Dietary Lipids, Sugar, Fiber, and Mortality from Coronary Heart Disease

Bivariate Analysis of International Data

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Univariate analyses with data for the years 1954–1969 from 20 economically advanced countries showed that a combined dietary lipid score based on per capita consumption of saturated fat, cholesterol, and polyunsaturated fat (equation of Keys, et al.) and the consumption of refined and processed sugars were both highly correlated with age-standardized coronary heart disease (CHD) mortality rates for the years 1969–1973 for both men and women aged 35–74 years (*r* values of 0.54 to 0.72). Fiber intake, estimated as the sum of calories available from vegetables, fruits, grains, and legumes, yielded a significant inverse correlation with CHD mortality rates ($r = -0.49$ to -0.68). These three dietary variables are highly intercorrelated. With bivariate analyses (2 × 2 cross-classification and analysis of variance), lipid score, but neither that of sucrose or fiber, was consistently and significantly related to CHD mortality. However, with both higher and lower lipid scores, CHD mortality rates tended to be slightly (nonsignificantly) higher with higher sugar values and with lower fiber values.
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Univariate analyses of international data indicate that mean per capita dietary lipid and sugar intakes of populations are positively related to mortality rates from coronary heart disease (CHD) and that fiber intakes are negatively related to CHD.[1–8] All the correlation coefficients are sizable and highly significant. For socioeconomic reasons, countries that are high in lipid intake are likely to be high in sugar and low in fiber intakes.[1] This study explored the question as to whether fat, sugar, and fiber each remain significantly and independently related to CHD in bivariate analyses.

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Methods

Food disappearance data for 1954–1965 were collected from the food balance sheets of the Food and Agriculture Organization for 20 industrialized countries: Australia, Austria, Belgium, Canada, Denmark, Finland, France, German Federal Republic, Ireland, Israel, Italy, Japan, Netherlands, New Zealand, Norway, Switzerland, Sweden, United Kingdom, United States, and Venezuela. Details of the data have been published previously.[1] These data are the net values of the foods and nutrients available for consumption (based on foods produced by each country) less foods exported, plus foods imported, divided by the total population and by 365, to yield a per-person per-day estimate. No allowance is made for spoilage, trimming, plate waste, or interpersonal differences based on age, sex, or activity. All conversions from foods to nutrients were done using U.S. tables of food composition. Clearly, these estimates are relatively crude approximations of actual consumption; they are of limited validity, and comparative validity across countries is very difficult to assess. This is also true for the age-, sex-, and cause-specific mortality data. For the four periods, 1954–1956, 1957–1959, 1960–1962, and 1963–1965, average values were calculated and converted into nutrient and food group data. These included values for saturated and polyunsaturated fatty acids, cholesterol, refined and processed sugar, and fiber (estimated by the sum of fruits, nonstarchy vegetables, grains, legumes, and starchy vegetables). A three-factor combined dietary lipid score was calculated from the equation of Keys et al.[9] (i.e., 1.35 (2S-P) + 1.5Z, where S and P are the percentage of total calories from saturated and polyunsaturated fatty acids and Z is the square root of dietary cholesterol in milligrams per 1000 calories). Sugar and fiber were expressed as percentage of total calories. Age- and sex-specific CHD mortality rates for each of the years 1969–1973 were collected from World Health Organization reports. These years were used both because they allowed for a time to elapse for a possible effect of the diet variables on mortality, and because they were all within one revision (the 8th Revision) of the International Statistical Classification of Diseases (ICD). Previous analyses yielded similar results when mortality rates for the years 1963–1967 were used (ICD, 7th Revision). Mortality rates for men, women, and both sexes combined were age-standardized by averaging the yearly rates for the four 10-year age groups from 35 to 74; these rates were then averaged for the 5 years.

Results

The data on lipid scores, sugar and fiber intake, and age-averaged CHD mortality rates for the 20 countries are given in table 1. For Japan, the lipid score, sugar intake, and mortality rates are much lower and the fiber consumption is much higher than for the other countries. Therefore, the data were analyzed both with and without the Japanese data.

