The Composition of Human Adipose Tissue from Several Parts of the World

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That the composition of the fat of adipose tissue in animals may be varied by the kind of dietary fat fed has long been known although the quantitative aspects, the extent to which specific fatty acids change under various dietary loads and conditions, remains to be determined. Hirsch et al.[1] have demonstrated changes in the adipose tissue of man when fed diets high in corn oil. These findings become of considerable interest with the intensive study of the effect of dietary fat upon atherosclerosis and coronary heart disease.

This paper reports data upon the fatty acid composition of adipose tissues collected from autopsy material or at surgery from several areas of the world where the diets differ considerably in the amount and kind of fat.

EXPERIMENTAL METHOD

The samples represent pieces of adipose tissue taken from various sites in the body either at autopsy or during surgery. No attempt has been made to relate fatty acid composition to the location in the body from which the sample was taken, since no pattern is apparent from the data at hand and the exact body site from which some of the samples were taken is unknown. The exception to this is for those few cases in which multiple samples were obtained from several cadavers in Boston. Similarly, because of the many different types of illness represented, no attempt has been made to relate the fatty acid composition to the cause of death or illness. Although some information is available upon the general nature of the diets in the areas from which the samples came, no data are available on the specific diets of the subjects from whom the samples were obtained.

The samples were obtained from several Boston hospitals and from Japan, Colombia, Jamaica and Nigeria. The Nigerian samples came from three tribal groups which have somewhat different dietary patterns that have been described by Nicol et al.[2] Some of the samples from Boston were prepared for analyses within a few hours after they were obtained. The remaining samples were formalin-fixed and analyzed within a few weeks after collection. Limited data suggest no deterioration of samples with regard to their fatty acid content over this period of time. Small bits of tissue were extracted with hot methanol-chloroform, the extract taken to dryness under nitrogen, and the methyl esters prepared according to the method of Stoffel et al.[3] Chromatograms were obtained as previously described[4] with the Pye Argon Chromatograph utilizing 20 per cent ethylene glycol succinate polyester as the stationary phase on a Chromosorb W column.

It is difficult, if not impossible, to quantitate the size of the methyl ester load placed upon the columns. All results are presented as per cent of the total area of the chromatogram tracing. Data upon three different samples, two of which were made from mixtures of available methyl esters, were used to develop estimates of the reproducibility of the method.

RESULTS AND COMMENTS

The reproducibility of the analytical method is indicated by the data in Table 1. Two mixtures of methyl esters, A and B as indicated, were analyzed eleven and twelve times, respectively, and the methyl esters prepared from linseed oil were analyzed twenty-three times.

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TABLE I
Data on the Reproducibility of the Analytical Method

Fatty Acid	Mixture A			Mixture B			Linseed Oil Found (%)
	Amount (mg.)	Calculated (%)	Found (%)	Amount (mg.)	Calculated (%)	Found (%)	
Lauric-C_{12}	10.43	5.10	4.79 ± 0.39*	20.86	10.15	10.39 ± 0.93*	...
Myristic-C_{14}	24.02	11.75	11.81 ± 0.69	12.02	5.85	6.13 ± 0.46	...
Palmitic-C_{16}	31.29	14.75	14.61 ± 0.42	83.44	39.15	37.75 ± 0.61	6.53 ± 0.54*
Palmitoleic-$C_{16}/1$	...	0.98	1.42 ± 0.54	...	1.77	3.93 ± 0.30	...
Stearic-C_{18}	59.70	28.17	28.82 ± 0.67	29.85	14.02	13.80 ± 0.50	4.85 ± 0.86
Oleic-$C_{18}/1$	79.04	39.25	38.54 ± 0.92	59.28	29.04	28.16 ± 1.04	23.81 ± 0.69
Linoleic-$C_{18}/2$	...	...	...	...	...	...	15.36 ± 0.66
Linolenic-$C_{18}/3$	...	...	...	...	...	...	49.83 ± 1.75

* Standard deviation.

