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Effects of an increased content of cereal fibre in the diet of Type 2 (non-insulin-dependent) diabetic patients

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Summary. The metabolic effects of an increased dietary content of cereal fibre were studied in 14 Type 2 diabetic subjects. They were given two isoenergetic diets in randomised order during two consecutive 3-week periods. A diabetic diet, containing 18.9 g dietary fibre/6.7 MJ (1 600 kcal), was compared with a diet of identical composition except for an increased content of cereal fibre (42.4 g dietary fibre/6.7 MJ). The mean blood glucose level and the urinary glucose excretion were significantly lower in patients on the cereal-fibre-rich diet, while the serum insulin concentrations were similar. The mean blood glucose level was significantly reduced at 0700 h by 6% ($p<0.05$) and at 1100 h by 13% ($p<0.01$) on the high-fibre diet. Consequently the insulin/glucose ratio was higher (33%, $p<0.02$) in patients on the fibre-enriched diet. There were only minor differences with regard to the serum lipoprotein concentrations. The lipoprotein lipase activities were similar in the two dietary groups. The reduction of blood glucose concentrations together with unchanged serum insulin concentrations is compatible with improved peripheral insulin sensitivity.

Key words: Type 2 diabetes, dietary treatment, dietary fibre, blood glucose, serum insulin, serum lipoproteins.

During the last few years a great deal of interest has been focussed on the effect of dietary fibre on glucose and fat metabolism, especially in relation to the treatment of diabetes mellitus [1, 2]. Many investigations have dealt with Type 1 (insulin-dependent) diabetes mellitus. There have been relatively few controlled studies concerning the importance of dietary fibre in the management of Type 2 (non-insulin-dependent) diabetes where the food intake has been strictly controlled and only one type of fibre has been added.

The aim of this study was to determine whether an increased content of dietary fibre in a conventional diabetic diet could improve metabolic control in Type 2 diabetes. Two diets of almost identical nutritional composition, except for the dietary fibre content, were used. The increase in fibre was confined solely to cereal fibre, as different types of dietary fibre have different effects on carbohydrate metabolism. In the fibre-enriched diet, the cereal fibre content was only moderately increased, in order that the diet should be palatable and should also be useful in long-term treatment of diabetes.

Patients and methods

Patients

The study comprised 14 patients with Type 2 diabetes (seven males and seven females, median age 60 years [range 55–64 years] and 66 years [range 61–82 years] respectively). The mean body weight of the males on admission was 76.7 kg (range 63.4–97.1 kg) and that of the females 62.2 kg (range 57.4–70.2 kg). The body mass index (body weight/height^2, mean ± SEM) was 25.0 ± 0.9 for men and 24.5 ± 0.5 for women. There was no significant difference between the sexes in body mass index. All patients were poorly controlled on admission and had high baseline blood glucose values (13.4 ± 0.8 mmol/l, mean ± SEM). All patients had known duration of diabetes of more than 1 year, in 10 more than 5 years. All 14 had previously received dietary advice as outpatients. Eleven of the 14 patients were treated with oral antidiabetic drugs, seven with sulphonylurea, four with combined sulphonylurea and metformin. The medication was continued unchanged throughout the study.

Diet

The study was performed on a metabolic ward. The different diets were given in randomised order during two consecutive 3-week peri-

Table 1. Nutrients in the control diet and the high-fibre diet, calculated for 1 week's menu

	kJ	Kcal	Protein		Fat		Carbohydrate		Cholesterol (mg)	P/S ratio
			(g)	% of total energy	(g)	% of total energy	(g)	% of total energy		
Control diet	6730 ± 9	1610 ± 2	81 ± 0.5	21 ± 0.2	58 ± 0.4	34 ± 0.2	184 ± 0.6	47 ± 0.1	180 ± 42	1.0 ± 0.0
High-fibre diet	6740 ± 12	1610 ± 3	82 ± 0.5	21 ± 0.1	58 ± 0.4	34 ± 0.2	183 ± 0.4	47 ± 0.2	177 ± 43	1.0 ± 0.0

