Cholesterol, coconuts, and diet on Polynesian atolls: a natural experiment: the Pukapuka and Tokelau Island studies[1-3]

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ABSTRACT Two populations of Polynesians living on atolls near the equator provide an opportunity to investigate the relative effects of saturated fat and dietary cholesterol in determining serum cholesterol levels. The habitual diets of the atoll dwellers from both Pukapuka and Tokelau are high in saturated fat but low in dietary cholesterol and sucrose. Coconut is the chief source of energy for both groups. Tokelauans obtain a much higher percentage of energy from coconut than the Pukapukans, 63% compared with 34%, so their intake of saturated fat is higher. The serum cholesterol levels are 35 to 40 mg higher in Tokelauans than in Pukapukans. These major differences in serum cholesterol levels are considered to be due to the higher saturated fat intake of the Tokelauans. Analysis of a variety of food samples, and human fat biopsies show a high lauric (12:0) and myristic (14:0) content. Vascular disease is uncommon is both populations and there is no evidence of the high saturated fat intake having a harmful effect in these populations. *Am. J. Clin. Nutr.* 34: 1552–1561, 1981.

KEY WORDS Dietary fats, cholesterol, risk

Introduction

The quantitative relationships between dietary lipids and serum cholesterol levels have been demonstrated in human feeding experiments reported by Keys et al. (1) and Hegsted et al. (2). A review by Reiser (3) and reply by Keys et al. (4) has again drawn attention to the interest in linking saturated fat in the diet and cholesterol levels. However, Mann (5) in a recent review questions whether there is any relationship between cholesterolemia and diet.

This paper takes advantage of the opportunity provided by two populations of Polynesians living near the equator, to examine the effects of saturated fat and dietary cholesterol in determining serum cholesterol levels.

The populations and their habitats

Pukapuka, an atoll in the Northern Cook Islands, and Tokelau lie approximately 500 km from each other, 11°S and 8°S of the

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equator, respectively. Tokelau consists of three small atolls; Atafu, Nukunonu, and Fakaofo, separated by 91 and 64 km, respectively. Both groups have a traditional Polynesian type of communal society, and are on a subsistence economy with a low per capita income per year. Exports consist of copra and small amounts of woven mats, basketware, and traditional items. Some extra income is derived from moneys remitted by relatives who have migrated to New Zealand (NZ).

In Pukapuka, land and food resources are owned by the community, and money and food are distributed on a communal basis. In Tokelau, land and resources are owned by the extended family groups, and there is a greater range of distribution of resources.

Pukapuka and Tokelau are among the more isolated Polynesian groups and have had relatively little intermarriage with Europeans or non-Polynesians. Traditionally there has been infrequent contact and very little intermarriage between the two atolls. In Tokelau and Pukapuka there are quite strong constraints against first cousin marriages so major familial aggregations of lipid disorders are unlikely.

The coral sand of the atolls is porous, lacks humus, and will not support the food plants that flourish on high tropical islands. Coconut palms, pandanus, breadfruit, and starchy aroids are the only food crops of importance. Breadfruit (*Artocarpus altilis*) is the primary carbohydrate food for about 8 months of the year in Tokelau, but in Pukapuka, where there are extensive taro (*Colocasia esculenta*) and pulaka (*Cyrtosperma chamissonis*) gardens, it does not grow readily and is rarely eaten. Some pulaka grows in Tokelau, but it is slow growing and small, and is much less frequently used than in Pukapuka. Breadfruit, pulaka, and taro are similar in food value and are replaceable in atoll recipes by flour and rice. Fish from the open sea, lagoon, and reef is the chief source of protein. Pigs and chickens are reserved for feasts. Eggs are seldom eaten. Alcohol is not commonly consumed (6). Imported foods (flour, rice, sugar, dripping, and canned meat and fish) are obtained from the small cargo boats that call at both atolls every few months.

The habitual diets of the atoll dwellers of both Pukapuka and Tokelau are high in saturated fat derived from coconut, but low in cholesterol. Although coconut is the chief source of energy for both groups, the Tokelauans derive a much higher percentage of energy from coconut and their saturated fat intake as a result is much higher. On both atolls the diet is rich in fiber-containing foods, and low in sucrose.

Methods

The Pukapuka and Tokelau studies

The Pukapuka study was carried out in May and June 1964. The total population was 796, of whom 436 were 15 yr and over. All members of the population were examined (7).