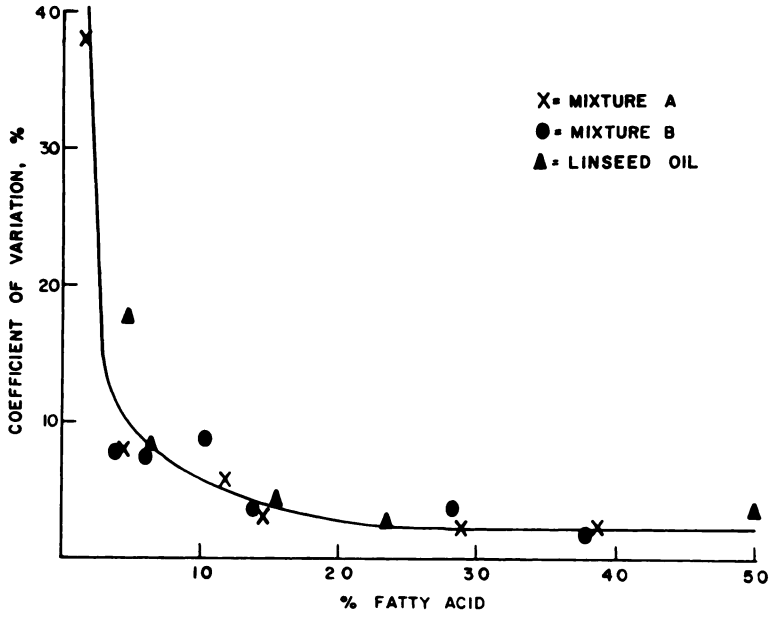

FIG. 1. A plot of the coefficient of variation versus the amount of the fatty acids in the mixture demonstrating the relative errors in reproducibility for constituents present in different amounts.

Prior analysis of the methyl esters used to prepare the mixtures demonstrated the presence of appreciable amounts of other esters in some of them. The methyl palmitate and methyl oleate were found to contain approximately 3.6 and 1.1 per cent methyl palmitoleate, respectively. The methyl stearate contained approximately 3.5 per cent methyl oleate. These values have been used to calculate the composition of the final mixture as shown in the table.

The standard deviations of the values are with two exceptions less than 1 per cent with some tendency to become larger as the amount of fatty acid present increases. Considering 2 standard deviations on either side of the mean as the likely range, most determinations should be within plus or minus 1 to 2 per cent

TABLE II
Analyses on Adipose Tissue Taken from Different Sites in the Body

Acid	Sample Identification	Axillary Fat	Pelvic Fat	Skin Fat	Anterior Mediastinal	Abdominal Wall	Abdominal Mesentery	Variance Ratio
Myristic	59-124	4.2	4.4	...	...	...	3.1	F = 4.61
	59-151	3.8	3.2	...	...	3.9	...	P = 0.05-0.01
	59-134	3.6	3.3	3.0	...	...	...	
	59-130	2.1	2.0	...	...	...	2.0	
	No. 4	3.4	...	...	4.1	2.2	3.0	
Palmitic	59-124	25.0	21.5	...	...	...	24.4	F = 2.92
	59-151	25.0	23.4	...	...	26.1	...	P = N.S.
	59-134	21.5	20.5	19.6	...	...	...	
	59-130	20.0	23.3	...	...	...	19.8	
	No. 4	23.6	...	...	24.5	20.7	19.6	
Palmitoleic	124	3.2	3.6	...	...	...	6.0	F = 7.03
	151	6.9	5.5	...	...	6.3	...	P = 7.01
	134	4.0	3.3	4.0	...	...	...	
	130	4.1	3.4	...	...	...	2.6	
	No. 4	5.0	...	...	5.6	4.6	5.7	
Oleic	124	48.6	51.9	...	...	...	51.3	F = 6.43
	151	50.3	49.9	...	...	48.9	...	P = 0.01
	134	47.5	50.7	51.8	...	...	...	
	130	53 2	52.3	...	...	...	54.5	
	No. 4	53.1	...	...	52.2	58.8	56.7	
Linoleic	124	8.7	8.0	...	...	...	8.2	F = 25.08
	151	7.3	11.5	...	...	7.2	...	P = 0.01
	134	13.6	14.1	14.2	...	...	...	
	130	12.9	12.1	...	...	...	12.4	
	No. 4	7.1	...	...	5.3	6.8	6.4	

NOTE: N.S. = not significant.

of the actual percentage present in the total mixture. This means of course, that the values for those materials present in small amounts are subject to large relative errors. The coefficients of variation (standard deviation expressed as per cent of its mean) are plotted in Figure 1. Whereas the percentage of the major constituents can be estimated within 2 or 3 per cent, the error increases rapidly when the constituent being measured makes up 10 per cent or less of the mixture. The estimate becomes quite unreliable for those below 5 per cent of the mixture. These large errors are due to the difficulty of accurately estimating the area of small deviations above the baseline. If interest were centered upon such constituents, the accuracy of the estimate could undoubtedly be improved either by several analyses of each sample or by other means.

