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MAXIMAL OXYGEN UPTAKE AND BLOOD LIPIDS*

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Abstract—One thousand and sixty males and 119 females age 10–69, were tested on the treadmill as they walked at 3 mph (2 mph in subjects 60 yr and older). Every 3 min, the grade was increased 3%. Oxygen uptake and related measurements were recorded during the 3rd min at each grade. Subjects, age 10–39, exercised to exhaustion and maximal oxygen uptake ($\dot{V}O_2$ max) was measured. In subjects age 40–69, $\dot{V}O_2$ max was estimated from sub-max $\dot{V}O_2$ and heart rate. Serum cholesterol and serum triglyceride were determined in most of these subjects. After removing the effects of age, wt and sum of four skinfolds, nonfasting values of cholesterol and triglyceride concentrations were unrelated to $\dot{V}O_2$ max.

INTRODUCTION

Serum concentrations of cholesterol and triglycerides are recognized as being related to the development of coronary heart disease. It has been thought that habitual physical activity and physical fitness for muscular work might be related to the blood concentration of these lipids. The Tecumseh, Michigan Community Health Study afforded an opportunity to study these relationships. In two previous examinations in the Tecumseh population (1959–1960 and 1961–1965) neither maximal oxygen uptake ($\dot{V}O_2$ max) nor maximal work capacity was measured. However, these measurements were taken in some of the residents of Tecumseh during the third series of examinations (1967–1969). It is difficult to measure habitual physical activity accurately. Since exercise training is known to increase $\dot{V}O_2$ max some believe the relationship of exercise habits to serum lipids might better be studied by using the more objective measure of $\dot{V}O_2$ max. Also, it is well known that exercise increases the mobilization of free fatty acids for energy [1–4]. Gordon [5] has even suggested that the generation of DPNH in striated muscle, which appears to suppress cholesterol synthesis, may lower cholesterol in the blood. Because of these observations, it appeared important to study the relationship of blood lipids to $\dot{V}O_2$ max and maximal performance on a treadmill test.

The relationship between the concentration of cholesterol and triglycerides in blood serum on the one hand, and habitual activity on the other, has been summarized recently [6]. The present report contains an analysis of the relationship of these blood lipids to $\dot{V}O_2$ max in respondents in the Tecumseh, Michigan Community Health Study.

METHODS

Subjects

The Tecumseh Community Health Study has been described briefly in this journal [6] and in detail elsewhere [7]. It is an ecologic investigation of a community of about 10,000 persons. The genetic influences and the biological, physical, and social environment are being studied with a view to determine how these factors interact to enable some individuals to maintain health while others become susceptive to disease.

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The third series of examinations (1967–1969) was limited to:

(1) persons who have been previously examined at least once and

(2) persons of all ages, whether previously examined or not, who were residing in a 10% random sampling of dwelling units. It was not possible to obtain treadmill test data on all these respondents. The decision was, therefore, made to give a treadmill test to medically eligible subjects as follows: (a) males and females, age 10–69, in the 10% random sample (b) all males previously examined who were age 35–69, and (c) males age 10–34 in a small group of special subjects described elsewhere [7, p.5]. The first task was to compare the treadmill data in the 10% random sample, which was selected to be representative of the entire community, with the subjects in (b) and (c). There were no important differences so the addition of subjects in (b) and (c) did not alter the representativeness of the sample taking the treadmill test. Among all subjects defined above, who were medically eligible to take the treadmill test, 83% of the males and 59% of the females actually took the test. Medical criteria for excluding subjects from the exercise test have been published [7, p.51].

Treadmill test

The detailed procedures of the treadmill test have been published [7, 8]. Briefly, the test employed by us consists of walking on the treadmill at 4.83 km (3.0 miles) per hr at zero grade for 3 min; thereafter, the mill is raised 3% every 3 min with speed maintained. In subjects 60 years of age, and on rare occasions in younger subjects, the speed is maintained at 3.27 km (2.0 miles) per hr. The percent grade is calculated as the height over the belt travel (sine of the angle), not the rise over the run (tangent of the angle) as defined in engineering terms.

The electrocardiogram, heart rate, ventilation and percent oxygen and carbon dioxide were recorded on an E for M 8-channel-recorder. Ventilation was measured with a D-4 or CD-4 Parkinson Cowan dry gas meter. The exhaled air was led into a mixing chamber and a sample pumped through a Beckman model F3 oxygen analyzer and a Capnograph (CO_2 analyzer). Although the data were recorded continuously, only data for the last minute at each treadmill grade were usually utilized. A sample of exhaled air was taken for micro-Scholander analysis on approximately every fifth subject. The accuracy of the electronic meters was highly satisfactory [8].

Criteria for stopping the exercise by the attending physician were agreed upon before the exercise tests in Tecumseh were initiated. These included certain symptoms and physical and electrocardiographic signs [7, 8]. If the exercise was not terminated by the physician, the end point of the exercise was the subject's own estimate of exhaustion, if he or she was 10–39 yr. For subjects 40–59 yr, the test was terminated when the heart rate reached 160. For subjects 60–69 yr, the test was terminated at a heart rate of 150. In the older age groups (40–69), if the subject felt exhausted and could not continue the exercise, the test was terminated even though the specified heart rate had not been reached.