The Tokelau Island Migrant Study is a long-term multidisciplinary study set up to examine the physical, social, and health consequences of migration from the atolls to NZ. The first collection of data in Tokelau was made in 1968 when the total population was 1792, of whom 948 were 15 yr and over. Of the total population 99% were examined (8).

Dietary data were collected in Pukapuka over an 8-wk period in 1964 and included household food consumption from a sample of households and the nutrient intake of adults in the 25- to 54-yr age groups. In Tokelau, dietary data were collected on the atoll Fakaofo in two stages; household consumption in 1968 and nutrient intake of adults in 1971. There was no evidence of change in food supply or usage in Tokelau over this period.

The data on the overall food consumption and meal patterns were obtained by studies of randomly selected family groups, 13 in Pukapuka; 18 in Tokelau. All food used by the families over a 7-day period was weighed, measured, or counted by the nutritionist and local assistants. Data on the energy and nutrient intake of adults aged 25 to 54 yr were obtained by 24-hr recall. This group comprised 87 males and 78 females in Pukapuka; 26 males and 51 females in Tokelau.

None of the dietary survey subjects was fasting or dieting at the time the data were collected. The data were analyzed using composite food tables. The 165 subjects in Pukapuka comprised 74% of those in the 25 to 54 age group. The smaller sample in Tokelau related to the shorter time available on the atoll and represented 46% of those on Fakaofo in the 25 to 54 age group.

Medical, anthropometric, and biochemical methods

The medical and anthropometric methods have been previously reported (9, 10). Serum cholesterols were estimated by the modified Abell method, (11); serum triglycerides by the Carlson method (12). The Epidemiology Unit laboratory has participated in the lipid standardization program of the Communicable Disease Center, Atlanta, GA, since 1964 and good quality control has been achieved. In 1968 fat biopsies were taken from the buttocks of 18 Tokelauan men and transferred into approximately 20 ml of isopropyl alcohol-petroleum ether (1:1, v/v) following the procedure of Hirsch et al. (13). The Pukapukan samples were collected from men in 1964, using the same method. The samples were prepared for gas liquid chromatography using a method described in a previous publication (14). The European samples referred to in Table 6 were collected in Wellington in 1968 (14).

Food samples and analysis

Food samples were collected in Pukapuka in 1964 and in Tokelau in 1971. They were deep frozen until the time of analysis. The extraction to give the percentage fat and the preparation of methyl esters followed standard methods and were carried out at the Applied Biochemistry Division, Department of Scientific and Industrial Research, Palmerston North.

Prediction regression equations

The regression equations of Keys et al. (1): Δ chol = 1.35 (2 Δ S - Δ P), and of Hegsted et al. (2): Δ chol = 2.32 Δ S - 1.3 Δ P have been applied to the data, where S and P represent the proportions of saturated (S) and polyunsaturated (P) glycerides as percentage of the energy content of the diet.

The differences between the observed cholesterol of the different age/sex groups and those obtained by using the formulae have been statistically tested. The regression equations derived from metabolic studies in American adults reported by Jacob et al. (15) have been applied to predict the cholesterol levels that would be expected based on the diet composition in the two Polynesian groups.

The form of the function used was:

$$\emptyset = 1.26\,(2S - P) + 1.5\,(1000\ C/E)^{1/2}$$

Predicted serum cholesterol = (1.84 - 0.84) ($\emptyset$+62)+ 102, where S = percentage of calories as saturated fatty acids, 12 to 16 carbon chain lengths; P = percentage of calories as polyunsaturated fatty acids; and 1000 C/E = mg dietary cholesterol/1000 kcal.

Results

Anthropometric data

The mean heights, weights, and median subscapular skin folds are shown for subjects aged 15 to 64 yr in **Table 1**. The Tokelauans are heavier, of greater body bulk, and have larger subscapular skin folds than the Pukapukans.

Biochemical data

The mean cholesterol levels for both groups are set out in **Table 2**. The cholesterol levels are 35 to 40 mg higher in Tokelau males in each age group and the differences are highly significant. A similar pattern is shown in the females. There is a trend for levels to be higher in females than males in both groups. The mean triglyceride levels in fasting subjects are set out in **Table 3**. Levels are apparently higher in Pukapuka than in Tokelau and are lower in females than males in both groups. This could relate to the higher percentage of energy from carbohydrate, 52%, in Pukapuka, compared with 32% in Tokelau. The numbers are, however, small in Pukapuka because subjects there were not asked to fast as was done in Tokelau and these differences have not been statistically tested.