The results of the analyses of multiple samples taken from different sites in five cadavers are shown in Table II. Although considerable variation in composition of fat samples taken from the same person can be seen, variance analysis demonstrates that subjects do vary in fatty acid composition to a significant extent. F values indicating significance at the 5 and 1 per cent levels with the 4 and 11 degrees of freedom are 3.36 and 5.67, respectively. In view of the current emphasis upon the polyunsaturated fatty acids, it is of some interest that the most significant difference was found in the linoleic acid content (F = 25). Highly

TABLE III

Comparative Data on the Fatty Acid Composition of Adipose Tissue Collected from Different Population Groups

Fatty Acids	Boston Adults (17)	Nigerians			Japanese (27)	Columbians (13)	Jamaicans (12)
		Diet A (11)	Diet B (19)	Diet C (12)			
12/0	(15) 0.5 ± 0.14* tr–2.1†	(5) ... 0.2–0.6	(8) ... 0.2–1.1	(8) 0.2 ± 0.07 tr–0.8	(20) 0.2 ± 0.10 tr–2.9	(10) 0.9 ± 0.20 0.5–2.2	(12) 3.5 ± 0.62 0.6–8.4
14/0	(17) 3.6 ± 0.24 1.6–4.6	(11) 2.2 ± 0.21 0.7–3.0	(19) 2.7 ± 0.17 1.4–4.5	(19) 2.5 ± 0.18 1.5–3.3	(27) 3.4 ± 0.31 0.5–10.3	(13) 4.3 ± 0.25 3.3–6.3	(12) 8.4 ± 0.58 4.7–11.3
14/1	(6) ... tr–1.0	(6) 0.3 ± 0.11 0.3–1.0	(8) ... tr–1.0	(5) ... tr–0.3	(25) 0.8 ± 0.07 0.3–1.4	(9) 0.5 ± 0.14 tr–1.2	(12) 1.4 ± 0.18 tr–2.3
15/0	(3) ... tr	(7) 0.4 ± 0.22 tr–2.1	(7) ... tr–1.0	(6) 0.2 ± 0.07 tr–0.7	(19) 0.2 ± 0.04 tr–0.6	(6) ... tr–1.1	(10) 0.4 ± 0.13 tr–1.3
?	(3) ... tr	(6) 0.3 ± 0.14 tr–1.1	(7) ... tr–0.7	(6) 0.3 ± 0.10 0.4–1.1	(19) 0.4 ± 0.09 tr–1.5	(4) ... tr–1.0	(10) 0.2 ± 0.07 tr–0.7
16/0	(17) 24.6 ± 0.74 19.9–30.4	(11) 26.2 ± 1.12 20.6–30.8	(19) 28.5 ± 0.66 23.9–36.0	(12) 28.7 ± 0.71 25.0–33.9	(27) 24.9 ± 0.63 16.7–31.6	(13) 25.1 ± 0.30 21.6–30.5	(12) 26.6 ± 0.82 21.9–30.5
16/1	(17) 6.1 ± 0.48 3.3–9.8	(11) 6.7 ± 0.77 3.1–11.2	(19) 5.9 ± 0.42 3.3–10.8	(12) 5.4 ± 0.59 2.8–9.6	(27) 10.5 ± 0.54 4.0–16.7	(13) 8.5 ± 0.57 5.6–14.1	(12) 10.1 ± 0.74 6.2–14.9
17/0	(3) ... tr	(5) ... 0.5–4.3	(7) ... tr–2.4	(6) 0.4 ± 0.18 tr–1.7	(19) 0.3 ± 0.08 tr–1.2	(7) 0.4 ± 0.14 tr–1.4	(8) 0.1 ± 0.01 tr–0.8
?	(3) ... tr	(3) ... tr–0.3	(3) ... tr–0.7	(2) ... tr	(19) 0.3 ± 0.07 tr–1.2	(8) 0.4 ± 0.12 tr–1.1	(8) ... tr
18/0	(17) 6.7 ± 0.45 3.3–9.2	(11) 9.6 ± 0.80 4.2–13.8	(19) 7.1 ± 0.29 5.6–9.3	(12) 8.0 ± 0.49 5.3–10.3	(27) 4.8 ± 0.43 2.0–8.5	(13) 6.9 ± 0.42 4.8–9.8	(12) 5.8 ± 0.50 2.5–8.5
18/1	(17) 50.3 ± 0.84 44.9–58.1	(11) 42.3 ± 1.03 36.8–49.4	(19) 46.2 ± 0.83 42.4–57.5	(12) 46.1 ± 0.70 42.0–51.0	(27) 40.6 ± 0.80 32.7–48.1	(13) 45.7 ± 1.14 40.6–52.8	(12) 37.7 ± 0.91 32.7–42.4
18/2	(17) 7.9 ± 0.86 1.1–14.1	(11) 8.7 ± 1.12 3.4–14.8	(19) 7.9 ± 0.42 5.1–10.2	(12) 8.0 ± 0.62 4.3–11.9	(27) 9.4 ± 0.67 1.4–16.1	(13) 5.5 ± 0.31 3.6–7.1	(12) 5.8 ± 0.58 2.7–8.7
18/3	(4) ... 0.7–1.4	(3) ... 1.0–2.6	(2) ... 1.1–1.2	(1) ... 1.0	... ...	... ...	... ...
20/0	(4) ... 0.9–1.4	(6) 0.8 ± 0.32 tr–2.8	(7) ... tr–3.8	(1) ... 1.0	(20) 0.5 ± 0.11 tr–2.3	(10) 1.4 ± 0.28 tr–6.0	... ...
20/1	(2) ... tr	(3) ... 2.0–5.0	(1) ... tr	(1) ... tr	(27) 2.6 ± 0.32 tr–6.4	... ...	... ..
20/?	...	...	...	...	(2) ...	...	(4) ...
20/4	...	...	...	...	1.2–2.5 (19) 1.1 ± 0.39 tr–9.1	...	tr–1.5