In univariate analyses, lipid score, and sugar and fiber intake are all highly correlated with CHD mortality rates for men, women, and both sexes combined. These three dietary variables are also highly intercorrelated (table 2). The correlation coefficients between dietary variables and CHD mortality remain significant when Japanese data are removed from

Table 1. Lipid Score, Refined and Processed Sugar, Fiber and Mortality Rates from Coronary Heart Disease

Country	Lipid score*	Refined and processed sugar		Fiber†		Mortality rate/100,000‡		
		Cal	% Cal	Cal	% Cal	Male	Female	Total
Japan	12.6	160.0	7.2	1782.0	80.3	119.3	61.3	88.1
Italy	27.5	222.0	8.2	1677.0	62.3	299.9	125.2	204.1
Venezuela	29.1	358.4	15.7	1330.2	58.2	335.3	193.9	261.6
Israel	29.5	375.2	13.3	1486.8	52.5	639.3	360.5	499.7
Norway	34.0	438.8	14.5	1122.5	36.9	577.2	188.9	370.2
Austria	40.4	371.6	12.5	1356.3	45.8	437.0	169.5	280.4
Netherlands	41.9	493.2	16.6	1048.5	35.4	503.8	174.1	326.3
German Fed. Rep.	43.1	328.0	11.1	1251.4	42.3	439.3	145.6	267.4
Switzerland	43.3	444.8	14.1	1272.1	40.2	288.6	93.2	180.8
France	45.5	341.9	11.3	1331.0	44.0	201.0	72.1	130.1
Sweden	46.6	456.4	15.4	1020.7	34.3	560.5	215.5	379.2
Denmark	47.1	512.0	15.3	1184.3	35.4	586.1	226.3	393.6
Belgium	47.7	335.2	11.3	1283.8	43.2	454.9	167.8	298.1
United States	52.3	504.8	16.1	980.7	31.4	828.6	341.1	563.6
Ireland	53.1	484.4	13.8	1524.6	43.3	646.3	276.6	456.6
United Kingdom	53.2	538.8	16.5	1169.6	35.9	688.3	247.7	445.0
Finland	54.0	414.8	13.5	1309.3	42.4	878.4	275.2	529.1
Canada	57.2	508.4	16.3	991.8	31.9	684.7	260.7	464.3
Australia	57.5	572.4	18.0	1093.7	34.4	821.1	335.6	564.9
New Zealand	67.7	495.6	14.4	1141.4	33.0	772.4	303.0	524.6

*Lipid Score was calculated by the equation of Keys, et al.,[9] i.e., 1.35 (2S-P) + 1.5Z where S and P are the percentage of total calories from saturated and polyunsaturated fatty acids and Z is the square root of dietary cholesterol in mg per 1,000 calories.

†Fiber was estimated as the sum of fruits, nonstarchy vegetables, grains, legumes, and starchy vegetables available for consumption.

‡Mortality rates were age-adjusted by averaging the rates for the four 10-year age groups from 35 to 74 for each year and then averaging the rates for the 5 years.

Lipid score, sugar, and fiber data cover the years 1954–1965. Mortality rates are from the year 1969–1973.

Table 2. Correlation Matrix, Lipid Score, Refined and Processed Sugar, Fiber, and Mortality Rate from Coronary Heart Disease

	Mortality			Lipid score	Refined and processed sugar (% cal)
	Male	Female	Total		
With Japan:					
Lipid score	0.72‡	0.54*	0.67†	—	0.61†
Sugar (% cal)	0.67†	0.64†	0.68‡	—	—
Fiber (% cal)	−0.68‡	−0.49*	−0.63†	−0.85‡	−0.77‡
Without Japan:					
Lipid Score	0.63†	0.42	0.57*	—	0.42
Sugar (% cal)	0.57*	0.54*	0.59†	—	—
Fiber (% cal)	−0.56*	−0.32	−0.50*	−0.75‡	−0.65†

*$p < 0.05$.
†$p < 0.01$.
‡$p < 0.001$.

the analysis, although their magnitude is reduced (table 2).