High-density lipoprotein cholesterol (HDLC) and low-density lipoprotein cholesterol (LDLC) estimations were not carried out with these samples, but have been carried out in surveys in Tokelau in 1976 and in Tokelau migrants seen in NZ in the period 1975 to 1977 (16).

In both adults and children from 5 to 14 yr the HDLC are higher in Tokelau than in NZ. The LDLC becomes higher in NZ despite the fact that contribution of fat to daily energy declines from 57% in Tokelau with 80% from coconut, to 43% in NZ (16).

Medical status

The overall health of both groups was good. Urines were tested in all subjects and no cases of nephrotic syndrome or hypothyroidism were found that might influence lipid levels. There were no families with familial type 2 hypercholesterolemia. A preliminary review of our data by a consultant geneticist did not suggest the presence of a single major gene for hypercholesterolemia and genetic studies are continuing in greater depth.

Dietary data

The nature of the diets of the two islands can be seen in **Table 4**. In both groups staples were coconut, fish, and a starch fruit or aroid, breadfruit in Tokelau and taro in Pukapuka. In Pukapuka, where local food supplies were less abundant than those of Tokelau, the diet was affected by the arrival of the boat on its 3 monthly visit and the consumption of rice, flour, and canned meat was higher.

Every meal contained coconut in some form: the green nut provided the main beverage; the mature nut, grated or as coconut cream, was cooked with taro, breadfruit or rice; and small pieces of coconut meat were an important snack food. In Tokelau, coconut sap or toddy was used as a sweetener and as

TABLE 1
Anthropometric data Pukapuka and Tokelau 1968 (mean and SE by age and sex)

Variable	Sex	Age	Pukapuka			Tokelau 1968			p*
			Mean	SE	n	Mean	SE	n	
Height (cm)	M	15–19	161.5	1.5	27	164.9	0.6	73	<0.05
		20–24	170.3	1.3	27	167.4	0.8	26	NS
		25–34	168.8	0.9	39	170.8	0.7	60	NS
		35–44	167.2	0.8	37	169.2	0.7	79	NS
		45–54	166.5	0.9	39	168.4	0.8	63	NS
		55–64	164.4	0.5	30	166.7	1.0	38	<0.05
	F	15–19	155.6	1.1	17	160.2	0.6	86	<0.01
		20–24	157.2	1.1	23	161.0	0.8	41	<0.01
		25–34	158.7	0.7	52	159.7	0.6	71	NS
		35–44	157.6	0.7	32	159.8	0.5	87	<0.05
		45–54	156.2	0.8	25	158.0	0.8	65	NS
		55–64	155.1	1.0	31	157.4	0.5	55	<0.05
Weight (kg)	M	15–19	55.6	1.7	27	60.4	0.9	73	<0.01
		20–24	69.0	1.6	27	69.7	1.6	26	NS
		25–34	70.6	1.4	39	76.1	1.2	60	<0.0005†
		35–44	68.7	1.4	37	77.9	1.5	79	<0.0001†
		45–54	70.1	1.6	39	78.9	1.4	63	<0.0005
		55–64	72.3	2.1	30	74.1	1.7	38	NS†
	F	15–19	55.3	1.8	17	66.0	1.1	86	<0.0005
		20–24	60.7	1.3	23	70.6	1.8	41	<0.0005
		25–34	66.5	1.3	51	71.8	1.5	71	<0.01
		35–44	65.0	2.1	32	77.7	1.3	87	<0.0005
		45–54	70.1	2.8	25	78.1	1.8	65	<0.01†
		55–64	62.5	2.0	31	74.2	1.7	55	<0.0005
Subcapsular skinfold			[Median (mm)]		n	[Median (mm)]		n	p‡
	M	15–19	8.0		27	9.4		32	NS
		20–24	9.4		27	12.8		5	<0.05
		25–34	10.4		39	11.8		22	<0.05
		35–44	10.7		37	13.5		25	<0.05
		45–54	11.3		38	16.8		25	<0.01
		55–64	11.5		30	17.5		11	NS
	F	15–19	13.3		17	24.7		35	<0.001
		20–24	16.6		23	24.8		12	NS
		25–34	18.2		52	29.8		27	<0.0001
		35–44	17.8		32	33.0		24	<0.0001
		45–54	20.3		25	33.3		21	<0.0001
		55–64	14.8		31	33.6		21	<0.0001

* *t* test.
† Mann-Whitney U test because of significant skewness.
‡ Mann-Whitney U tests.

leavening agent in bread. Fish was boiled, broiled on coral embers, and occasionally fried. It was rarely eaten raw except as a snack by small children and fishermen.