NOTE: Numbers in parentheses in table headings indicate the number of samples analyzed. Numbers in parentheses in columns indicate the number of samples in which this fatty acid was detected.

* Mean value ± standard error of the mean.

† Range encountered in those samples in which it was detected; tr = trace.

TABLE IV
Comparisons of Various Sums and Ratios of Fatty Acid Values

Sample	Total Saturated Fatty Acids (%)	Total Mono-unsaturated Fatty Acids (%)	Total Poly-unsaturated Fatty Acids (%)	Oleic Acid / Stearic Acid	Palmitoleic / Stearic
1 (Japanese)	34.4	54.5	10.6	10.2	2.8
2 (Bostonians)	35.7	56.6	8.1	8.3	1.1
3 (Colombians)	39.1	54.8	5.5	7.0	1.3
4 (Nigerians A)	40.4	50.1	9.2	4.9	0.8
5 (Nigerians B)	39.5	52.3	8.0	6.7	0.8
6 (Nigerians C)	40.2	51.6	8.1	6.0	0.7
7 (Jamaicans)	44.8	49.3	5.8	7.2	2.0
F*	12.5	5.03	5.98	4.97	10.7
Significance tests	1†-3, 4, 5, 6, 7	1–4, 6, 7	1–2, 3, 5, 6, 7	1–3, 4, 5, 6, 7	1–2, 3, 4, 5, 6, 4
	2–3, 4, 5, 6, 7	2–4, 5, 6, 7	2–1, 3	2–4	2–1, 7
	3–1, 2, 7	3–4, 7	3–1, 2, 4, 5, 6	3–1, 4	3–1, 5, 6
	4–1, 2, 7	4–1, 2, 3	4–3	4–1, 2, 3, 5, 6, 7	4–1, 7
	5–1, 2, 7	5–1, 2, 7	5–1, 3	5–1, 4	5–1, 3, 7
	6–1, 2, 7	6–1, 2,	6–1, 3	6–1, 3, 4	6–1, 3, 7
	7–1, 2, 3, 4, 5, 6	7–1, 2, 3, 5	7–1, 3, 4, 5, 6	7–1, 4	7–2, 4, 5, 6

* F for p = 0.001 is 4.1.
† 1–3, 4 etc. signifies that sample 1 (Japanese) differs significantly ($P < 0.05$) from samples 3 and 4. Pairs of values have been repeated in each row of numbers for ease of comparison.

significant differences were found for oleic, palmitoleic and stearic acid contents (results in stearic acid not shown to conserve space). Differences in myristic acid were of borderline significance and differences in palmitic and lauric acid (latter not shown) were of no statistical significance.