Since the dietary variables are highly intercorrelated, partial correlation analysis between mortality rates and a dietary variable controlling for the other variables is not appropriate. For example, the correlation between lipid score and fiber is 0.85, and this can readily lead to a spuriously low value for the partial correlation between mortality and one of these factors with the other one controlled. Moreover, correlation analysis tends to be very sensitive to extreme values when the sample size is small. Therefore, for bivariate analysis, the 20 countries were cross-classified into four categories based on two dietary variables (i.e., the countries were divided into the 10 with higher and the 10 with lower values for the two independent variables), and two-way analysis of variance was done to see whether the main effects and the interaction term are significant.

With lipid score and sugar intake in these analyses, the main effects for lipid score for male, female, and combined mortality rates are all highly significant (the corresponding p values are 0.002, 0.021, and 0.004, respectively) (tables 3–5). The main effects for sugar intake are not statistically significant, although slightly higher mortality rates were observed for the higher sugar group than for the lower group within each of the lipid groups. Furthermore, the interaction terms are also not significant for men, women, or the two sexes combined (tables 3–5). Similar results were obtained with Japanese data excluded from the analyses.

This analysis of variance of mortality was also done for the four categories cross-classified by lipid score and fiber intake. Again, the data were highly significant for lipid score but not for fiber intake or the interaction term (tables 6–8). This was also the case with Japanese values excluded from the analyses.

Table 3. Lipid Score, Refined and Processed Sugar and Coronary Heart Disease Mortality Rates for Men Aged 35 to 74 Years

	Bivariate classification of 20 countries				
Variable	Lipid score ≤ 45.5 Sugar < 14.1% cal	Lipid score > 45.5 Sugar < 14.1% cal	Lipid score ≤ 45.5 Sugar ≥ 14.1% cal	Lipid score > 45.5 Sugar ≥ 14.1% cal	All countries
No. of countries	7*	3†	3‡	7§	20
Lipid score	34.6 ± 12.0	51.6 ± 3.4	35.0 ± 6.5	54.5 ± 7.2	44.2 ± 12.8
Sugar (% cal)	11.1 ± 2.6	12.8 ± 1.4	15.6 ± 1.1	16.0 ± 1.2	13.7 ± 2.8
CHD death rate 100,000/year	346.3	659.9	472.1	705.9	538.1

Analysis of variance: lipid score, $p = 0.002$; sugar, $p = 0.264$; and interaction, $p = 0.599$.
*Austria, France, Federal Republic of Germany, Israel, Italy, Japan, Switzerland.
†Belgium, Finland, Ireland.
‡Netherlands, Norway, Venezuela.
§Australia, Canada, Denmark, New Zealand, Sweden, United Kingdom, United States.
Lipid score, sugar, and fiber data are from 1954–1965. Mortality rates are from 1967–1973.

Table 4. Dietary Lipid Score, Refined and Processed Sugar, and Coronary Heart Disease Mortality Rates for Women Aged 35 to 74 Years

Variable	Bivariate classification of 20 countries: Lipid score ⩽ 45.5, Sugar < 14.1% cal	Lipid score > 45.5, Sugar < 14.1% cal	Lipid score ⩽ 45.5, Sugar ⩾ 14.1% cal	Lipid score > 45.5, Sugar ⩾ 14.1% cal	All countries
No. of countries	7*	3†	3‡	7§	20
Lipid score	34.6 ± 12.0	51.6 ± 3.4	35.0 ± 6.5	54.5 ± 7.2	44.2 ± 12.8
Sugar (% cal)	11.1 ± 2.6	12.8 ± 1.4	15.6 ± 1.1	16.0 ± 1.2	13.7 ± 2.8
CHD death rate 100,000/year	146.8	239.9	185.6	275.7	211.7

Analysis of variance: lipid score, $p = 0.021$; sugar, $p = 0.313$; and interaction, $p = 0.967$.
*Austria, France, Federal Republic of Germany, Israel, Italy, Japan, Switzerland.
†Belgium, Finland, Ireland.
‡Netherlands, Norway, Venezuela.
§Australia, Canada, Denmark, New Zealand, Sweden, United Kingdom, United States.