Results expressed as mean ± SEM (daily intake)

ods. The control diet contained a 'conventional' amount of dietary fibre (18.9 ± 0.9 g, mean ± SEM), while the test diet had an increased dietary fibre content (42.4 ± 1.0 g). The diets were based on 1-week menus. The compositions of the diets with regard to energy distribution, contents of protein, fat, carbohydrate and cholesterol and relation between polyunsaturated and saturated fatty acids (P/S ratio) are given in Table 1. The contents of other nutrients were virtually identical in both diets, including calcium (970 ± 51 and 985 ± 51 mg, mean ± SEM, in the control diet and the high-fibre diet, respectively, per 6.7 MJ; 1600 kcal), iron (12.9 ± 0.3 and 13.0 ± 0.4 mg) and ascorbic acid (106 ± 13 and 109 ± 12 mg). For calculating the nutrient content, data from different Swedish industries and from the Swedish Food Composition Tables [3] were used. The values of carbohydrate given in the Swedish food tables are carbohydrate by difference.

The fibre content was calculated from food tables [4] in which Southgate's method had been applied. The content of cereal fibre in the crisp-bread was calculated from data provided by the manufacturer (Wasa Bröd, Filipstad, Sweden), and based on an enzymatic method [5].

The calculated amount of dietary fibre in one week's menu of the control diet was 17.6 ± 0.6 g (mean ± SEM) per 6.7 MJ/1600 kcal and the analysed amount was 18.9 ± 0.9 g. The calculated dietary fibre content of the high-fibre diet was 38.5 ± 0.5 g (mean ± SEM). The corresponding analysed figures were slightly higher (42.4 ± 1.0 g). The total dietary fibre content of the crisp-bread and the wheat bran in the high-fibre diet was calculated as 21.1 ± 0.6 g (mean ± SEM). This figure is not included in the energy and carbohydrate content of the high-fibre diet, as most of the fibre in bran is not available as a source of energy.

Both the crisp-bread and the soft bread of the control diet were made of white wheat flour. In the high-fibre diet two kinds of soft bread were used, one made of a blend of wheat and rye flour, wheat bran, crushed wheat grain and white wheat flour, and the other of wholemeal rye and white wheat flour. The high-fibre diet contained a special fibre-rich rye crisp-bread containing 26 g dietary fibre/100 g. In the control diet a wheat crisp-bread containing 5 g dietary fibre/100 g was used. The contents of nutrients per 100 g in the wheat and the rye crisp-bread respectively were 408 and 325 kcal, 11 and 12 g protein, 9 and 6 g fat, 68 and 55 g carbohydrates.

Total dietary fibre, i.e. both soluble and insoluble components, was also determined in duplicate portions of the control and high-fibre diets. An enzymatic, gravimetric method suggested to the Association of Official Analytical Chemists was used [6]. After fat extraction, protein and starch are hydrolysed by enzymes. The soluble dietary fibre components are precipitated by four volumes of ethanol. The sample is then filtered and the residue dried and weighed. Correction is made for undigested protein and ash associated with the fibre. This method and the method described in [5] are based on the same principle and even though two different enzymes are used, good accordance is achieved [6].

The content of fat and its constituents were also determined by chemical methods as described elsewhere [7]. The measured fat content was 57 ± 1 g (mean ± SEM) in the control diet and 60 ± 1 g in the high-fibre diet per 6.7 MJ/1600 kcal. The P/S ratios obtained from measurements (1.3 ± 0.0 and 1.4 ± 0.0) were somewhat higher than the corresponding calculated values (Table 1).

All patients were given diets with individually calculated energy content to assure stable body weight throughout the study. To achieve the different energy levels required, all the ingredients of the basic diet of 6.7 MJ (1600 kcal) were multiplied by 1.25, 1.50 and 1.75 to provide 8.4 MJ (2000 kcal), 10.1 MJ (2400 kcal) and 11.8 MJ (2800 kcal) respectively [7]. In this way the relative contents of nutrients were identical at different levels of energy intake. To achieve a constant body weight throughout the study the female patients received 125 kJ (30 kcal) per kg body weight and the male patients 146 kJ (35 kcal). If a patient gained or lost weight the energy level was adjusted. An example of a 1-day menu of the two diets is given in Table 2.

Admission and change of diets took place on the same day of the week. The blood glucose and urinary glucose concentrations were measured fasting and throughout the day (3 days a week). The blood glucose and urinary glucose concentrations were monitored throughout the study. At the end of each treatment period, the blood glucose and serum insulin concentrations were measured during fasting and after a standardized breakfast. The breakfast contained protein providing 18%–19% and fat 33% of energy and the dietary fibre contents in the control and high-fibre diets were 2.2 g and 12.4 g respectively at the daily energy level of 6.7 MJ/1600 kcal. All other laboratory tests were performed according to a fixed schedule during the last 2 days of each diet period.