Preparation and cooking of foods followed similar patterns in the two islands. The only marked dissimilarity between the groups, apart from quantities used, was the meal pattern. The Tokelauans followed the traditional Polynesian custom; an early morning snack, often a drinking nut, a more substantial meal at midday, and another main meal in the late afternoon. The Pukapukans followed no kind of routine except for feasting on Sunday and would sometimes eat little or nothing for a whole day or more. The same phenomenon was observed by Beaglehole 30 years earlier (17). The energy and nutrient content of the daily dietary intakes have been estimated from food tables (18) (see **Table 5**).

TABLE 2
Cholesterol levels in the Pukapuka and Tokelau 1968 groups*

Variable	Sex	Age	Pukapuka			Tokelau 1968			p†
			Mean	SE	n	Mean	SE	n	
Cholesterol (mg/100 ml)	M	15–19	148.9	4.8	27	184.5	6.4	40	<0.0005
		20–24	155.0	3.8	27	195.9	12.0	13	<0.01
		25–34	167.1	4.4	39	209.5	6.2	35	<0.0005
		35–44	181.8	5.2	37	215.7	6.1	48	<0.0005
		45–54	178.0	5.5	39	220.2	5.4	46	<0.0005
		55–64	180.5	5.7	30	217.1	5.1	24	<0.0005
	F	15–19	170.5	7.9	17	197.3	4.1	42	<0.01
		20–24	161.2	5.5	23	176.1	4.0	18	<0.05
		25–34	170.9	4.2	52	213.8	8.0	44	<0.0001†
		35–44	168.1	5.2	32	222.5	6.0	53	<0.0001†
		45–54	190.5	6.6	25	220.6	5.1	50	<0.0005†
		55–64	194.2	7.5	31	245.4	7.2	38	<0.0001†

* Conversion: Traditional units to SI in mmol/l = 0.025 g × mg/100 ml.
* *t* tests.
† Mann-Whitney U test.

TABLE 3
Triglyceride levels in Pukapuka and Tokelau 1968

Variable	Sex	Age	Pukapuka			Tokelau 1968		
			Mean	SE	n	Mean	SE	n
Triglyceride	M	15–19	0.82	0.14	6	0.35	0.03	38
		20–24	0.80		1	0.44	0.07	12
		25–34	0.71	0.06	8	0.53	0.05	33
	3	35–44	0.69	0.08	7	0.68	0.05	47
		45–54	1.11	0.22	7	0.62	0.05	43
		55–64	1.18	0.31	6	0.63	0.07	24
	F	15–19	0.65	0.35	2	0.42	0.03	40
		20–24	0.45	0.05	2	0.44	0.06	19
		25–34	0.88	0.20	6	0.47	0.04	44
		35–44	0.50	0.04	4	0.57	0.04	51
		45–54	0.93	0.16	6	0.57	0.04	50
		55–64	0.95	0.05	2	0.64	0.05	34

* Conversion: SI to traditional units: mmol/l × 88.5 = mg/100 ml.

TABLE 4
Foods supplying energy, percentage contribution

Food	Pukapuka	Tokelau
Coconut	34	63
Taro/breadfruit	15	18
Cereals	30	3
Sucrose	4	3
Fish and meat	17	13
Represents an adult daily intake of:		
Drinking nuts	1	2
Mature nuts	½	1¼
Coconut embryo	½	Negligible
Taro (g)	150	100
Breadfruit (g)	nil	400
Cereal (g)	180	20
Sugar (g)	17	21
Fish g EP*	150	230
Canned meat (g)	30	Negligible

* Edible portion.

Fat biopsies and food analyses

Results of analysis of the fat biopsies from 18 adult Tokelauan males were comparable with those from fat biopsies previously reported for Pukapukans and contrasted markedly with the results from New Zealand Europeans (14). The results are set out in **Table 6**.

