Dietary fiber does not displace energy but is associated with decreased serum cholesterol concentrations in healthy children[1–3]

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ABSTRACT

Background: Dietary fiber has health benefits, but fiber recommendations for children are controversial because fiber may displace energy.

Objective: The objective was to longitudinally evaluate dietary fiber intake in children and to study associations between growth variables, serum cholesterol concentrations, and intakes of fiber, energy, and nutrients.

Design: Altogether, 543 children from a prospective randomized atherosclerosis prevention trial (the Special Turku Coronary Risk factor Intervention Project; STRIP) participated in this study between the ages of 8 mo and 9 y. The intervention children (n = 264) were counseled to replace part of saturated fat with unsaturated fat. Nutrient intakes, weight, height, and serum total, HDL-, and LDL-cholesterol and triglyceride concentrations were analyzed. Children were divided into 3 groups according to mean dietary fiber intake in foods: low (lowest 10%), high (highest 10%), and average (middle 80%) fiber intakes.

Results: Fiber intake associated positively with energy intake and inversely with fat intake. Children with a high fiber intake received more vitamins and minerals than did children in other groups. In longitudinal growth analyses, weights and heights were similar in all 3 fiber intake groups, and fiber intake (g/d) associated positively with weight gain between 8 mo and 2 y. Serum cholesterol concentrations decreased with increasing fiber intakes. Children in the intervention group had a higher fiber intake than did the control children during the entire follow-up period.

Conclusion: Fiber intake did not displace energy or disturb growth between 13 mo and 9 y of age. Serum cholesterol values correlated inversely with fiber intake, which indicated that part of the cholesterol-lowering intervention effect in the STRIP project may have been explained by dietary fiber. *Am J Clin Nutr* 2010;91:651–61.

INTRODUCTION

Dietary fiber is an important constituent of diet. High dietary fiber intake has several health benefits in both adults and children. It promotes gastrointestinal function and helps to reduce the risk of cardiovascular diseases by reducing serum total and LDL-cholesterol concentrations in adults (1–3) and children (4). Dietary fiber intake usually has no effect on HDL-cholesterol or triglyceride concentrations (2); however, inverse associations are possible (1, 3, 5). A diet high in fiber lowers serum insulin concentrations (5) and reduces the risk of obesity (6), thus reducing the risk of type 2 diabetes. High dietary fiber intake also protects against some types of cancer (7, 8).

The current dietary recommendations for fiber intake in children are based on assumptions and data extrapolated from studies in adults (9). Per the Dietary Reference Intakes (DRIs), fiber intakes of 19 g/d for 1- to 3-y-olds and 25 g/d for 4- to 8-y-olds are recommended (10). The American Health Foundation (AHF) recommends a fiber intake of age in years plus 5–10 g/d for children older than 2 y of age (11), whereas the American Academy of Pediatrics (AAP) Committee on Nutrition recommends an intake of 0.5 g/kg body weight for children older than 2 y (12). According to the Nordic Nutrition Recommendations (NNRs), the daily fiber intake should be ≥10 g by school age and should gradually increase to reach the adult recommendation (25–35 g/d) during adolescence (13). The Finnish dietary recommendations emphasize that infants should not consume dietary fiber excessively, because an extremely high fiber intake decreases energy density and may increase the bulkiness of the diet (14). However, the data supporting possible unfavorable effects of a high-fiber diet in children are unconvincing. Poor growth and nutritional status have been reported in children with an exceptionally high dietary fiber intake, such as in vegans (15), and in children who consume a macrobiotic diet (16). Besides, in young children, the effect of dietary fiber intake on growth might also be important at the time of the pubertal growth spurt

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(9). Only a few prospective studies on the association between dietary fiber and growth factors in children have been conducted. In recent studies, fiber intake at age 2 y was not related to the percentage of body fat, and the changes in fiber intake between 2 and 7 y of age were not associated with BMI (17) or weight changes in children and adolescents (18).

The purpose of this study was to investigate the effects of dietary fiber intake on the intake of other nutrients and energy, growth, serum cholesterol concentrations, and blood pressure in children followed up prospectively from 8 mo to 9 y of age.

SUBJECTS AND METHODS

STRIP study children

The study design of the STRIP project (the Special Turku Coronary Risk factor Intervention Project for children) has been published (19, 20). Briefly, families for this prospective, randomized long-term coronary heart disease risk factor intervention trial were recruited by nurses at well-baby clinics in the city of Turku, Finland. At the time of recruitment the children were 5 mo of age. Between March 1990 and June 1992, 1054 volunteer families with 1062 infants were enrolled and randomly assigned to form an intervention group (n = 540) or a control group (n = 522). The Joint Commission on Ethics of the Turku University and the Turku University Central Hospital approved the STRIP study. Informed consent was obtained from the parents at the beginning of the trial.

Counseling

The counseling given to the intervention families is described in detail elsewhere (20–22). The counseling was carried out by nutritionists who had both theoretical and practical education on childhood nutrition. In brief, the intervention families received individualized dietary counseling aimed at a decrease in the child's intake of saturated fat and cholesterol and an increase in the intake of monounsaturated and polyunsaturated fats. The families were seen at 1- to 3-mo intervals until the children were 2 y of age and at 6-mo intervals thereafter. When the children reached the age of 7.5 y, direct counseling of the children themselves commenced (21). The aims of the counseling remained the same as before. At 8 y of age, counseling on how to reduce salt intake began but no specific counseling to increase dietary fiber intake was implemented before or at 9 y of age. The counseling was always based on the family's dietary habits and food record analyses. A fixed diet was never ordered. Instead, suggestions were made on how to replace high-fat and high-saturated-fat foods with other products. The control families received only general dietary information as delivered at Finnish well-baby clinics and in school.

Food records

All families (parents and other caregivers, eg, staff at daycare centers and schools) kept a 3-d food record of the child's food intake every 6 mo until the age of 2 y. Later, when the daily variation in the child's diet became larger, food records were kept for 4 consecutive days. The food records included at least one weekend day. The records were reviewed by a nutritionist for completeness and accuracy at each follow-up visit. Nutrient intakes were analyzed with the Micro Nutrica program (23) developed at the Research and Development Centre of Social Insurance Institution, Turku, Finland. The program calculates 66 nutrients of commonly used foods and dishes in Finland and includes data on all foods commonly consumed by Finnish children. In the Micro Nutrica, dietary fiber comprises the edible parts of plants that cannot be digested or absorbed in the small intestine and is based on Finnish analyses about foods grown in Finland (24–26) and also on recent analyses about prepared foods from the Finnish food industry. In addition, complementary data are obtained from international food-composition tables. The data bank is flexible, permitting continuous updating and the addition of new single or composite foods and specific or personal recipes. Vitamins and minerals consumed as supplements were not included in the calculations.