Laboratory estimations

Blood and urinary glucose concentrations were determined by a glucose oxidase method [8]. Serum insulin assays were performed by the Phadebas Insulin Test (Pharmacia, Uppsala), which is based upon a radioimmunosorbent technique [9].

Lipoprotein lipid concentrations were determined in serum after an overnight fast (0700 h) and at 1900 h after dinner. Very-low density lipoproteins (VLDL), low-density lipoproteins (LDL) and high-density lipoproteins (HDL) were isolated by means of a combination of preparative ultracentrifugation and precipitation and a heparin-manganese chloride solution, as described earlier [7]. Cholesterol and triglyceride concentrations in serum and in the isolated lipoprotein classes were determined in isopropanol extracts by semi-automatic methods in a Technicon Auto Analyzer Type II [10].

The determination of adipose tissue lipoprotein lipase activity and skeletal muscle lipoprotein lipase activity was based on a method described elsewhere [11, 12]. A triolein emulsion with ^{3}H-trioleate as trace substance and with purified egg lecithin as emulsifier [13] was used as substrate for the enzyme.

The intravenous fat tolerance test was performed as previously described [14].

Determinations of the serum concentrations of iron and zinc, γ-glutamyl transferase and transferrin, of haemoglobin and haematocrit, and of the content of fat in the faeces were performed according to routine methods at the Laboratory of Clinical Chemistry of the University Hospital in Uppsala.

Statistical analysis

The hypothesis of equal mean values for the two diets at each time point was tested for each variable by Student's two-sample t-test (two-tailed). Urinary-glucose excretion, however, was tested by the Wilcoxon matched-pairs signed-ranks test (two-tailed).

Table 2. Example of a 1-day menu of the high-fibre diet and the control diet, both providing 6.7 MJ (1600 kcal)

	High-fibre diet (g)	Control diet (g)
Breakfast		
Porridge (rolled oats)	20	20
Wheat bran	7	–
Apple sauce, unsweetened	20	20
Milk	150	150
Wholemeal bread	25	–
White wheat-bread	–	35
Low-fat cheese	20	20
Cucumber	5	5
Fibre-enriched rye crisp-bread	10	–
Lunch		
Fried diced meat mixed with onion		
Potatoes, boiled	75	75
Margarine	15	15
Onion	25	25
Beef	75	75
Beetroot	25	25
Fibre-enriched rye crisp-bread	15	–
Wheat crisp-bread	–	13
White cabbage	15	15
Carrots	30	30
Milk	150	150
Dinner		
Chicken stew with rice		
Chicken meat	85	85
Margarine	9	9
Mushrooms	20	20
Sweet green pepper	10	10
Canned tomatoes	40	40
Peas	50	50
Rice	25	20
Fibre-enriched rye crisp-bread	10	–
Wheat crisp-bread	–	13
Apple, whole	100	100
Snacks		
Fibre-enriched rye crisp-bread	20	–
Wheat crisp-bread	–	18
Cucumber	10	10
Low-fat cheese	10	15
Fibre-enriched rye crisp-bread	10	–
Wholemeal bread	30	–
White wheat-bread	–	35
Smoked meat	10	10
Milk	150	150
Fruit-salad:		
Orange	50	50
Apple	30	30
Banana	30	30
Cottage cheese	25	25
Total fibre by analysis (g)	40.0	19.4

The margarine on the bread consisted of 25% linoleic acid. Margarine containing 50%–60% linoleic acid was used for frying and cooking. Low-fat milk was used. Coffee or tea was allowed in unrestricted amounts

Results

The mean body weights after the control and the high-fibre diet treatment periods were 68.8 ± 3.4 kg and 68.9 ± 3.3 kg respectively. The intra-individual difference between the weights at the ends of the two periods varied between 0.0 and 0.9 kg, except in one patient who lost 1.5 kg from the last day of the high-fibre diet to the last day of the control diet.

