galactans from psyllium. Product was 2.79% acid detergent fiber, 95.45% neutral detergent fiber, and 1.56% lignin (detergent fiber method of Goering and Van Soest 1970).
[d] Includes 7.5 g fiber as provided by basal diet (detergent fiber methods of Goering and Van Soest 1970) described in Table II.
[e] Includes 1.3 mg from a $ZnCl_2$ supplement and 10.0 mg from the basal diet described in Table II.

TABLE II
Experimental Diet

Item	Amount (g/day)	Zinc Content (mg/day)
Ground peanuts	130	2.90
Starch bread	Varied[a]	4.08
Applesauce	100	0.18
Peaches	100	0.17
Pears	100	0.13
Green beans	100	1.40
Tomato juice	100	1.04
Vitamin supplement	Listed below[b]	0.00
Mineral supplement	Listed below[b]	Varied
Soft drinks	Varied[a]	(0.09)[c]
Hard candy	Varied[a]	0.00
Jelly	Varied[a]	0.03
Nonprotein bouillon	3.0 g (dry)	0.03
Water	ad libitum	0.00[d]

[a] Fed in amounts to meet caloric needs for weight maintenance of each individual. Although varied between subjects, amounts were constant for each individual. Less than 10% of the calories were from monosaccharides or disaccharides, 40–45% of calories from starch, and 35–40% of calories from fat.
[b] The mineral supplement in addition to ZnCl (part capsule form, part mixed in starch bread) supplied the following (g/subject/day): Ca, 1.00; P, 1.00; Mg, 0.199; Fe, 0.015; Cu, 0.002; K, 0.323; I, 0.00015; Mn, 0.002. Ordinary foods supplied approximately 0.121 mg of additional Mg and approximately 0.850 mg of additional K. NaCl was allowed ad libitum. The vitamin supplement supplied the following (per subject per day, capsule form): 5000 USP units of vitamin A acetate; 600 USP units of vitamin D (ergocalciferol); 2 mg thiamin; 2.5 mg riboflavin; 20 mg niacinamide; 50 mg ascorbic acid; 1 mg pyridoxine; 1 μm cyanocobalamin; 1 mg calcium pantothenate.
[c] Mean value.
[d] The city water supplied is extremely low in zinc. Zinc content of water could not be separated from background reading when analyzed by atomic absorption spectrophotometry. The zinc content is approximately 0.02 mg/L.

study was approved for human participation by the University of Nebraska Institutional Committee on Investigations Involving Human Subjects and by the institution's medical and administrative staff. All volunteers were free to withdraw from the project at any time. The health status of volunteers was based on physical examinations done by the institution's medical officer.

Complete collections of urine and feces were made by subjects throughout the 50-day study. Urine collections were divided into 24-hour lots for analyses. Creatinine content of urine by Folin's method (1914) was used to ascertain the completeness of each 24-hr collection and the accuracy of divisions. During the experimental periods, seven-day composites of fecal collections were made using orally given carmine dye to mark the division between each lot. Since each period was 14 days long, two fecal composites were made for each subject for each period. Fasting blood samples were drawn from subjects at the beginning of the study and at the end of each experimental period. Composites of food were made twice during the study for later analyses.

Zinc analyses of urine and fecal collections, blood samples, and dietary food products were done using atomic absorption spectrophotometry. Fiber contents of food composites were evaluated by crude fiber methods and the detergent methods of Goering and Van Soest (1970). Data obtained were subjected to statistical analysis of variance and Duncan's multiple range test.

RESULTS AND DISCUSSION

Effect of dietary hemicellulose on protein and lipid nutritional status of subjects was reported earlier (Kies and Fox 1977). Results of measurements to ascertain effects on graded levels of dietary hemicellulose on zinc nutritional status of men are shown in Table IV.