Table 5. Dietary Lipid Score, Refined and Processed Sugar and Coronary Heart Disease Mortality Rates for All Persons Aged 35 to 74 Years

Variable	Bivariate classification of 20 countries: Lipid score ⩽ 45.5, Sugar < 14.1% cal	Lipid score > 45.5, Sugar < 14.1% cal	Lipid score ⩽ 45.5, Sugar ⩾ 14.1% cal	Lipid score > 45.5, Sugar ⩾ 14.1% cal	All countries
No. of countries	7*	3†	3‡	7§	20
Lipid score	34.6 ± 12.0	51.6 ± 3.4	35.0 ± 6.5	54.5 ± 7.2	44.2 ± 12.8
Sugar (% cal)	11.1 ± 2.6	12.8 ± 1.4	15.6 ± 1.1	16.0 ± 1.2	13.7 ± 2.8
CHD death rate 100,000/year	235.8	427.9	319.4	476.4	361.4

Analysis of variance: lipid score, $p = 0.004$; sugar, $p = 0.219$; and interaction, $p = 0.739$.
*Austria, France, Federal Republic of Germany, Israel, Italy, Japan, Switzerland.
†Belgium, Finland, Ireland.
‡Netherlands, Norway, Venezuela.
§Australia, Canada, Denmark, New Zealand, Sweden, United Kingdom, United States.

Table 6. Dietary Lipid Score, Fiber, and Coronary Heart Disease Mortality for Men Aged 35 to 74 Years

Variable	Bivariate classification of 20 countries: Lipid score ⩽ 45.5, Fiber < 40.2% cal	Lipid score > 45.5, Fiber < 40.2% cal	Lipid score ⩽ 45.5, Fiber ⩾ 40.2% cal	Lipid score > 45.5, Fiber ⩾ 40.2% cal	All countries
No. of countries	3*	7†	7‡	3§	20
Lipid score	39.8 ± 5.1	54.5 ± 7.2	32.5 ± 11.5	51.6 ± 3.4	44.2 ± 12.8
Fiber (% cal)	37.5 ± 2.5	33.8 ± 1.7	55.0 ± 13.4	43.0 ± 0.5	43.2 ± 12.2
CHD death rate 100,000/year	456.5	705.9	353.0	659.9	538.1

Analysis of variance: lipid score, $p = 0.002$; fiber, $p = 0.336$; and interaction, $p = 0.708$.
Fiber was estimated by the sum of fruits, non-starchy vegetables, grains, legumes, and starchy vegetables.
*Netherlands, Norway, Switzerland.
†Australia, Canada, Denmark, New Zealand, Sweden, United Kingdom, United States.
‡Austria, France, Federal Republic of Germany, Israel, Italy, Japan, Venezuela.
§Belgium, Finland, Ireland.

Table 7. Dietary Lipid Score, Fiber and Coronary Heart Disease Mortality for Women Aged 35 to 74 Years

Variable	Bivariate classification of 20 countries: Lipid score ≤ 45.5 Fiber < 40.2% cal	Lipid score > 45.5 Fiber < 40.2% cal	Lipid score ≤ 45.5 Fiber ≥ 40.2% cal	Lipid score > 45.5 Fiber ≥ 40.2% cal	All countries
No. of countries	3*	7†	7‡	3§	20
Lipid score	39.8 ± 5.1	54.5 ± 7.2	32.5 ± 11.5	51.6 ± 3.4	44.2 ± 12.8
Fiber (% cal)	37.5 ± 2.5	33.8 ± 1.7	55.0 ± 13.4	43.0 ± 0.5	43.2 ± 12.2
CHD death rate 100,000/year	152.1	275.7	161.2	239.9	211.7

Analysis of variance: lipid score, $p = 0.013$; fiber, $p = 0.718$; and interaction, $p = 0.546$.

Fiber was estimated by the sum of fruits, non-starchy vegetables, grains, legumes, and starchy vegetables.

*Netherlands, Norway, Switzerland.