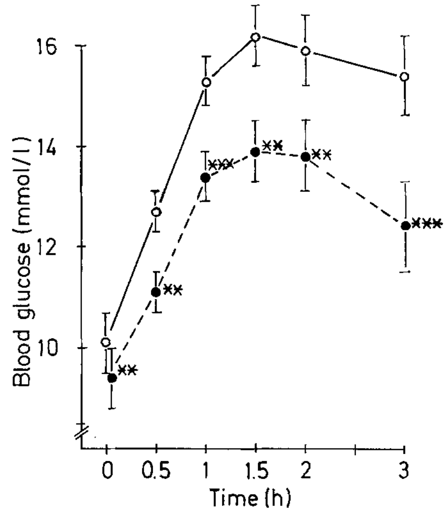

Fig. 1. Blood glucose concentrations fasting and after a standardized breakfast during treatment with the control diet (O——O) and with the high-fibre diet (●——●) (n = 14, mean ± SEM). **, *** = $p <$ 0.01 and 0.001, respectively compared with the control period (paired t-test, two tailed)

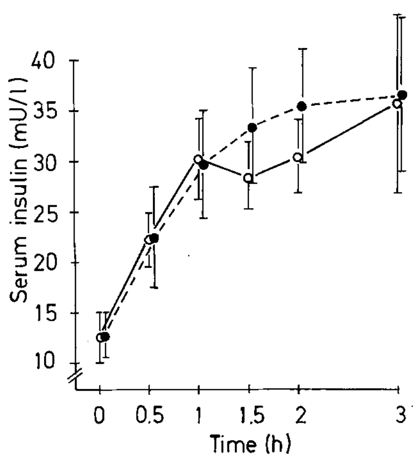

Fig. 2. Serum insulin concentrations fasting and after a standardized breakfast during treatment with the control diet (O——O) and with the high-fibre diet (●——●) ($n = 14$, mean ± SEM)

At the end of the two treatment periods, all patients showed improved blood glucose control both during overnight fasting and during the day, compared with that on admission. During the day, the blood glucose level was lower on the high-fibre than on the control diet (Table 3). The blood glucose concentrations during fasting and after a standardized breakfast were also significantly lower on the high-fibre diet (Fig. 1). The serum insulin concentrations were similar on the two diets, both during fasting and post-prandially (Fig. 2).

After the standardized breakfast, the insulin/glucose ratio was higher on the fibre-enriched diet, signifi-

Table 3. Weekly mean blood glucose concentrations during treatment with the control diet and the high-fibre diet ($n = 14$)

	Blood glucose concentrations (mmol/l)					
	Control diet			High-fibre diet		
	0700 h	1100 h	1500 h	0700 h	1100 h	1500 h
Week 1	11.2 ± 0.6	16.3 ± 0.9	14.5 ± 1.0	11.1 ± 0.9	14.7 ± 1.0	13.9 ± 1.2
Week 2	10.9 ± 0.7	15.6 ± 0.8	14.4 ± 1.0	9.6 ± 0.7[a]	13.5 ± 0.9[b]	12.6 ± 1.0[b]
Week 3	10.1 ± 0.6	15.1 ± 0.6	13.2 ± 0.7	9.5 ± 0.6[a]	13.1 ± 0.9[b]	12.7 ± 1.0

Results expressed as mean ± SEM. [a]$p < 0.05$; [b]$p < 0.01$ respectively compared with the control diet period (paired t-test, two-tailed)

Table 4. Weekly mean 24-h urinary glucose excretion during treatment with the control diet and the high-fibre diet ($n = 14$)

	24-h urinary glucose excretion (mmol/l)		
	Week 1	Week 2	Week 3
Control diet	134 ± 38	119 ± 30	102 ± 34
High-fibre diet	110 ± 44	79 ± 37	64 ± 34[a]

Results expressed as mean ± SEM.
[a] $p < 0.05$ compared with the control diet period. Significance assessed by Wilcoxon's two-tailed signed-ranks test

Table 5. Serum triglycerides and cholesterol on fasting (0700 h) and in daytime during treatment with the control diet and the high-fibre diet. ($n = 13$)

Time (h)	Serum lipids (mmol/l)	Control diet	High-fibre diet
0700	Triglycerides	3.39 ± 0.54	3.89 ± 0.78
	Cholesterol	5.63 ± 0.18	5.83 ± 0.23
1100	Triglycerides	4.39 ± 0.51	4.43 ± 0.79
	Cholesterol	5.66 ± 0.21	5.82 ± 0.16
1500	Triglycerides	4.90 ± 0.70	5.41 ± 1.07
	Cholesterol	5.81 ± 0.22	5.89 ± 0.23
1900	Triglycerides	5.10 ± 0.96	5.75 ± 1.09
	Cholesterol	5.67 ± 0.18	6.08 ± 0.18[a]
2300	Triglycerides	4.62 ± 0.91	5.20 ± 1.09
	Cholesterol	5.50 ± 0.21	5.71 ± 0.23