A summary of the results obtained from the samples collected from different parts of the world is shown in Table III. The mean values, the corresponding standard error of the mean and the range encountered in those samples in which the fatty acid was detected are shown. Standard errors have been caculated only when the fatty acid was present in measurable amounts in most of the samples. It is apparent that the range of values for each fatty acid is wide within each population group. The spread is considerably larger than can be accounted for by the errors of the determination. This would confirm the first conclusion reached on the basis of the data in Table II that difference in the composition of the body fat of subjects from the same population group can be detected.

The second conclusion, and one possibly not expected, is that the mean values for most of the fatty acids are rather similar in the different population groups. The wide variation encountered within each group and the general similarity of the mean values results in insignificant statistical differences between most of the mean values. Exceptions to this statement are the higher laurate and myristate values obtained in Jamaican samples, these being significantly higher than those in any other group. It is presumed that this is a reflection of an appreciable consumption of coconut oil which is high in these two fatty acids. None of the means of the other major fatty acids present in considerable amounts are statistically different. This is not to say, of course, that they are the same. The Japanese samples contain more of the long chain C-20 acids. The C-20 monounsaturated acid was detected in all the Japanese samples and the C-20 tetraene in nineteen of the twenty-seven samples. These were rarely found in any of the other groups. It seems likely that this may be a reflection of an appreciable consumption of fish oils.

While few of these populations demonstrate significant differences in the content of individual fatty acids, significant differences in

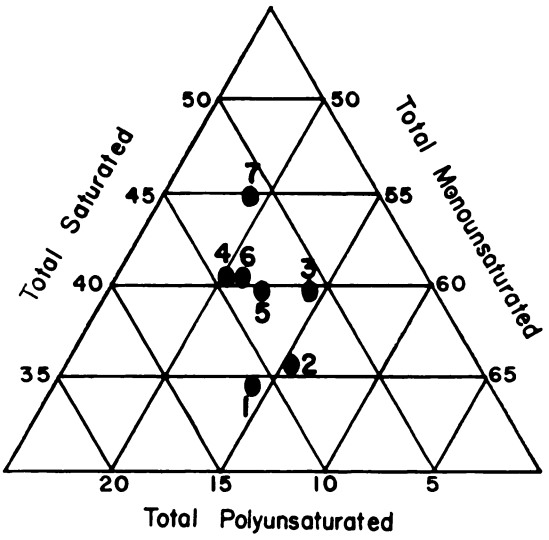

FIG. 2. A three-dimensional plot showing the mean composition of the adipose tissue of the population groups studied. 1 represents Japanese, 2 Bostonians 3 Colombians, 4 Nigerians group A, 5 Nigerians group B, 6 Nigerians group C, and 7 Jamaicans.

composition are readily demonstrated. This can be shown by comparing the total saturated fatty acids, the total monounsaturated acids, the total polyunsaturated acids, and the ratios of oleic and palmitoleic to stearic acid as shown in Table IV. Whether these are the most significant or critical comparisons that might be made is unknown. Cochran and Cox[5] point out that in multiple comparisons utilizing the t test, the probability of obtaining a significant value is greater than expected. A partial check upon this is provided by first calculating an F test on all the treatment means. If the result of the F test is significant, the t tests may be applied with some degree of confidence although the limitations are clearly recognized. F values shown in Table IV are all larger than those required to indicate significance at the 0.001 level of probability.

Of the various comparisons made, the amount of total saturated fatty acids appears to be the most discriminating ($F = 12.5$). The Japanese samples differ significantly from those in all other groups except the Boston samples. Similarly the Boston samples are significantly lower than all others except the Japanese. Of the twenty-one comparisons possible, fourteen are significant at p 0.01 and thirteen at p 0.05. The monounsaturated fatty acid contents differ significantly (p 0.05) in ten of the possible comparisons. The other three comparisons which have been made also demonstrate significant differences in approximately half the samples. However the particular samples distinguished by the various criteria are not the same. For example, in group A the Nigerian samples show a significantly lower oleic:stearic acid ratio than any of the other samples and this was the only one of the five criteria applied which distinguished this group from the other two Nigerian groups.