†Australia, Canada, Denmark, New Zealand, Sweden, United Kingdom, United States.

‡Austria, France, Federal Republic of Germany, Israel, Italy, Japan, Venezuela.

§Belgium, Finland, Ireland.

Table 8. Dietary Lipid Score, Fiber and Coronary Heart Disease Mortality for All Persons Aged 35 to 74 Years

Variable	Bivariate classification of 20 countries: Lipid score ≤ 45.5 Fiber < 40.2% cal	Lipid score > 45.5 Fiber < 40.2% cal	Lipid score ≤ 45.5 Fiber ≥ 40.2% cal	Lipid score > 45.5 Fiber ≥ 40.2% cal	All countries
No. of countries	3*	7†	7‡	3§	20
Lipid score	39.8 ± 5.1	54.5 ± 7.2	32.5 ± 11.5	51.6 ± 3.4	44.2 ± 12.8
Fiber (% cal)	37.5 ± 2.5	33.8 ± 1.7	55.0 ± 13.4	43.0 ± 0.5	43.2 ± 12.2
CHD death rate 100,000/year	292.4	476.4	247.3	427.9	361.4

Analysis of variance: lipid score, $p = 0.003$; fiber, $p = 0.391$; and interaction, $p = 0.975$.

Fiber was estimated by the sum of fruits, non-starchy vegetables, grains, legumes, and starchy vegetables.

*Netherlands, Norway, Switzerland.

†Australia, Canada, Denmark, New Zealand, Sweden, United Kingdom, United States.

‡Austria, France, Federal Republic of Germany, Israel, Italy, Japan, Venezuela.

§Belgium, Finland, Ireland.

Discussion

The findings of the bivariate analyses in this study indicate that among nutritional factors, dietary lipid score (based on cholesterol, saturated fat, and polyunsaturated fat), and not sugar or fiber intake, significantly relates to both male and female mortality rates from premature coronary heart disease in the economically advanced countries. For reasons related to socioeconomic development,[1] consumption of dietary lipids, sugar, and fiber are all highly intercorrelated, and in univariate analyses each is significantly related to CHD mortality rates. Therefore, univariate analyses do not distinguish which factor, if any, is most strongly and decisively related to CHD. The method of 2 × 2 cross-classification and analysis of variance used in this study took the assessment a step further, and yielded data indicating a highly significant relationship of dietary lipid score to CHD mortality rates, independent of the other two dietary variables. For sugar and fiber intake, evidence of a limited, nonsignificant association was obtained (i.e., within each lipid group a nonsignificantly higher average mortality rate was recorded for the countries with high per capita sugar consumption or low per capita fiber consumption).

The univariate findings on dietary lipid score and CHD mortality rates are consistent with data from many cross-population studies.[1-5,8] In contrast, there are few reports in the literature of bivariate analyses involving dietary lipids and sugar intake or dietary lipids and fiber intake. In a study similar to the present one, Armstrong, et al.[8] analyzed data on the relationship of commodity availability to CHD mortality in 30 countries. Using partial correlation as the technique for bivariate analysis, they recorded a strong relationship between sugar and CHD mortality. This study used either total fat or saturated fat in the bivariate analyses, unlike the present study, which used a lipid score combining three dietary lipid components (saturated fat, polyunsaturated fat, and cholesterol). This may account for the different findings of the two studies. Also, it is our judgment that when variables are highly correlated, the method of partial correlation is not the optimal technique for bivariate analysis. The Seven Countries Study,[2] which used partial correlation for bivariate analysis, showed that dietary saturated fat, but not sugar, was significantly and independently related to CHD mortality rates of the cohorts.