The two coconut eating groups have 10 to 12% lauric (12:0) and 16 to 17% myristic (14:0) compared with 0.3% lauric (12:0) and 4.2% myristic (14:0) in European New Zealanders. They show a lower percentage of total unsaturated fatty acids, chiefly oleic (18:1).

Results of analysis of some prepared Tokelauan food samples are set out in **Table 7**.

TABLE 5
Daily dietary intake, males and females 25 to 54 yr

Energy and nutrients	Males		Females	
	Pukapuka (n = 87)	Tokelau (n = 26)	Pukapuka (n = 78)	Tokelau (n = 51)
Kcal	2120	2520	1810	2100
Kcal/kg body wt	31	34	27	27
Protein (g)	69	79	53	63
Fat (total g)	83	156	80	131
Fat (saturated g)	63	137	64	120
Fat polyunsaturated (g)	7	6	4	4
Carbohydrate (g)	283	229	230	189
Cholesterol (mg/1000 kcal)	73	51	70	48
Percent energy from protein	13	13	12	12
Fat, total	35	53	38	54
Fat, saturated	26	47	30	49
Fat, polyunsaturated	3	2	2	2
Carbohydrate	52	34	50	34

TABLE 6
Fatty acid composition of the adipose tissue lipids of Tokelauans, Pukapukans, and New Zealand Europeans

Fatty acids		Tokelauans		Pukupukans		NZ Europeans	
		Mean %	SE	Mean %	SE	Mean %	SE
	10:0	0.1	0.03	0.3	0.04	0.1	0.02
	12:0	10.4	0.37	11.5	1.39	0.3	0.04
	13:0	Trace		0.3	0.06		
	14:0	17.3	0.52	16.4	1.34	4.2	0.25
	15:0	0.3	0.02	0.5	0.07	0.5	0.03
	16:0	20.0	0.36	20.4	1.03	23.3	0.71
	17:0	0.3	0.02	0.5	0.22	0.6	0.04
	18:0	2.8	0.16	2.5	0.31	5.0	0.72
	20:0	0.4	0.04	0.2	0.08	0.5	0.06
Total saturated		51.6	0.70	52.6	2.24	34.5	1.34
Total branched							
	12:1	1.2	0.09	1.1	0.12		
	14:1	3.3	0.20	3.0	0.37		
	15:1	0.1	0.02	0.1			
	16:1	10.0	0.32	9.6	0.44	9.0	0.40
	17:1	0.6	0.03	0.6	0.10		
	18:1	27.8	0.60	29.0	1.62	49.4	1.09
	18:2	3.8	0.20	3.2	0.38	3.0	0.11
	18:3	0.4	0.04	0.1	0.05	0.8	0.08
	19:1	Trace		0.1	0.06	0.3	0.03
	20:1						
	20:4	1.2	0.11	0.6	0.15	1.0	0.10
Total unsaturated		48.4	0.70	47.4	2.25	63.5	1.37

These include plants and fruit cooked with coconut, octopus cooked with coconut oil, and fish balls made with banana.

The fatty acid composition of pork and chicken fat are shown in **Table 8**. These results confirm the very high lauric content of the chicken earlier reported by Shorland and Czochanska (19).

Application of prediction formulae

The observed differences in cholesterol levels between Pukapukans and Tokelauans are set out in **Table 9**. Results predicted by the Hegsted formula are reasonably close to those observed, particularly in the females. Results predicted by the Keys formula are

TABLE 7
Fatty acid composition of the lipids of certain prepared foods from Tokelau, percentage fatty acid

	Fatty acids	Bread fruit and coconut milk	Pandanus fruit and coconut meat boiled	Banana fried and mixed with flour and coconut cream	Seafoods: Octopus and onion cooked in coconut oil	Seafoods: Fish balls, unripe banana, fish, onion, salt
Below C	10:0	9.7	7.2	0.8	8.6	1.0
Lauric	12:0	50.9	46.3	8.3	51.1	11.5
Myristic	14:0	17.7	18.2	4.4	18.5	22.3
Palmitic	16:0	9.8	10.8	19.8	4.2	21.9
Stearic	18:0	3.1	3.4	2.4	0.1	5.0
	20:0	0.1	0.2			0.4
Total saturated		91.4	86.3	36.1	91.4	62.9
	16:1	0.1	0.1	0.9	0.1	6.0
	18:1	4.9	8.2	12.4	5.2	22.1
	18:2	1.6	4.4	46.2	0.9	3.7
	18:3	1.1	0.9	3.4	0.2	1.6
20: Unsaturated		0.4	0.1	0.6	1.2	0.9
22: Unsaturated		0.5			1.0	1.4
Total unsaturated		8.6	13.7	63.9	8.6	37.1