As the level of dietary hemicellulose was increased, fecal zinc content on a milligram per day basis was significantly increased. Mean fecal zinc values at 4.2, 14.2, and 24.2 g of hemicellulose intake per day were 9.85, 10.21, and 11.92 mg per day, respectively, for days 1 through 7 of each experimental period and 9.67, 10.44, and 11.73 mg/day, respectively, for days 8 through 14. Differences in values for the first and last half of each period were not statistically significant. This indicates that effects of hemicellulose on fecal zinc excretion are rapid and relatively permanent, allowing use of short experimental periods for studies of this type.

Urinary zinc excretion and blood serum zinc levels were unaffected by increases in dietary hemicellulose. These parameters of zinc nutritional status may require greater stress in terms of higher levels of hemicellulose feeding or longer duration of feeding to manifest themselves. If the negative zinc balances indicated at higher levels of hemicellulose feeding were true negative balances, in time both urinary zinc levels and blood zinc levels would be expected to change. The ethics of purposely feeding diets that apparently adversely affect humans in order to illustrate other research parameters might be questioned, however.

Apparent mean zinc balances of subjects while receiving 4.2, 14.2, and 24.2 g of hemicellulose per day for days 1 through 7 were +0.89, +0.54, and −1.09 mg/day, respectively, and for days 8 through 14 were +0.97, +0.27, and −0.91 mg/day, respectively. As in most balance studies, not all sources of zinc loss were measured. These would include sweat losses, hair and nail losses, and losses to skin. Because of these, apparent balances should be used in the comparative rather than in the absolute sense. As with fecal zinc levels, changes in zinc balances of subjects noted when different levels of fiber were fed were statistically significant. Values for the first seven days of each period, were not significantly different from those of the last seven days, however.

The possibility that specific dietary fibers or bran may inhibit zinc utilization was reported or implied in earlier studies. Inclusion of plant seed proteins in the diet of chicks induced the development of zinc deficiency symptoms (O'Dell and Savage 1957). This was later confirmed in several other species (Edwards 1966, Forbes and Yohe, 1960, Pomare and Heaton 1973, Savage et al 1964, Smith et al 1962). Prasad and co-workers (1963) were the first to identify the human counterpart of zinc deficiency. They reported clinical manifestations of retarded growth, delayed skeletal maturation, hypogonadism, and hepatosplenomegaly in adolescent Iranian boys. similar cases were encountered in Egypt and other areas of Iran (Halsted et al 1972, Prasad 1966, Prasad 1969, Prasad 1976, Prasad et al 1963a, Prasad et al 1963b, Prasad et al 1963c, Ronaghy 1974, Ronaghy et al 1968). In addition to the earlier reported deficiency symptoms, low concentrations of zinc were noted in the hair, sweat, urine, and plasma.

Common to these areas is a diet composed primarily of high extraction wheat flour made into unleavened bread. As the wholemeals used by the villagers approach a 100% extraction rate, nearly all of the fiber and phytate of the wheat is included in the bread. Fiber in the bread, primarily in the form of cellulose, was estimated to be approximately 2.5 g/100 g (Reinhold et al 1976b). The zinc deficiencies were originally believed to be due to inadequacy in zinc intake. Further investigations revealed, however, that these diets exceeded zinc intake requirements considerably (Reinhold 1973). The conclusion was that the deficiencies must be the result of decreased availability of dietary zinc or accelerated loss of zinc from the body, or both.

TABLE III
Description of Subjects[a]

Subject No.	Race	Age (years)	Height (cm)	Weight (kg)
1081	White	20	180.3	88.4
1082	White	19	192.8	92.5
1083	White	22	177.8	85.2
1086	Black	24	190.5	82.5
1088	Black	23	185.4	79.3
1089	White	25	185.4	83.9
1092	White	20	180.3	68.0
1094	White	18	180.3	69.3
1095	White	23	179.0	68.0
1096	White	23	185.4	75.7
1097	White	23	185.4	63.4
1099	White	24	177.8	83.9

[a]All subjects were males.