Children in the present study

This study group consisted of the 543 children (281 boys, 262 girls) who had returned ≥10 of the requested 15 food records between the ages of 13 mo and 9 y. Mean dietary fiber intake was calculated as g/MJ (g/240 kcal) for every child by using all of the available food records (mean: 13 food records) between the ages of 13 mo and 9 y. The children were divided according to energy-adjusted mean fiber intakes from foods into 3 categories: low fiber intake, average fiber intake, and high fiber intake (**Table 1**). The low-fiber-intake group consisted of children with the lowest mean fiber intake (the lowest 10th percentile), the high-fiber-intake group consisted of children with the highest mean fiber intake (the highest 10th percentile), and the average-fiber-intake group consisted of the remaining 80% of children. The division of the children to the abovementioned groups was decided after examining the distribution of fiber intake graphically. The fiber intake showed moderate tracking over the years. Of the 56 children in the high-fiber-intake group with a mean fiber intake within the highest 10% in our data, 46 (82%) had an annual fiber intake within the highest quartile in ≥50% of the food records. Of the 58 children with a low fiber intake, 38 (65%) had an annual fiber intake within the lowest quartile in ≥50% of the food records.

At the child's age of 8 mo, food records were also collected (n = 464). However, dietary data on energy intake, for example, was incomplete at 8 mo because some of the children were still breastfed. Thus, at this age, dietary fiber intake was expressed only as g/d and not as g/MJ.

TABLE 1
Number of intervention and control boys and girls from the Special Turku Coronary Risk Factor Intervention Project (STRIP) by dietary fiber intake group at 9 y of age

	Fiber group					
	Low (<10th percentile)		Average (10th–90th percentile)		High (>90th percentile)	
	Intervention	Control	Intervention	Control	Intervention	Control
Boys	9	27	110	109	20	6
Girls	4	18	104	106	17	13
Total	13	45	214	215	37	19

Measurement of weight, height, and blood pressure

The weights of the children were measured to the nearest 0.01 kg with an infant scale (Seca 725; Seca, Hamburg, Germany) until the age of 15 mo and thereafter by using an electronic scale (S10; Soehnle, Murrhardt, Germany) to the nearest 0.1 kg. Recumbent lengths of the children younger than 2 y were recorded with an infant board (Bekvil; Paljerakenne, Helsinki, Finland); thereafter, standing heights were measured to the nearest millimeter with a wall-mounted Harpenden stadiometer (Holtain, Crymych, United Kingdom). Children were divided into 3 weight groups at 9 y of age: thin, normal weight, and overweight. Overweight was defined according to the age- and sex-specific BMI cutoffs of the International Obesity Task Force BMI for children (27), corresponding to the adult BMI (in kg/m^2) of 25. Children were classified as thin according to the international age- and sex-specific BMI cutoffs for children (28), corresponding to the adult BMI of 18.5.

The sitting blood pressure of children was measured annually from 13 mo to 9 y of age by using an oscillometric noninvasive blood pressure monitor (Dinamap 1846 SX; Criticon, Tampa, FL) after an appropriate rest of 15 min. The accuracy of the device was regularly checked against a mercury sphygmomanometer. Proper cuff size according to the size of the child's right arm was used.

Laboratory analyses

Nonfasting blood samples for total and HDL cholesterol and apolipoprotein (apo) A-I and apo B were drawn annually from 13 mo to 4 y of age. Fasting samples for total and HDL cholesterol and triglycerides and apolipoproteins A-I and B were drawn at the ages of 5, 7, and 9 y (20, 22, 29). The Friedewald formula was used to calculate LDL-cholesterol concentration at these ages (30). The serum cholesterol concentration was measured by using a fully enzymatic cholesterol oxidase-*p*-aminophenazone method, (CHOD-PAP; Merck, Darmstadt, Germany) (31). Apo A-I and apo B were measured immunoturbidimetrically by using apo A-I and apo B kits (Orion Diagnostica, Helsinki, Finland). The serum HDL-cholesterol concentration was analyzed after precipitation of LDL and VLDL with dextran sulfate 500 000 (32). The interassay (intraassay) CVs for total cholesterol and HDL cholesterol were 2.0% (1.5%) and 1.9% (1.2%), respectively. The serum triglyceride concentration was analyzed by using the colorimetric GPO-PAP method (Merck, Darmstadt, Germany) with an automatic Olympus AU 400 analyzer (Olympus, Hamburg, Germany).

Statistical analyses

The variables with skewed distribution were log transformed for the analyses. The results are expressed as means (±SDs) or geometric means (95% CIs). The proportions of boys and girls and children from the 2 STRIP study groups (intervention and control) within the 3 fiber intake groups were analyzed with the Cochran-Mantel-Haenszel method. The associations of weight gain or height gain in small children, assessed as differences between measured values at 8 mo and 2 y, and preceding mean fiber intake (8–13 mo) were evaluated with regression models. Repeated-measures analysis of covariance of the data from 13 mo to 9 y was used in all other analyses. Magnitudes of

TABLE 2
Dietary fiber intake of the intervention and control girls and boys in the Special Turku Coronary Risk Factor Intervention Project (STRIP) between 13 mo and 9 y of age

			Dietary fiber intake		Dietary fiber intake		Dietary fiber intake	
Age and STRIP group	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys
	n	*n*	*g/d*		*g/MJ*		*g/kg*	
13 mo								
Intervention	125	139	6.77 ± 3.11[1]	7.69 ± 3.33	1.74 ± 0.69	1.88 ± 0.73	0.68 ± 0.32	0.73 ± 0.35
Control	137	142	6.95 ± 3.05	7.28 ± 3.06	1.74 ± 0.70	1.74 ± 0.60	0.71 ± 0.31	0.69 ± 0.28
3 y								
Intervention	117	134	9.59 ± 3.00	10.44 ± 2.60	1.99 ± 0.53	2.05 ± 0.46	0.64 ± 0.20	0.69 ± 0.19
Control	126	139	9.55 ± 2.75	9.42 ± 2.85	1.89 ± 0.46	1.78 ± 0.45	0.65 ± 0.19	0.62 ± 0.18
5 y								
Intervention	120	132	11.53 ± 2.89	12.44 ± 3.13	2.04 ± 0.47	2.07 ± 0.49	0.61 ± 0.17	0.65 ± 0.17
Control	132	137	11.29 ± 3.32	11.44 ± 3.17	1.95 ± 0.55	1.83 ± 0.47	0.59 ± 0.18	0.60 ± 0.18
7 y								
Intervention	117	125	13.00 ± 3.40	13.96 ± 3.66	2.09 ± 0.45	2.05 ± 0.44	0.54 ± 0.15	0.57 ± 0.15
Control	127	132	12.48 ± 3.84	13.30 ± 3.73	1.96 ± 0.51	1.90 ± 0.44	0.50 ± 0.15	0.55 ± 0.16
9 y								
Intervention	125	139	13.26 ± 3.89	14.54 ± 4.10	2.04 ± 0.50	2.02 ± 0.51	0.43 ± 0.14	0.48 ± 0.15
Control	137	142	12.53 ± 4.44	13.26 ± 3.38	1.88 ± 0.59	1.76 ± 0.43	0.41 ± 0.16	0.44 ± 0.12
P for sex effect[2]			0.0007		0.25		0.015	
P for intervention effect[2]			0.0028		<0.001		0.0056	
P for age effect[2]			<0.001		<0.001		<0.001	
P for age-by-sex interaction[2]			NS		0.005		NS	

[1] Mean ± SD (all such values).
[2] Repeated-measures ANCOVA covariates: age, sex, STRIP study group and all their interactions, backward selection (exclusion criteria $P > 0.1$). All interactions except age-by-sex were excluded from the models.