TABLE 8
Fatty acid composition of lipids of pig and chicken fat from Tokelau, percentage fatty acid

		Pork fat raw	Chicken fat raw
Below C	10:0	0.3	1.7
	11:0		
Lauric	12:0	9.6	39.1
	13:0	0.2	0.2
Myristic	14:0	20.0	18.8
	15:0	0.2	0.2
Palmitic	16:0	25.3	13.3
	17:0	0.1	0.3
Stearic	18:0	6.4	4.0
	19:0		
	20:0	0.1	0.1
	21:0		
Total Saturated		62.2	77.7
	12:1	0.1	0.2
	14:1	1.1	0.7
	15:1		
	16:1	7.1	2.0
	17:1	0.1	
	18:1	26.3	16.2
	18:2	2.0	2.5
	18:3	0.6	0.7
20: Unsaturated		0.3	
22: Unsaturated		0.2	
Total Unsaturated		37.8	22.3

higher than the Hegsted predictions, especially in the males.

Using the formula reported by Jacobs et al. (15) the predicted total serum cholesterol concentrations based on the diet of each atoll and sex group were around 60 to 70 mg higher than the observed levels. The results are set out in **Table 10**.

Discussion

The Tokelauan diet is unique in the high percentage of energy derived from fat over 50% and the very high saturated fat content of the diet, largely derived from coconut. The fat in the Pukapukan diet is also largely from saturated fatty acids and coconut but both the total amount of fat and the percentage of energy from fat were much lower, around 35%. Dietary cholesterol intake of both groups was low as was their intake of polyunsaturated fatty acids. These were largely the long-chain highly unsaturated fatty acids from fish lipids. The major difference in the diets of the two groups is the higher saturated fat intake of the Tokelauans.

Studies by Hegsted have suggested that under specific experimental conditions the dietary effects of saturated fats on cholesterol level may be chiefly due to their myristic acid (14:0) component with less important effects from polyunsaturated acids (2). The high myristic acid content of coconut fat, of foods cooked with coconut, and of the pork and chicken fat eaten on both atolls is likely to be an important factor in the setting of blood cholesterol values in the two groups.

The availability of dietary and serum cho-

TABLE 9
Pukapuka-Tokelau cholesterol differences. cholesterol difference (Tokelau minus Pukapuka) (mg/100 ml)

		Actual ± SE	Keys estimate (p)	Hegsted estimate (p)
Males	25–34	42.4 ± 7.6	39.7 (0.722)	35.4 (0.357)
	35–44	33.9 ± 8.0	60.1 (0.001)	53.9 (0.013)
	45–54	42.2 ± 9.0	62.5 (0.024)	55.8 (0.130)
	25–54	40.1 ± 4.5	55.8 (0.000)*	49.9 (0.030)
Females	25–34	42.9 ± 9.0	54.1 (0.215)	48.4 (0.543)
	35–44	54.4 ± 7.9	43.7 (0.178)	39.0 (0.052)
	45–54	30.1 ± 9.2	50.9 (0.024)	45.5 (0.096)
	25–54	44.7 ± 4.7	48.5 (0.420)	43.3 (0.772)

* 0.000 means less than 0.001.

TABLE 10
Prediction of cholesterol levels from diet data

	Pukapuka		Tokelau	
	Observed	Predicted	Observed	Predicted
	mg	*mg*	*mg*	*mg*
Males	170	238	208	290
Females	176	251	216	296

lesterol data from the two populations has allowed the formulae developed from controlled metabolic feeding experiments on individuals to be applied to the difference in serum cholesterol concentrations. With the Keys formula, the estimated differences tend to be higher in the males but not the females. Using the Hegsted formula, there is less discrepancy between the predicted and observed differences suggesting that this formula may have advantages for this type of natural experimental study.