In general, it would appear that the saturated and monounsaturated fatty acid contents are more or less reciprocal, possibly measures of the same influence. The content of polyunsaturated acids shows little if any correlations with either of these. Thus it would appear to be a measure of some effects independent of the saturated or monounsaturated acids or whatever factors influence the content of these latter two groups of acids. The ratios of oleic and palmitoleic acids to stearic acid show a tendency to correlate with the monounsaturated acid content as might be expected. These measures appear to contribute relatively little new information although as indicated, the oleic:stearic ratio did apparently distinguish the group A of the Nigerians from all other groups.

The fact that groups or ratios of fatty acids are more discriminatory in distinguishing between population groups than the content of individual fatty acids, despite the greater error in these values than in the measure of a single component, suggests that there are probably some underlying patterns of metabolism involving groups of components rather than each fatty acid acting as an entity. This is also indicated by the fact that the composition of adipose tissue does not accurately reflect the composition of the dietary fat[4] although it is strongly influenced by it. Data are needed on the source, rate of change and extent of change of the various fatty acids in adipose tissue when various dietary levels of the different fatty acids are imposed.

The real significance of these various criteria is difficult to assess. It must be remembered that statistical significance depends upon the amount of variation within the groups as well as the sample size. The latter factor presumably, but not certainly, explains lack of significance between some of the mean vaues having a difference similar to others which did prove to be significantly different. Also, as has been demonstrated, the error of measurement is inherently greater in the components present in smaller amounts. Thus, the measure of polyunsaturated fatty acids is considerably less accurate than that of the saturated or monounsaturated fatty acids.

A three-dimensional plot of the major fatty acid groups (Fig. 2), while again demonstrating relatively large shifts in composition, does not appear more informative in this regard than the other methods of discrimination which we have applied.

There is reason to believe that the mortality from coronary heart disease is probably less in all the foreign areas from which these samples were obtained than in Boston.[6] Necropsy data from Jamaica and Japan indicate a much lower rate of myocardial infarction in these countries than in the U. S.[7] Differences in the degree of atherosclerosis was most marked in the coronary artery rather than in the aorta. It should be emphasized that the small samples represented by the analyses presented here cannot be expected to be representative of the population from which they have been taken. Nevertheless it is of interest that no pattern emerges from these studies which appears to distinguish the Bostonians, a group presumably susceptible to coronary disease, from the other groups studied.

The data presented in this paper demonstrate that significant differences in the fatty acid composition of adipose tissue are easily detected between subjects within the same population group, and that the various population groups which were studied also differ significantly. The extent to which these differences reflect genetic or dietary or other environmental or metabolic differences remains to be determined. It may be presumed, on the basis of current evidence, that the amount and kind of dietary fat is one important variable.

Although no pattern seemingly related to susceptibility to coronary disease is apparent the number of correlations or interrelationships which might be calculated is extremely large. Possibly minor constituents or patterns of fatty acids other than those so far studied might be informative. The problem of determining the most efficient means of discriminating between two groups when fifteen to twenty-five individual components are being measured is a difficult one. With this number of degrees of freedom in the statistical analysis, large groups will be required before confident statements can be made. James and Lovelock[8] found little difference in the composition of blood lipids in patients with ischemic heart disease and control subjects. Studies of this kind, of course, are complicated by the selection of appropriate control subjects in a population in which atherosclerosis is widespread. Much larger samples will be required before definite conclusions can be drawn.

SUMMARY AND CONCLUSIONS

Repeated analysis of several mixtures of methyl esters of fatty acids were made to determine the reproducibility of the gas chromatographic method in this laboratory. The coefficient of variation of major constituents, those comprising 10 per cent or more of the mixture, was approximately 2 to 3 per cent. The relative error increases rapidly with decreasing amounts.

Multiple samples of adipose tissue taken from several body sites in several cadavers demonstrate significant differences in the composition of body fat in subjects from the same general population.

Samples of adipose tissue obtained from Bostonians, Japanese, Nigerians, Colombians and Jamaicans were analyzed. The values for individual fatty acids showed wide variations within each population group. Mean values were not significantly different with few exceptions. Jamaicans showed larger amounts of lauric and myristic acids, presumably reflecting the consumption of coconut oil. Japanese

showed appreciable amounts of C-20 acids possibly due to consumption of fish oils.

On the other hand, each population could be distinguished from the others to a statistically significant degree by the content of various groups of fatty acids (such as total saturated fatty acids) or by ratios of different fatty acids. Since the Bostonian samples, presumably representing a population susceptible to coronary disease, were intermediate in position by all the criteria applied, no trends in fatty acid composition apparently related to this disease were discernible.

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