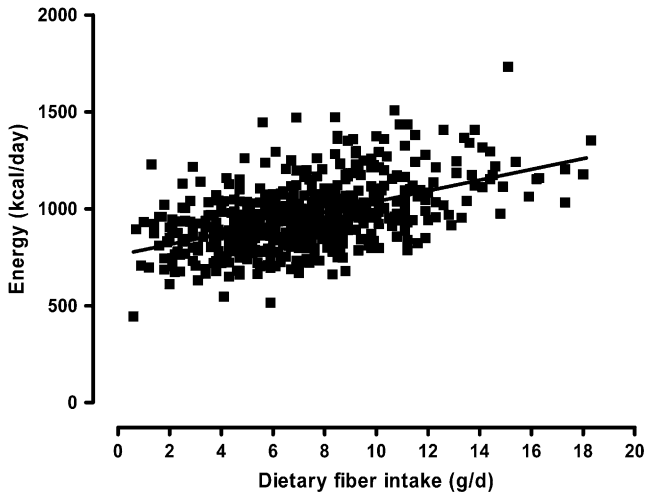

FIGURE 1. Association of energy intake with dietary fiber intake in 13-mo-old children (n = 543). Pearson's correlation coefficient = 0.51 ($P < 0.001$).

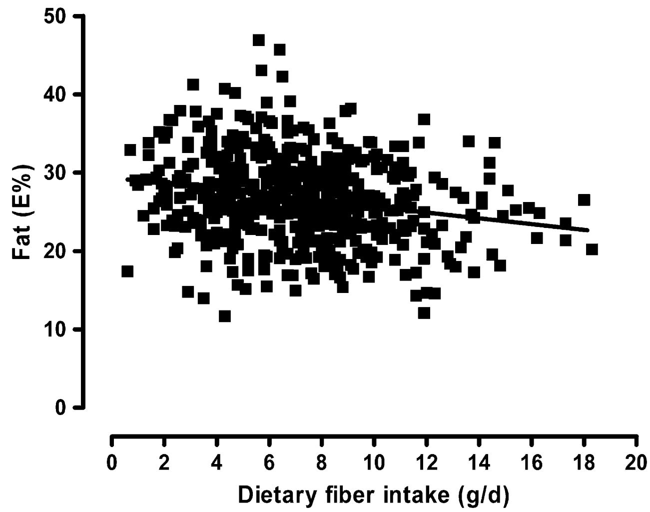

FIGURE 2. Association of fat intake as a percentage of total daily energy intake (E%) with dietary fiber intake in 13-mo-old children (n = 543). Pearson's correlation coefficient = −0.21 ($P < 0.001$).

the associations are expressed as mean levels (categorical predictors) or regression coefficients (continuous predictors). All regression models were adjusted for sex and STRIP study group, and repeated-measures analysis of covariance models were also adjusted for their interactions with age and main predictor. Nonsignificant predictors ($P > 0.1$, for interactions $P > 0.05$) were excluded from all analyses with backward selection. In case of significant interactions, pairwise post hoc comparisons were made with Bonferroni-corrected t tests. A Pearson correlation was used in the figures for the associations between intakes of energy, fat, and dietary fiber intakes. Results were considered significant at $P < 0.05$. Statistical analyses were performed by using SAS software, release 9.1.3 (SAS Institute, Cary, NC) and the SPSS 11.0 package for Windows (SPSS Inc, Chicago, IL).

RESULTS

Dietary fiber intake

Mean (±SD) dietary fiber intakes of 8-mo-old boys and girls were 3.9 ± 2.9 and 3.4 ± 2.6 g/d, respectively. The intakes of dietary fiber varied widely (**Table 2**). The mean fiber intake was higher, in all measured units (g/d, g/MJ, and g/kg), in the intervention children than in the control children. The absolute fiber intake (g/d and g/kg) was higher in boys than in girls (Table 2). However, energy-adjusted fiber intake (g/MJ) was higher in boys than in girls only during the first 2 y and lower thereafter (age-by-sex interaction, $P = 0.005$). The numbers of boys and girls were similar in the fiber intake groups ($P = 0.09$) (Table 1), but the proportions of intervention and control children differed between the fiber intake groups ($P < 0.001$).

TABLE 3
Daily consumption of energy and energy nutrients according to children in groups with low, average, or high dietary fiber intakes[1]

Child's age and fiber group	No. of subjects	Fiber	Energy	Fat	SFA	MUFA	PUFA	Protein	Carbohydrate	Sucrose
		g/MJ	*kJ*	*g*	*g*	*g*	*g*	*g*	*g*	*g*
13 mo										
Low	58	1.2 ± 0.5[2]	4025 ± 650	31.2 ± 8.3	14.3 ± 5.5	10.1 ± 2.6	4.6 ± 1.7	38.5 ± 8.5	128 ± 21	12.4 ± 6.8
Average	429	1.8 ± 0.6	4010 ± 736	28.2 ± 8.6	11.6 ± 4.4	9.5 ± 3.3	4.7 ± 2.1	41.3 ± 9.4	132 ± 26	13.1 ± 7.2
High	56	2.4 ± 0.7	4023 ± 684	27.4 ± 8.8	10.6 ± 4.1	9.3 ± 3.6	5.1 ± 2.7	42.4 ± 8.8	133 ± 23	10.5 ± 7.4
5 y										
Low	56	1.5 ± 0.3	6099 ± 879	54.0 ± 10.2	24.3 ± 4.9	17.8 ± 3.7	8.2 ± 2.5	55.6 ± 10.6	183 ± 30	39.4 ± 14.5
Average	411	2.0 ± 0.4	5971 ± 1000	49.1 ± 12.0	20.5 ± 6.2	16.9 ± 4.4	8.0 ± 2.3	56.4 ± 11.5	185 ± 33	34.3 ± 12.1
High	54	2.6 ± 0.6	5866 ± 727	44.6 ± 9.8	17.6 ± 4.7	15.5 ± 3.9	7.8 ± 2.5	56.6 ± 10.9	189 ± 27	30.7 ± 9.7
9 y										
Low	58	1.4 ± 0.3	7436 ± 1537	66.7 ± 20.6	28.7 ± 10.0	22.7 ± 7.1	11.0 ± 4.2	66.6 ± 15.8	222 ± 47	48.1 ± 18.4
Average	429	1.9 ± 0.5	7007 ± 1336	56.9 ± 15.8	23.0 ± 7.7	20.2 ± 5.8	9.9 ± 3.2	67.1 ± 14.7	218 ± 44	40.2 ± 17.3
High	56	2.5 ± 0.6	6956 ± 1099	53.9 ± 14.3	20.2 ± 5.7	19.7 ± 5.8	10.5 ± 3.2	67.8 ± 13.3	221 ± 34	31.6 ± 10.8
P for group effect[3]		<0.001	0.18	<0.001	<0.001	0.025	0.076	0.0002	<0.001	<0.001

[1] MUFA, monounsaturated fatty acid; PUFA, polyunsaturated fatty acid; SFA, saturated fatty acid.
[2] Mean ± SD (all such values).
[3] Repeated-measures ANCOVA between 13 mo and 9 y of age [covariates: sex and Special Turku Coronary Risk Factor Intervention Project (STRIP) group].