These results suggest that the serum cholesterol differences between the two atoll groups may be ascribed largely to differences in saturated fat intake. The similar intakes of dietary cholesterol, polyunsaturated fats, and sugar intake in the two groups control for the effects these variables might have on the setting of cholesterol levels. Fish constitutes an equally important part of the diet in both groups and it is suggested that the intake of cholesterol lowering polyunsaturated fatty acids from fish lipids will be similar (20–22). No data are available on phytosterol content of the diets.

The manipulation of dietary fat and cholesterol levels under metabolic ward conditions has provided insights concerning levels achieved by individuals on particular dietary regimes. Regression formulae based on these studies have been established (15).

Examination of the relationship between dietary lipid intake and serum cholesterol levels in population samples has shown zero or near zero correlations in a number of studies (15). Jacobs et al. (15) have put forward the concept of uncontrolled variation and unmeasured variables as the explanation as to why zero correlations do not negate a relationship between dietary fat and serum cholesterol level. Controlled experiments have shown a relationship and it is the regression formula derived from these which has been applied to the diet of the two atoll dwelling groups. The fact that the predicted levels are 70 to 80 mg higher than those observed raises some interesting questions. Is there reason to doubt the accuracy of the dietary data? Are the assumptions made in applying the formula to population samples valid? Should they only be applied to individuals? Are there unmeasured dietary or environmental variables that lower cholesterol levels?

The fish oil fatty acids may be important in this respect. The possible part played by fiber in the diet was not being considered when the study was carried out in Pukapuka in 1964, nor were estimates made of fiber content in the diet in Tokelau in 1968 or 1971. Data on bowel frequency were collected, however, as an indirect measure of fiber intake in Tokelau in 1971 and the majority of subjects had two or more bowel movements a day with constipation being uncommon.

In 1976, in Tokelau, further dietary information was obtained and samples of certain foods were taken for fiber estimation. The overall mean dietary fiber in 95 men was 16.5 g/24 hr, and in 161 women was 14.9 g/24 hr.

Bowel transit times were also carried out which showed more rapid transit than in migrants in NZ (23). These data confirm a moderate fiber intake in Tokelau, but there has been no opportunity to collect further data in Pukapuka.

The differences in serum cholesterol levels between the two populations are thought to be primarily due to the differences in saturated fat intake. Differences in body build, body bulk, and total energy intake have also been considered. Simple correlations of weight with cholesterol were examined for ages 15 to 64 and while reaching 0.194 (n = 199) and 0.188 (n = 179) in Pukapukan males and females, and 0.308 (n = 114) and 0.007 (n = 130) in Tokelauan males and females weight was not a significant predictor of cholesterol; nor was any measure of body bulk (weight/height^2). Weight and body mass are believed to make some contribution in both groups, but do not explain the differences.

The total energy intake of the Tokelauans was higher than that of the Pukapukans, but when allowance is made for body size the difference between the women disappears and that between men is minimal. Keys (24) in the Seven Countries Study found no tendency for the average daily calorie intake per unit of size to be related to average serum cholesterol concentration.

The analyses of foodstuffs provide good evidence of the high concentration of short-chain saturated fatty acids in the diet. The fat biopsies accord with the highly saturated fat intake of the diet and the high lauric and myristic levels in Tokelauans and Pukapukans are very similar. Pigs and chickens on these atolls also eat large amounts of coconut. This is reflected in the unusually high concentration of short-chain fatty acids in their fat which in turn contributes to the saturated fat intake of the islanders.

The influence these traditional diets may have on development of atherosclerosis is an important question. Twelve lead ECGs have been taken in both groups and the rate of subnormal Q waves, Minnesota Code 1_1 and 1_2 was very low in both groups. The samples of adults on the two atolls are, however, too small for definitive studies of coronary heart disease and vascular disease.

Coconuts are used extensively in the diet in many different parts of the world. These populations are in the developing world where coronary heart disease is uncommon or rare. Certainly, there is no reason based on this report, to alter the diet patterns of coconut eating groups in order to reduce coronary risk.

The migration of Tokelau Islanders from their atolls to the very different environment of New Zealand is associated with changes in lipids that indicate increased risk of atherogenesis. This is associated with an actual fall in saturated fat intake to around 41% of energy, an increase in dietary cholesterol intake to 340 mg, and an increase in carbohydrate and sugar. Lipid changes include increased total cholesterol, higher LDLC and triglycerides, and lower HDLC levels (16). The longitudinal examination of those in Tokelau and those in NZ will provide further information on the effects of migration and in particular on cardiovascular risk.

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