Results expressed as mean ± SEM. [a]$p < 0.05$ compared with the control diet period (paired, two-tailed test)

Table 6. Serum lipoprotein concentrations on fasting (0700 h) and post-prandially during treatment with the control diet and the high-fibre diet ($n = 14$)

Serum lipoprotein concentrations (mmol/l)	Morning 0700 h	Evening 1900 h
Serum triglycerides		
Control diet	3.42 ± 0.52	5.00 ± 0.95
High-fibre diet	3.80 ± 0.72	5.62 ± 1.11
Serum cholesterol		
Control diet	5.66 ± 0.16	5.75 ± 0.19
High-fibre diet	5.77 ± 0.21	6.06 ± 0.20
Very low density lipoprotein triglycerides		
Control diet	2.59 ± 0.50	4.08 ± 1.00
High-fibre diet	2.96 ± 0.70	4.59 ± 1.05
Very low density lipoprotein cholesterol		
Control diet	1.17 ± 0.19	1.44 ± 0.23
High-fibre diet	1.36 ± 0.29	1.54 ± 0.29
Low density lipoprotein triglycerides		
Control diet	0.61 ± 0.03	0.60 ± 0.04
High-fibre diet	0.53 ± 0.04[a]	0.56 ± 0.04
Low density lipoprotein cholesterol		
Control diet	3.68 ± 0.20	3.42 ± 0.20
High-fibre diet	3.49 ± 0.20[a]	3.55 ± 0.21
High density lipoprotein triglycerides		
Control diet	0.26 ± 0.01	0.34 ± 0.02
High-fibre diet	0.30 ± 0.03	0.37 ± 0.02
High density lipoprotein cholesterol		
Control diet	0.87 ± 0.09	0.87 ± 0.09
High-fibre diet	0.90 ± 0.07	0.92 ± 0.08

Results expressed as mean ± SEM. [a]$p < 0.05$ compared with the control diet period (paired t-test, two-tailed)

cantly so 2 h after the meal (2.1 ± 0.3 and 2.8 ± 0.6 on the control and high-fibre diets, respectively; $p < 0.02$).

The mean 24-h urinary glucose excretion was lower and the proportion of glucose-free urine higher on the high-fibre diet (Table 4), significantly so ($p < 0.05$) during the third week. Seven patients had glucose-free urine during the last week on the high-fibre diet compared with two on the control diet. Another four patients had urinary glucose excretion below 40 mmol/l on both diets. The high mean values in Table 4 are mainly due to two patients with high urinary glucose output on both diets.

The serum triglyceride concentrations were not significantly different at the end of the control and the high-fibre periods respectively, either during fasting or during the day (Table 5). The serum cholesterol showed a tendency to increase after the high-fibre diet, and at 1900 h this concentration was significantly higher on the high-fibre diet ($p < 0.05$). Analyses of the different lipoprotein fractions in the morning (0700 h) and at 1900 h after dinner (Table 6), showed that the LDL triglyceride and cholesterol concentrations during fasting were slightly lower on the high-fibre diet ($p < 0.05$). In the evening the mean cholesterol concentrations in LDL and HDL were somewhat higher after the high-fibre diet. Considered together these findings could explain the slight increase in serum cholesterol concentration at 1900 h (Table 5).

The lipoprotein lipase activities in adipose tissue and skeletal muscle were similar on the two diets. The adipose tissue lipase activities were 104 ± 8 and 102 ± 6 mU/g on the control and high-fibre diets, respectively. The lipase activities in skeletal muscle were 34 ± 4 and 38 ± 5 mU/g. Intravenous fat tolerance remained unchanged. The fractional removal rates (k_2) were 2.8 ± 0.3 and 2.7 ± 0.3 %/min, respectively.

Faecal fat content did not differ significantly. The mean fat content was 7.4 ± 1.0 mmol/day on the control diet and 11.4 ± 2.8 mmol/day on the high-fibre diet.

Serum iron concentrations were not significantly different on the control and high-fibre diets (15.7 ± 1.4 and 16.4 ± 1.3 µmol/l, respectively) and the corresponding figures for serum zinc concentration were 13.5 ± 0.3 and 13.5 ± 0.3 µmol/l.