TABLE 4
Daily consumption of selected vitamins and minerals according to children in groups with a low, average, or high dietary fiber intake

Child's age and fiber group	No. of subjects	Vitamin E[1]	Vitamin C[1]	Folic acid	Calcium	Iron[1]	Zinc	Potassium	Magnesium
		mg/d	*mg/d*	*μg/d*	*mg/d*	*mg/d*	*mg/d*	*mg/d*	*mg/d*
13 mo									
Low	58	4.3 ± 2.8[2]	68.5 ± 28.9	101.2 ± 31.4	766.0 ± 235.4	5.6 ± 1.6	5.5 ± 1.6	1980.3 ± 478.9	164.6 ± 40.3
Average	429	4.1 ± 2.1	68.5 ± 32.8	114.5 ± 37.3	790.6 ± 234.5	6.1 ± 1.8	6.2 ± 1.6	2178.2 ± 459.4	184.9 ± 40.1
High	56	4.7 ± 3.6	70.6 ± 23.4	125.3 ± 34.3	749.6 ± 209.4	6.8 ± 1.9	6.8 ± 1.6	2231.4 ± 476.3	200.7 ± 41.3
5 y									
Low	56	5.8 ± 1.6	60.7 ± 35.1	160.1 ± 39.6	963.3 ± 244.8	7.7 ± 2.1	8.1 ± 1.6	2354.9 ± 346.1	201.4 ± 29.9
Average	411	6.2 ± 1.7	72.2 ± 37.3	178.6 ± 42.2	984.6 ± 248.1	8.3 ± 2.4	8.3 ± 1.7	2547.3 ± 490.0	220.7 ± 40.9
High	54	6.6 ± 1.8	87.8 ± 33.6	198.0 ± 40.1	966.5 ± 235.8	9.1 ± 2.5	8.8 ± 1.8	2786.0 ± 497.8	246.8 ± 42.9
9 y									
Low	58	7.4 ± 2.4	65.9 ± 38.9	188.8 ± 48.7	1123.6 ± 304.7	9.0 ± 2.5	9.1 ± 2.3	2720.0 ± 471.3	235.3 ± 44.2
Average	429	7.4 ± 2.2	80.4 ± 45.8	203.7 ± 46.7	1097.3 ± 317.8	9.6 ± 2.2	9.8 ± 2.1	2911.3 ± 604.6	256.6 ± 52.4
High	56	8.4 ± 2.5	98.8 ± 54.0	236.5 ± 47.1	1104.2 ± 331.6	10.6 ± 2.3	10.3 ± 2.0	3212.3 ± 622.8	288.4 ± 53.8
P for group effect[3]		<0.001	<0.001	<0.001	0.29	<0.001	<0.001	<0.001	<0.001

[1] Log-transformed values were used in the analysis.
[2] Mean ± SD (all such values).
[3] Repeated-measures ANCOVA between 13 mo and 9 y of age [covariates: sex and Special Turku Coronary Risk Factor Intervention Project (STRIP) group].

Energy and energy-nutrient associations with dietary fiber

Fiber intake associated positively with energy intake; every 100-kcal increase was associated with a 0.7-g higher fiber intake. When adjusted for fat intake, a 1-g increase in fiber intake increased energy intake by 22 kcal between the ages of 13 mo to 9 y ($P < 0.001$). This association in 13-mo-old children is illustrated in **Figure 1**. Fat intake as a percentage of total daily energy intake (% of energy) was inversely associated with fiber intake. An increase in fat intake of 1% of energy was associated with a 0.08-g lower fiber intake between the ages of 13 mo to 9 y ($P < 0.001$). This association in 13-mo-old children is illustrated in **Figure 2**. Total carbohydrate intake associated positively with fiber intake; an increase in carbohydrate intake of 1% of energy was associated with a 0.08-g increase in fiber intake between the ages 13 mo and 9 y ($P < 0.001$). An increase in sucrose intake was associated with increased fiber intake at the age of 13 mo, but the effect was opposite in older children. An increase in protein intake of 1% of energy was associated with a 0.05-g decrease in fiber intake between the ages of 13 mo and 9 y ($P = 0.009$).

No differences in energy intake were observed between the 3 fiber intake groups, but fat, saturated fatty acid, and monounsaturated fatty acid intakes were continuously lower in the high-fiber-intake group than in the other 2 groups (**Table 3**). In addition, protein intake was higher whereas sucrose intake was lower in the high-fiber-intake group than in the other 2 groups (Table 3).

Nutrient intake and food group consumption and associations with dietary fiber

Children with high dietary fiber intakes received more vitamins and minerals than did children in the average- and low-fiber-

TABLE 5
Daily food consumption of selected food groups by children in groups with a low, average, or high dietary fiber intake

Child's age and fiber group	No. of subjects	Grains	Vegetables	Fruit and berries	Spreads	Dairy products	Meat and fish	Candy and sugar	Ready-to-eat baby foods
		g/d	*g/d*	*g/d*	*g/d*	*g/d*	*g/d*	*g/d*	*g/d*
13 mo									
Low	58	42 ± 26[1]	98 ± 75	62 ± 61	6 ± 6	441 ± 248	41 ± 32	4 ± 6	437 ± 312
Average	429	60 ± 34	138 ± 76	88 ± 63	7 ± 7	505 ± 236	51 ± 31	5 ± 6	298 ± 241
High	56	81 ± 43	168 ± 92	89 ± 59	8 ± 8	472 ± 189	57 ± 30	4 ± 5	238 ± 254
5 y									
Low	56	122 ± 47	118 ± 56	137 ± 95	22 ± 8	604 ± 184	112 ± 45	32 ± 16	14 ± 49
Average	411	127 ± 42	161 ± 66	161 ± 97	24 ± 9	619 ± 180	110 ± 41	26 ± 17	6 ± 23
High	54	139 ± 40	195 ± 94	209 ± 98	23 ± 10	607 ± 190	99 ± 35	21 ± 15	3 ± 9
9 y									
Low	58	162 ± 66	134 ± 62	121 ± 103	32 ± 14	692 ± 217	136 ± 54	46 ± 29	4 ± 17
Average	429	172 ± 58	179 ± 75	174 ± 126	28 ± 11	663 ± 231	135 ± 52	36 ± 27	3 ± 12
High	56	184 ± 49	221 ± 90	228 ± 162	30 ± 11	648 ± 232	119 ± 44	23 ± 16	2 ± 5
P for group effect[2]		<0.001	<0.001	<0.001	0.13	0.19	0.07	<0.001	<0.001

[1] Mean ± SD (all such values).
[2] Repeated-measures ANCOVA between 13 mo and 9 y of age [covariates: sex and Special Turku Coronary Risk Factor Intervention Project (STRIP) group, age and STRIP group-by-age].