TABLE IV
Parameters of Zinc Nutritional Status as Affected by Dietary Hemicellulose[a]

Parameter	Mean Value While Receiving Hemicellulose Supplement (g/day)		
	4.2	14.2	24.2
Urinary Zn (mg/day)			
Days 1–7	0.56[a]	0.55[a]	0.47[a]
Days 8–14	0.66[a]	0.59[a]	0.48[a]
Fecal Zn (mg/day)			
Days 1–7	8.85[b]	10.21[c]	11.92[d]
Days 8–14	8.67[b]	10.44[c]	11.73[d]
Apparent Zn Balance (mg/day)			
Days 1–7	+0.89[e]	+0.54[f]	−1.09[g]
Days 8–14	+0.97[e]	+0.27[f]	−0.91[g]
Blood Serum Zn (meq/100 ml)	202[g]	208[g]	199[g]

[a]Mean value of 12 subjects. Values with different letter within each set of data are significantly different from one another ($P < 0.05$) by analysis of variance and Duncan's multiple range test.

That phytate interferes with zinc utilization has been repeatedly demonstrated. Several recent observations, however, cast doubt on its role as the sole or even the primary inhibitory factor determining zinc availability. Suggestions of the possible importance of other chelating factors arose from the analysis of different foodstuffs in which great variations in the availability of zinc could not be directly related to their phytate content (O'Dell 1969). Experiments by Reinhold et al (1974) comparing the effects of leavened and unleavened wholemeal breads on mineral availability demonstrated that fermentation with yeast significantly increased the physiological availability of zinc from the breads. Yet the enhanced availability as a result of the action of yeast leaven brought about changes in the solubility and availability of zinc greatly exceeding expectations based on the destruction of phytate alone. Further studies in vitro in which phytate was removed from bran and whole meals either by the action of phytase or by extraction with acid resulted in an increased binding of metals instead of the anticipated decrease (Reinhold et al 1975). Limited human studies revealed that phytate consumed in a purified form were less effective in decreasing zinc retention than were equivalent amounts of phytate consumed in the form of Tanok, a typical Iranian bread with high phytate content (Reinhold et al 1973).

A high residue effect may exist for zinc and be a contributory factor in accounting for its losses from the body (Reinhold et al 1976b). In this study, although fecal zinc losses increased daily with increased levels of dietary hemicellulose, zinc content of feces per unit of dry weight actually decreased. The increase in total stool weight accounted for the increased daily zinc loss. Recent studies by Reinhold et al (1976a, 1976b) examined the effects of dietary cellulose supplementation on zinc utilization. Findings of increased fecal zinc excretion and decreased plasma zinc concentrations were correlated with an impairment in zinc absorption and utilization resulting from the increased levels of dietary fiber. Bremner (1970) suggested earlier that zinc is associated in insoluble forms with the cellulose-lignin matrix in ryegrass. Evidence that cellulose impairs the intestinal absorption of zinc was recently produced by Reinhold et al (1976a, 1976b). As cellulose is the primary constituent of plant cell walls, its occurrence in foodstuffs is widespread. This is also true of hemicellulose. The major etiological factors of the zinc deficiencies observed in the Middle East, especially the high concentration of dietary phytate, were not thought relevant to the United States or to other Western countries (Bremner 1970). In cases already reported, symptoms of suboptimal growth, delayed wound healing, and impaired taste acuity were observed (Hambridge 1974). These bear similarities to findings of delayed puberty and moderate growth retardation in otherwise healthy Middle Eastern adolescent boys (Ronaghy 1974). The specific dietary similarities remain to be confirmed, however. Due to possible beneficial effects in lowering the incidence of certain disease conditions, increased dietary fiber intake has been advocated for the American population (Tribble and Scoular 1954). Fiber fortification and enrichment of selected food products has been proposed. The implications of these changes on zinc availability and utilization should be considered.

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