The concentrations of transferrin (56.6 ± 1.9; 55.3 ± 2.3 µmol/l), haemoglobin (141 ± 3; 140 ± 3 g/l) and gamma glutamyl transferase (0.54 ± 0.13; 0.46 ± 12 µkat/l) and the haematocrit (43 ± 1.1; 42 ± 1.1%) did not show any significant differences between the control diet and the high-fibre diet.

Discussion

The effects of dietary fibre on glucose and fat metabolism have formed the subject of an increasing number of investigations during recent decades, in both man and experimental animals. In these studies it has been clearly demonstrated that different types of dietary fibre may exert different metabolic effects [1, 15, 16].

In previous controlled studies on the effects of dietary fibre in Type 2 diabetic patients, mixed types of fibres have usually been added, including, for example, fruit, vegetables, and high-fibre bread [17–19]. In other studies other nutrients have also been changed [20, 21] and/or the energy level has been decreased, resulting in a pronounced loss of body weight, which may influence the results of the studies [22].

All subjects in the present study tolerated both diets very well. The control diet was a prudent diabetic diet with a dietary fibre content of 12 g/1 000 kcal, a level which is somewhat higher than in a conventional Western diet [23] (in Sweden about 6 g/1 000 kcal [24]). In the experimental diet, the fibre content was doubled.

The fibre-enriched diet was associated with a significant decrease in the blood glucose concentration both post-prandially and during fasting. In earlier studies on the effect of dietary fibre in Type 2 diabetes, reductions of the basal [20] or post-prandial [18] blood glucose concentration, or both [25, 26] have been reported. The divergent results in the different studies may have various explanations, such as differences in dietary composition and patient characteristics. In the present study the patients had poor glycaemic control on admission in spite of continuing therapy. The dietary effects might perhaps have been less pronounced or different in a group of better-controlled patients.

The serum insulin concentration did not differ on the two diets either during fasting or during the day. The significant increase in insulin/glucose ratio may possibly be interpreted as an improvement in peripheral insulin sensitivity.

The 24-h excretion of glucose in the urine was lower after addition of cereal fibre to the diet. Decreased urinary glucose excretion was also observed by Simpson et al after addition of leguminous fibre [21] and by Aro et al after addition of guar gum [26].

Type 1 diabetic patients appear to have an essentially normal lipoprotein pattern, while patients with Type 2 diabetes usually have increased concentrations of serum triglycerides and VLDL and a decreased level of HDL [27, 28]. Little is known about the qualitative effects of dietary treatment on the lipoprotein pattern in Type 2 diabetes. In general, addition of cereal fibre does not seem to influence the serum lipid levels [29, 30]. A possible exception is bran derived from oats [29, 31].

In this study the LDL triglyceride and cholesterol concentrations during fasting were significantly decreased on the high-fibre diet. The differences between the two diets were, however, small. All other lipoprotein lipid concentrations were unchanged. More pronounced effects could probably have been expected if other types of dietary fibre had been used [29, 32, 33].

The lipoprotein lipase activities in adipose tissue were in the same range as those reported earlier for this category of patients [34]. In the present study, the activity of lipoprotein lipase in skeletal muscle tissue corresponded well with the level of VLDL triglycerides (unpublished observations). Neither the enzyme activity in skeletal muscle nor that in adipose tissue was influenced by the addition of fibre, as was also verified by the unchanged fractional removal rate in the intravenous fat tolerance test, which may be regarded as a measure of the total capacity of the body to hydrolyse triglycerides [35].

An increased loss of faecal fat has been reported in association with increased dietary fibre intake [16]. In this study the mean value after fibre addition, although somewhat higher on the average, was not significantly different from that on the conventional diet. There were no differences in serum iron or zinc concentrations between patients on the two diets. Similar results were obtained by Sandstead et al. [36], while other authors have indicated that a high content of dietary fibre may decrease the blood levels of certain minerals [15]. In this study the period on a high fibre diet was 3 weeks. If the study had been continued for a longer period of time, it is possible that other effects might have been observed.

In conclusion, it seems that an increased content of cereal fibre can be recommended in the dietary treatment of Type 2 diabetic patients. To clarify the effects of other types of dietary fibres, however, and to define an optimal diet for diabetic patients of this type, further studies involving natural foodstuffs in reasonable proportions are required.

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