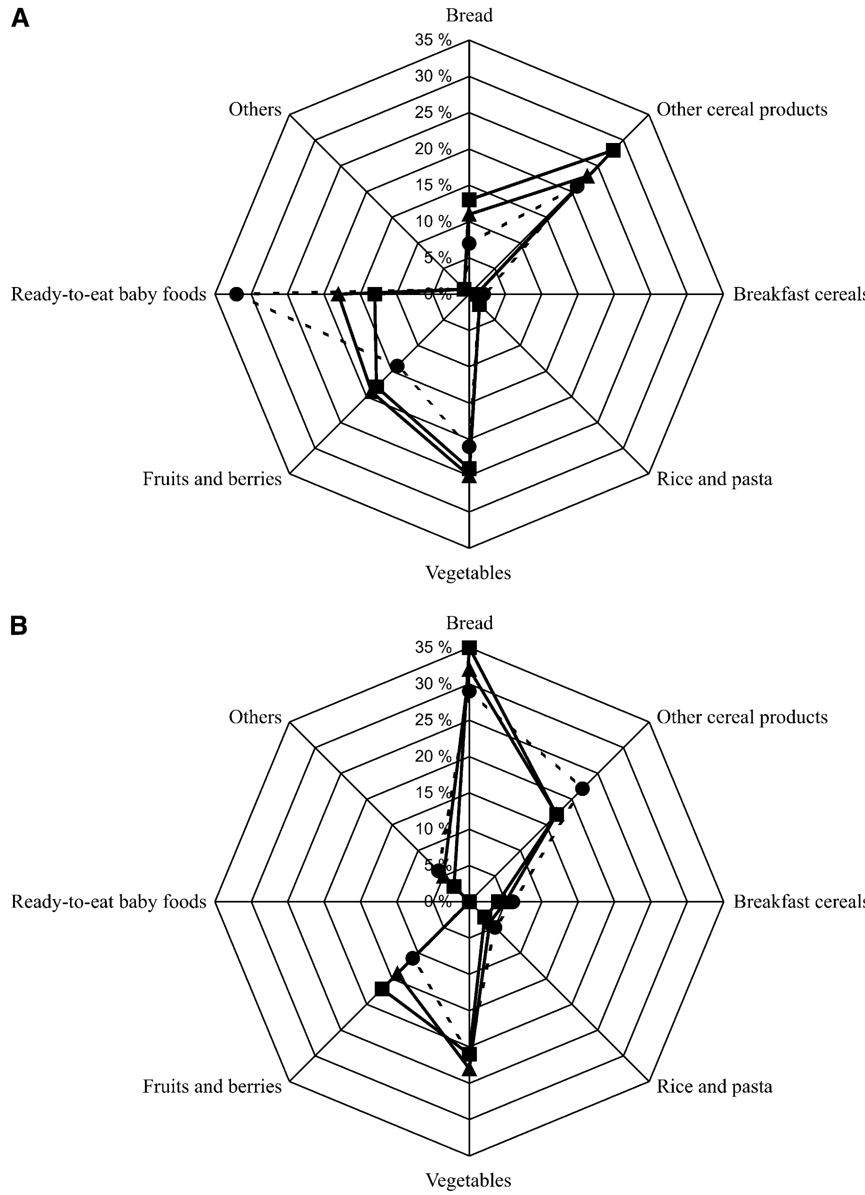

FIGURE 3. Sources of fiber as percentages of fiber intake in children with high (n = 56; ■), average (n = 429; ▲), and low (n = 58; ●) fiber intakes at 13 mo of age (A) and at 9 y of age (B).

intake groups (**Table 4**). Children in the high-fiber-intake group also received more thiamine ($P < 0.001$) and vitamin B-6 ($P < 0.001$) than did children with a low dietary fiber intake (data not shown). There were no differences between dietary fiber intake groups in calcium (Table 4), riboflavin, or vitamin B-12 intakes (data not shown).

The children in the high dietary fiber intake group consumed more grains, vegetables, fruit, and berries than did the other children (**Table 5**), whereas the children in the low-fiber-intake group consumed substantially more ready-to-eat baby foods than did children in the high-fiber-intake group. The most common source of dietary fiber in the high-fiber-intake group at 13 mo of age was other cereal products than bread (porridge and gruel) (28%), whereas children with a low fiber intake received most of their dietary fiber (32%) from ready-to-eat baby foods at 13 mo of age (**Figure 3**A). At 9 y of age, there were no differences between groups in fiber intake sources, and bread contributed most to dietary fiber intake (29–35%) in all fiber intake groups (Figure 3B).

Growth associations with dietary fiber

Dietary fiber intake (as g/d) between 8 and 13 mo of age was positively associated with weight gain between 8 mo and 2 y (**Figure 4**). In children aged 8 mo to 2 y, weight gain increased by 34 g per 1-g increase in fiber intake. In longitudinal analyses between the ages of 13 mo and 9 y, however, weight was similar in all 3 dietary fiber intake groups. The mean weight of the children with a low dietary fiber intake increased from 10.3 kg at 13 mo to 30.3 kg at 9 y, whereas the respective increases were from 10.2 to 30.8 kg in the children with an average dietary fiber intake and from 10.3 to 31.0 kg in children with a high fiber

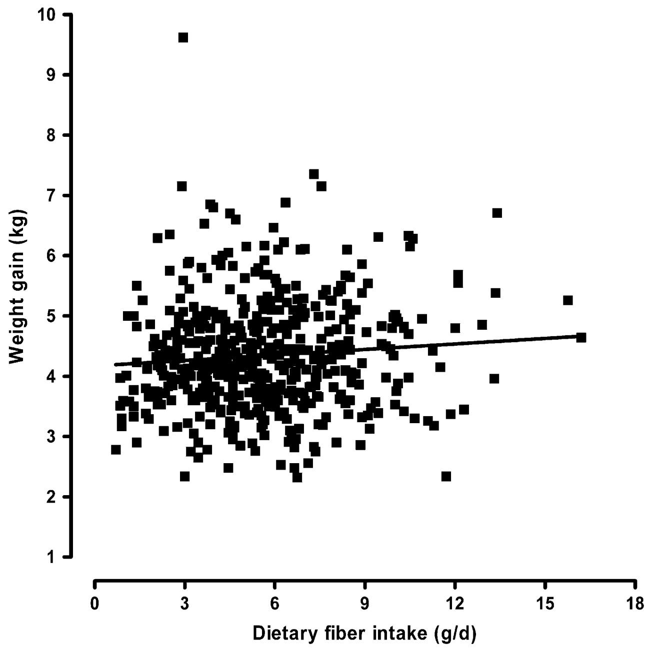

FIGURE 4. Mean dietary fiber intake in 8- and 13-mo-old children and weight gain from 8 mo to 2 y of age (n = 438). ANCOVA: β = 0.034, P = 0.032.

intake (P = 0.54 between groups). Dietary fiber intake did not associate with the lengths and heights of the children between 8 mo and 2 y of age or in longitudinal growth analyses between the ages of 13 mo and 9 y. Long-term dietary fiber intake (as g/d or g/MJ) between the ages of 13 mo and 9 y was similar in children who were thin, normal weight, or overweight at age 9 y (P = 0.44 for g/d, P = 0.91 for fiber g/MJ) (data not shown).