Extensive evidence available from several research disciplines (epidemiology, controlled dietary experiments on man, and animal experimental studies) indicates that a key mechanism accounting for the association between dietary lipid and CHD is the effect of dietary lipid on serum cholesterol level of populations and individuals.[1-3, 9] That is, dietary cholesterol and saturated fat have a substantial capacity to raise serum cholesterol, and polyunsaturated fat exerts a modest serum cholesterol lowering effect. It is well known that serum cholesterol is one of the established major risk factors for CHD.[1-3, 10-13] The relationships between dietary lipids and serum cholesterol have been summarized in regression equations,[1-3, 9, 14] including the one by Keys, et al., used in the present study. These equations, derived from controlled feeding experiments on institutionalized men, are generalizable both across populations and to groups of individuals within populations.[1-3, 15, 16] In fact, estimating population mean serum cholesterol levels for middle-aged men using the data from the 20 countries and the equation of Keys, et al. yields values in good agreement with those reported on samples of the free-living population.[1] Moreover, in a recent report from the Chicago Western Electric Prospective Study,[17] which used the equation of Keys, et al., dietary lipid score at baseline and dietary cholesterol considered separately were shown to be significantly related to serum cholesterol of these middle-aged American men, and also to 19-year CHD mortality. In multiple logistic regression analysis, these dietary variables were significantly and independently related to mortality in addition to baseline serum cholesterol, blood pressure, and cigarette smoking status. In addition, animal experiments involving a wide range of species including nonhuman primates show dietary lipid, particularly cholesterol, levels to be a key factor in effecting change in serum cholesterol and cholesterol-bearing lipoproteins, and in inducing atherosclerosis, including severe lesions leading to organ damage (myocardial infarction, peripheral gangrene, etc.).[1-3, 10, 13, 18-21]

For some of the countries studied here, the years of the middle 1950s were so close to World War II that the nutrition residua from the deprivations of that period might still be manifest, with subsequent change to overcome such difficulties. Given this possibility, it is reasonable to ask whether the *trends* in available nutrients over the years 1954–1965 are related to the *trends* of CHD mortality. Analyses of these trends by our group show that this is indeed the case for such variables as dietary cholesterol and foods of animal origin (meats, poultry, eggs, dairy products).[22]

In contrast to the extensive consistent evidence implicating dietary lipid — particularly cholesterol and saturated fat — in atherogenesis, the totality of the animal and human research on sugar is not indicative of etiologic effects, either in regard to influences on serum cholesterol and cholesterol-bearing lipoproteins, or on CHD risk.[1-5, 8, 10, 13, 23-26] Thus, the lack of a significant independent association between sugar and CHD mortality in the bivariate analyses of the present study is a finding consistent with most other reported data.

Since fiber's role in protecting against hyperlipidemia and coronary heart disease was hypothesized in the early 1970s,[6, 7, 27] considerable work has been done in testing the effects of various types of fiber on serum cholesterol lipoproteins, and the findings have augmented reports of research done earlier. The available evidence indicates an ability of some fibrous products of vegetable origin, particularly pectins from fruits and gums from legumes, to reduce serum total cholesterol and low density lipoprotein cholesterol levels.[3, 28-32] Leguminous diets high in fiber also have a favorable effect on glucose tolerance of diabetic patients.[29, 33, 34] These and a few other data sets available on animals and man indicate the need for further work on this matter.[35-37]

In this regard, the limitations of the present study must be kept in mind. It showed a significant relationship of dietary lipid intake, but not of sugar and fiber intake, to CHD mortality rates of men and women in the economically advanced countries. Its findings dealt with *countries* as the units of analysis of the dependent variable, not the risk of *individuals* within populations. These findings are not necessarily generalizable to individuals. In addition, the fiber available for consumption per capita for persons in each of the 20 countries was estimated in the most reasonable way available for these data, and these estimates may be limited in precision. Moreover, only certain types of fiber, rather than all fiber, may be related to CHD as indicated above. Therefore, the results of the present study do not foreclose the need for further research in this area.

In regard to the general limitations of the data used in studies of this type, it may be noted that their imprecisions tend to obscure true associations. Therefore, the finding of a significant relationship between dietary lipid and CHD by many investigators in univariate analyses over the years,[1-5, 8] and by these authors in bivariate analyses as well, is particularly meaningful. This study adds one more brick to a vast edifice of knowledge on this variable and CHD, and underscores once again the potential for prevention of this epidemic disease through modification of this key aspect of life style.

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Index Terms: • lipid score • fiber • sugar • bivariate analysis

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