In the comparison of the constantly high- or low-fiber-intake groups (for definition, *see* Subjects and Methods), we found no significant difference in the height (P = 0.69) of the children. For weight, there was a significant fiber group-by-age interaction (P = 0.032); the children with a high fiber intake tended to be slightly heavier, differences fluctuating between 180 g at 13 mo and 1.7 kg at 9 y of age, but the Bonferroni-corrected pairwise post hoc tests were not significant at any age.

Serum lipid and blood pressure associations with dietary fiber

In longitudinal analyses from 13 mo to 9 y of age, an increase in dietary fiber intake by 1 g/MJ decreased serum cholesterol concentrations by 0.059 mmol/L (P = 0.0012) and an increase by 1 g/d decreased serum cholesterol by 0.007 mmol/L (P = 0.012) (**Table 6**). When adjusted for saturated fatty acid intake, a 1-g/MJ increase in dietary fiber intake decreased serum cholesterol by 0.17 mmol/L (P = 0.007), and an increase by 1 g/d decreased serum cholesterol by 0.001 mmol/L (P = 0.0013) (**Table 7**). A 1-g/MJ increase in dietary fiber intake decreased HDL cholesterol by 0.021 mmol/L (P = 0.0005) and apo A-I by 0.002 (P = 0.0003), whereas fiber intake as g/d was not associated with HDL cholesterol or apo A-I between the ages of 13 mo and 9 y. When adjusted for saturated fatty acid intake, dietary fiber as g/MJ had no effect on HDL cholesterol or apo A-I. Fiber intake was not associated with LDL-cholesterol or triglyceride concentrations at ages 5, 7, and 9 y. Dietary fiber as g/d associated inversely with apo B and even when adjusted with saturated fatty acids. Non-HDL-cholesterol results paralleled serum total cholesterol results between the ages of 13 mo and 9 y (Tables 6 and 7).

The effect of dietary fiber on serum cholesterol values was stronger with lower saturated fat intakes (fiber-by-saturated fatty acid interaction, P = 0.013). Serum cholesterol concentration was lower whereas fiber intake was higher in STRIP intervention boys than control boys between ages 13 mo and 9 y ($P < 0.001$) (**Figure 5**, A and B). However, there were no differences in serum cholesterol concentrations between intervention and control girls (P = 0.18), even though the dietary fiber intakes were higher in the intervention girls than in the control girls (P = 0.017) (Figure 5, C and D). Dietary fiber intake as g/d or as g/MJ was not associated with systolic or diastolic blood pressure in children between the ages of 13 mo and 9 y, and blood pressures were similar in all 3 dietary fiber intake groups.

TABLE 6
Associations of serum total and HDL-cholesterol, apolipoprotein (apo) A-I, and apo B concentrations in children aged 13 mo to 9 y (LDL cholesterol and triglycerides at 5, 7, and 9 y) with dietary fiber intake in model 1[1]

	Dietary fiber intake (g/d)		Dietary fiber intake (g/MJ)	
Model 1	β[2]	P	β[2]	P
Total cholesterol (mmol/L)	−0.0074	0.012	−0.059	0.0012
HDL cholesterol (mmol/L)	−0.0006	0.51	−0.021	0.0005
HDL:total cholesterol	0.00026	0.20	−0.0009	0.50
LDL cholesterol (mmol/L)	−0.0054	0.13	−0.040	0.13
Non-HDL cholesterol (mmol/L)	−0.0069	0.0083	−0.041	0.011
Triglycerides (mmol/L)[3]	0.00080	0.76	0.012	0.53
apo A-I (g/L)	−0.00006	0.94	−0.0016	0.0003
apo B (g/L)	−0.0015	0.042	−0.0070	0.12

[1] n = 461 to 518. Repeated-measures ANCOVA was used. All models included Special Turku Coronary Risk Factor Intervention Project (STRIP) group, age, sex, and fiber intake–by-age, fiber intake–by-sex, and age-by-sex as covariates; all interactions of fiber intake were excluded from the analyses with backward selection (criteria $P > 0.05$).

[2] β describes the net change in serum lipid values per 1 g/d or 1 g/MJ dietary fiber.

[3] Log-transformed values were used in the analysis.

TABLE 7

Associations of serum total and HDL-cholesterol, apolipoprotein (apo) A-I, and apo B concentrations in children aged 13 mo to 9 y (LDL cholesterol and triglycerides at 5, 7, and 9 y) with dietary fiber intake in model 2[1]

	Dietary fiber intake (g/d)		Dietary fiber intake (g/MJ)	
Model 2	β[2]	P	β[2]	P
Total cholesterol (mmol/L)	−0.0098	0.0013	−0.167	0.0073[3]
HDL cholesterol (mmol/L)	−0.0026	0.0078	−0.008	0.19
HDL:total cholesterol	0.00018	0.39	−0.00051	0.70
LDL cholesterol (mmol/L)	−0.0050	0.18	−0.025	0.37
Non-HDL cholesterol (mmol/L)	−0.0084	0.0014	−0.132	0.015[4]
Triglycerides (mmol/L)[5]	0.0010	0.71	−0.005	0.80
apo A-I (g/L)	−0.0011	0.20	−0.0091	0.094
apo B (g/L)	−0.0016	0.027	−0.0044	0.35

[1] n = 461 to 518. Repeated-measures ANCOVA was used. All models included Special Turku Coronary Risk Factor Intervention Project (STRIP) group, age, sex, and fiber intake–by-age, fiber intake–by-sex, and age-by-sex as covariates; all interactions of fiber intake were excluded from the analyses with backward selection (criteria $P > 0.05$). Additionally adjusted for saturated fatty acid as g/d (dietary fiber intake as g/d) or saturated fatty acid as % of energy (fiber intake as g/MJ).

[2] β describes the net change in serum lipid values per 1 g/d or 1 g/MJ dietary fiber while saturated fatty acid was constant.

[3] Significant interaction: fiber-by–saturated fatty acid (P = 0.022, β = 0.010).

[4] Significant interaction: fiber-by–saturated fatty acid (P = 0.013, β = 0.013).

[5] Log-transformed values were used in the analysis.

DISCUSSION

In this prospective long-term study, we showed that children aged 13 mo to 9 y with high fiber intakes had a better-quality diet than did those with a low fiber intake. Furthermore, dietary fiber intake was associated inversely with the serum cholesterol concentration but showed only a slightly positive association with weight development.

In STRIP children 2 to 9 y of age, the mean fiber intake was within the AHF's "age+5 rule" (11) and AAP Committee on Nutrition (0.5 g/kg body weight) (12) recommendations but outside the DRI guidelines (10). The dietary fiber intake varied greatly, and a rather large group of children received smaller than recommended amounts of fiber. The AHF recommendation was met by 47% of food records between 2 and 9 y of age (n = 4163), and the AAP recommendation was met by 62% of food records between the ages of 13 mo and 9 y (n = 4675), whereas only <1% of all food records (n = 4706) met the DRI fiber recommendation. The DRI recommendations (2005) are based on the assumption that all children aged >1 y and adults should consume 14 g fiber for every 1000 kcal energy consumed, which exceeds other recommendations. Only 15% of German children achieved a fiber intake of 14 g/1000 kcal, even though as many as 84% of the 2- to 8-y-old children met the AHF "age+5 rule" (33). In the study by Hampl et al (34), 45% of 4- to 6-y-old children met the "age+5 rule," whereas only 8% of the children met the fiber recommendation of ≥14 g/d for 2- to 3-y-olds and of ≥20 g/d for 4- to 5-y-olds in the study by Kranz et al (35).

The fiber intakes in this study were comparable with those reported earlier. In our study, the mean energy-adjusted fiber intake was fairly constant in children older than 2 y, whereas in the German DONALD (Dortmund Nutritional and Anthropometric Longitudinally Designed) Study, the adjusted intake reached the maximum at age 1 y and decreased thereafter (33). The absolute dietary fiber intake of STRIP children was similar, but the energy-adjusted intake was higher than that in a Swedish study (36). In British children (37), the intake of nonstarch polysaccharides was lower than in our study. However, the absolute fiber intake provides only limited information, and it is preferable to also measure dietary fiber intake in units other than g/d. Furthermore, comparisons between fiber intakes in different studies are complicated by differing definitions of fiber. Consensus on reference intakes of dietary fiber has been partially limited by differences in analytic techniques (38), lack of agreement on the definition of dietary fiber, and changes in the definition of *fiber* over the years. The Institute of Medicine suggested that the term *total fiber* is the sum of dietary fiber and functional fiber (10). Dietary fiber consists of nondigestible carbohydrates and lignin, whereas functional fiber consists of isolated, nondigestible carbohydrates that have beneficial physiologic effects in humans. In our study, dietary fiber was defined as nondigestible carbohydrates. We were not able to investigate functional fiber (eg, fiber added to foods).

An increase in dietary fiber is associated with an increased nutrient density of most nutrients. In the study by Hampl et al (34), the recommended dietary fiber intake was associated with lower energy-adjusted intakes of fat and cholesterol and higher intakes of vitamin A, folate, magnesium, and iron. Similarly, in American children, a higher dietary fiber intake was associated with higher intakes of iron, folate, vitamin A, and vitamin C, whereas intakes of calcium and vitamin B-12 were inversely associated with fiber intake (39). In the study by Nicklas et al (40), a high-fiber diet was associated with greater intakes of vitamins A, B-6, B-12, and C and with niacin, thiamine, riboflavin, folate, magnesium, iron, zinc, and calcium. We also found positive associations with most vitamins and minerals, except for calcium, which in our study showed no association with dietary fiber.

We showed that the consumption of ready-to-eat baby foods was more frequent in the low-fiber-intake group than in the high-fiber-intake group. Sources of fiber intake differed between fiber groups at 13 mo of age, when the most common fiber intake source in children with a high fiber intake was cereal products other than bread (eg, porridge and gruel) instead of ready-to-eat baby foods. In 7- to 10-y-old American children, vegetables, bread, and fruit contribute 33% of total dietary fiber intake (34)

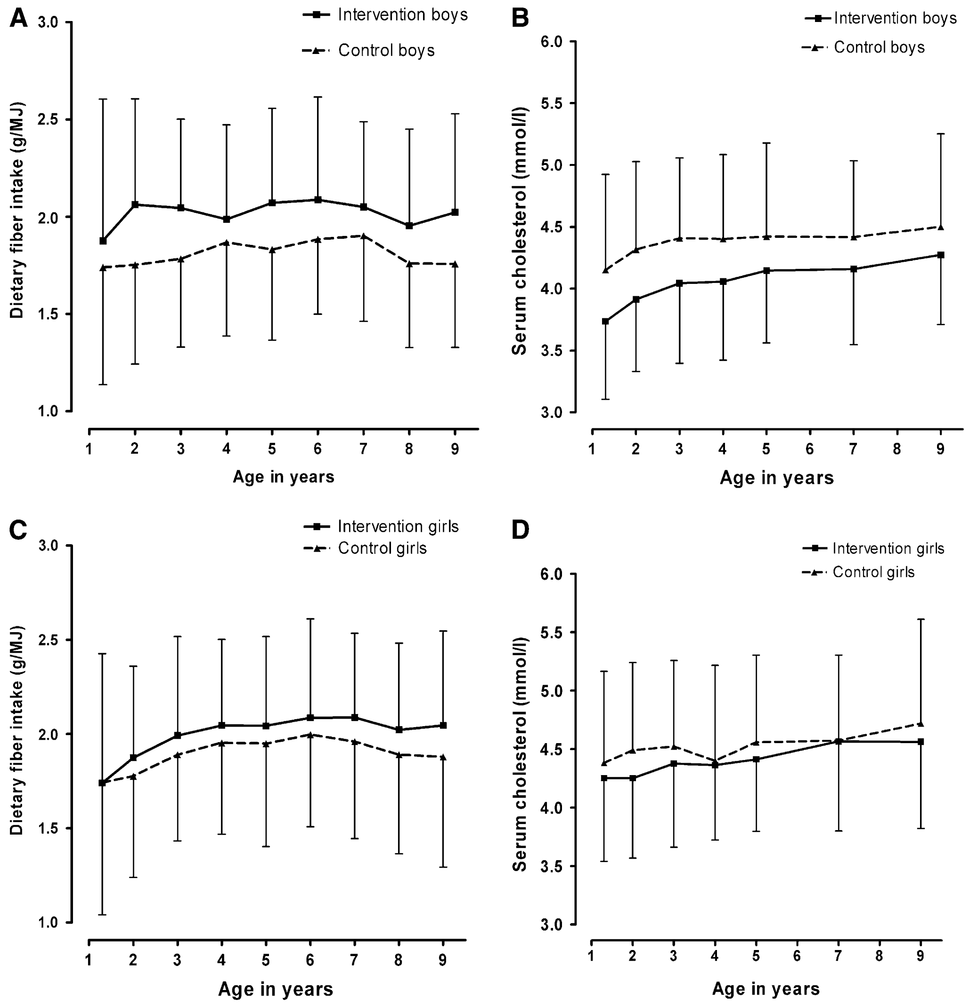

FIGURE 5. A: Dietary fiber intake in intervention boys (solid line) and control boys (broken line) between 13 mo and 9 y of age. Intervention effect: $P < 0.001$ (repeated-measures ANCOVA). B: Serum cholesterol in intervention boys (solid line) and control boys (broken line) between 13 mo and 9 y of age. $P < 0.001$ (repeated-measures ANCOVA). C: Dietary fiber intake in intervention girls (solid line) and control girls (broken line) between 13 mo and 9 y of age. $P = 0.017$ (repeated-measures ANCOVA). D: Serum cholesterol in intervention girls (solid line) and control girls (broken line) between 13 mo and 9 y of age. $P = 0.18$ (repeated-measures ANCOVA). Data are expressed as means ± SDs.

and in 7–8-y-old English children breakfast cereals, bread, fruit, and potato crisps were the main sources of dietary fiber (37). Similarly, the most common fiber intake sources in our study at 9 y of age were bread and other cereal products, vegetables, and fruit in all fiber intake groups.

In the past, an increased fiber intake was linked with poor growth. Such an inverse connection seems to exist in Western countries only in extreme populations, ie, in vegans (15) or in children on macrobiotic diet (16). In healthy children following age-appropriate nutrient recommendations, high fiber intake relates to better nutritional status and to a higher intake of several minerals and vitamins and unaltered physical growth. In our study, as in other studies in children (36, 39), fiber intake was positively associated with energy intake because sources of fiber were also sources of energy, and this association was found even when adjusted for fat intake. It is, however, of utmost importance to note that a high fiber intake in our study children did not disturb the children's growth. In adults, fiber intake correlates inversely with BMI (41–44) and is associated with lower weight gain (5, 45), which protects against overweight. Fiber consumption has been shown to be associated with a reduced risk of overweight in children (46), but this assumption was not supported in our study. There are several explanations why fiber intake aids in weight control. High-fiber foods have a much lower energy density than do high-fat foods, and dietary fiber intake decreases overall food intake by promoting satiation via different mechanisms (6).

Accurate recording of children's food consumption is problematic. However, the food records provided by parents and caregivers of children have been reliable and valid at the group level (47, 48), and survey methods are ultimately dependent on the motivation and compliance of subjects (49). We believe that families in the STRIP project were very motivated and compliant because the children received feedback about their diet based on food records, and the personnel of the project were familiar to the families. Sources of dietary fiber are also considered healthy; therefore, underreporting of fiber should not be a problem. The correlation of dietary fiber between precoded food records and weighed records was 0.61 in girls and 0.55 in boys at the age of 9 y, and the correlation coefficients were higher for fiber than for other nutrients (47).

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Dropout may be an important limitation in long-term follow-up studies. We previously performed a dropout analysis in the STRIP children until age 10 y, which showed that total cholesterol concentrations and saturated fat intakes were (before discontinuation) similar in the children who had withdrawn from the study and in those who remained in the study (50). Therefore, it is unlikely that the dropout would have led to meaningful bias regarding the fiber data in the present study.

In general, a high fiber intake is associated with a lower serum cholesterol concentration in children (4) and in adults (1–3). Very high intakes of soluble fiber reduce cholesterol concentrations, even in adults with a diet low in saturated fat and cholesterol (51). In the STRIP study, part of the cholesterol-lowering intervention effect might be explained by changes in dietary fiber intake, because fiber intake is inversely associated with serum cholesterol concentrations, even when adjusted for saturated fat intake. The beneficial role of dietary fiber is also supported by different effects of STRIP intervention on cholesterol concentrations in boys and girls: intervention and control girls had similar cholesterol values, whereas intervention boys had markedly lower cholesterol values than did control boys. Saturated fat intake was lower in the intervention children than in the control children of both sexes (22), but differences in dietary fiber intakes between intervention and control boys were clearly larger than those between intervention and control girls. Moreover, we found that dietary fiber more effectively lowers serum cholesterol concentrations when the saturated fatty acid intake is low. These lipid changes provide additional support for the dietary counseling of low-saturated-fat diets, which are usually high in dietary fiber and micronutrients. It is convenient to recommend an increase in sources of dietary fiber that include grains, fruit, berries, and vegetables, which are all rich sources of micronutrients but contain low amounts of fat and sugar. The results of other studies in children and young adults (4, 5) provide support for a significant role of dietary fiber in protecting against cardiovascular disease risk factors such as overweight, high blood pressure, high blood glucose, and high cholesterol values.

Besides total cholesterol, dietary fiber, in particular soluble fiber, seems to reduce serum LDL-cholesterol concentrations (2, 4, 52). In our study, there was a trend toward lower LDL cholesterol with increasing dietary fiber intake, but this effect was not statistically significant. One possible explanation for this was that we had LDL-cholesterol values only from 3 age points, whereas total cholesterol was measured 7 times. Thus, the statistical power for LDL cholesterol was much lower than for total cholesterol. Non-HDL cholesterol, which is often used as a substitute for LDL cholesterol as an atherogenic lipid variable and for which we had 7 age points, showed a significant inverse association with dietary fiber intake. Dietary fiber as g/d was not associated with HDL cholesterol, but dietary fiber as g/MJ was inversely associated with HDL cholesterol, as was also previously reported by Marckmann et al (53) and Sandström et al (54). However, when adjusted with saturated fatty acid intake, dietary fiber as g/MJ had no effect on HDL cholesterol. Quantitatively, approximately two-thirds of the decreasing effect of dietary fiber (as g/MJ) on total cholesterol comes from the effect on LDL cholesterol and one-third comes from HDL cholesterol (Table 6). Thus, the overall effect of increases in dietary fiber intake on cholesterol metabolism seems to be advantageous. In line with previous studies (52), we observed no effect of dietary fiber intake on serum triglyceride concentrations.

In conclusion, a high fiber intake does not displace energy or disturb growth in children between 13 mo and 9 y of age. Part of the intervention effect on serum cholesterol concentration observed in the STRIP project might be explained by the effect of dietary fiber. Consumption of a low-fat diet increased the intake of dietary fiber automatically, without any specific dietary counseling.

The authors' responsibilities were as follows—SR: conceived and designed the research and was principally responsible for writing the manuscript; HKL, HN, and TR: conceived and designed the research and revised the manuscript; MS: performed the statistical analyses and drafted parts of the manuscript; KAP and MH: critically revised the manuscript; JSAV: conceived and designed the research and critically revised the manuscript; and OS: conceived and designed the research, critically revised the manuscript, and supervised the project. All authors agreed on the final version of the manuscript. The Juho Vainio Foundation funded both SR and the STRIP project in the aggregate. The purpose of the Foundation is to "support scientific research and publication concerning Finnish public health, particularly healthy vegetarian nutrition, physical exercise and education and water therapy" (http://www.juhovainionsaatio.fi/). None of the authors had any personal or financial conflicts of interest.

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