Despite encouragement, a few subjects seemed unwilling to exercise to exhaustion. This was a subjective evaluation made at the time of the test by the investigators. These few cases were coded "uncooperative." There were also a few instances when the respondent terminated the test because of leg cramps rather than general exhaustion and this was noted at the time of the test. The total numbers of subjects in these two categories were 21 males and 7 females. Also, in 9 instances, the test could not be completed because of equipment difficulties. For the most part, these were cases in which a good ECG could not be obtained.

For subjects who terminated the exercise because of exhaustion, $\dot{V}O_2$ max was the actually measured maximal oxygen uptake. This included almost all subjects below 40 yr and a few beyond this age. For subjects 40 yr and above who did not reach exhaustion (for example, those who were stopped because of reaching a heart rate of 160) their $\dot{V}O_2$ max was predicted. This was done by fitting a straight line to measured

TABLE 1. REASONS FOR EXCLUSIONS OF SUBJECTS FROM STATISTICAL ANALYSES

	Males	Females
Number given treadmill test	1060	119
Number over 40 yr for whom $\dot{V}O_2$ max could not be predicted*	152	21
Number for whom no blood data and/or skinfolds was available	81	15
Number with complete data	827	83

*These include subjects with significant ECG changes, equipment problems, insufficient heart rate–oxygen uptake values to accurately predict VO_2 max, and a few who were uncooperative or who developed leg cramps.

submaximal oxygen uptake-heart rate points, and extrapolating to the estimated maximal heart rate for the subject's age. The estimated maximum heart rate was derived from a regression line based on the published maximum heart rates for males and females. There were several restrictions placed on this procedure. No $\dot{V}O_2$ max was predicted if it was necessary to extrapolate beyond twenty heart beats. Also, unless there was a minimum of three oxygen uptake-heart rate points, $\dot{V}O_2$ max was not predicted. Thus, no $\dot{V}O_2$ max was available in some of the subjects; for example, those whose test was terminated early because of significant ECG changes. The numbers of subjects with complete treadmill and other data were 827 males and 83 females. Table 1 contains an explanation for the exclusion of some of the subjects from the statistical analysis.

Blood lipids

Usually within a week, but not more than 5 weeks, before the treadmill test was administered, the respondents came to the clinic, ordinarily in family groups. At this time, height, weight, and skinfolds were measured and a blood sample was drawn. Insofar as the blood analyses were concerned most of the respondents were not in a post absorptive state. Serum total cholesterol was determined on the autoanalyzer by the method of Block *et al.* [9]. Serum triglycerides were done on the autoanalyzer by the Kessler method as modified by Block and Jarrett [10]. The day-to-day within individual variations in cholesterol and triglycerides was about 6 and 8%, respectively. The blood analyses were done in the laboratory of one of the co-authors (W.D.B.). This is one of the laboratories standardized by the Center for Disease Control in Atlanta.

Body fatness

Skinfolds were measured at four sites: namely, triceps, subscapula, suprailium and adjacent to the umbilicus. The measurements were taken with a Lange caliper which was calibrated by means of small springs of known force–compression curves. The measure of body fatness was simply the sum of the four skinfolds.

Distributions

Before the data were analyzed, all treadmill, lipid and skinfold distributions were studied. All of the variables, with the exception of triglycerides and sum of skinfolds, closely approximated the normal distribution. Triglycerides were markedly positively skewed and skinfolds were only slightly positively skewed.

RESULTS

Serum cholesterol

The usual approach in analyzing the data would be to correlate $\dot{V}O_2$ max (ml/kg body wt/min) with serum cholesterol and triglycerides. This essentially eliminates the effect of body wt on $\dot{V}O_2$ max as measured in liters per min. These correlation coeffi-

TABLE 2. PARTIAL CORRELATION COEFFICIENTS: SERUM TOTAL CHOLESTEROL VS $\dot{V}O_2$ max (EFFECTS OF AGE, WEIGHT AND SKINFOLDS REMOVED)

Age group	Males N	Males Partial correlation coefficient*	Females N	Females Partial correlation coefficient*
10–19	285	0.08	44	−0.06
20–29	103	−0.14	15	−0.21
30–39	189	0.00	16	0.04
40–49	189	−0.12		
50–59	53	−0.09	8	−0.54
60–69	8	0.40		
10–69	827	−0.08	83	−0.17

*None of the correlation coefficients was statistically significant, $P < 0.01$.

cients were calculated for our data. For males, $\dot{V}O_2$ max is significantly related to serum cholesterol and triglycerides with the males with the higher $\dot{V}O_2$ max having the lower lipid values. The relationships are in the same direction for females and in the case of $\dot{V}O_2$ max and cholesterol the coefficient is statistically significant. However, blood lipids are positively related to both age and skinfolds, whereas $\dot{V}O_2$ max is negatively related to age and skinfolds. Therefore, the $\dot{V}O_2$ max–blood lipid correlations may only reflect the influence of age and body fatness.

Partial correlation coefficients were therefore calculated to study the relationship between blood lipids and $\dot{V}O_2$ max (1/min) with the influence of age, wt and skinfolds removed by multiple regression. The relationship between age and $\dot{V}O_2$ max is not linear over the entire age range. However, within the narrow age ranges we used, the deviation for linearity is insignificant. The results of this analysis for serum total cholesterol appears in Table 2. None of the partial correlation coefficients are statistically

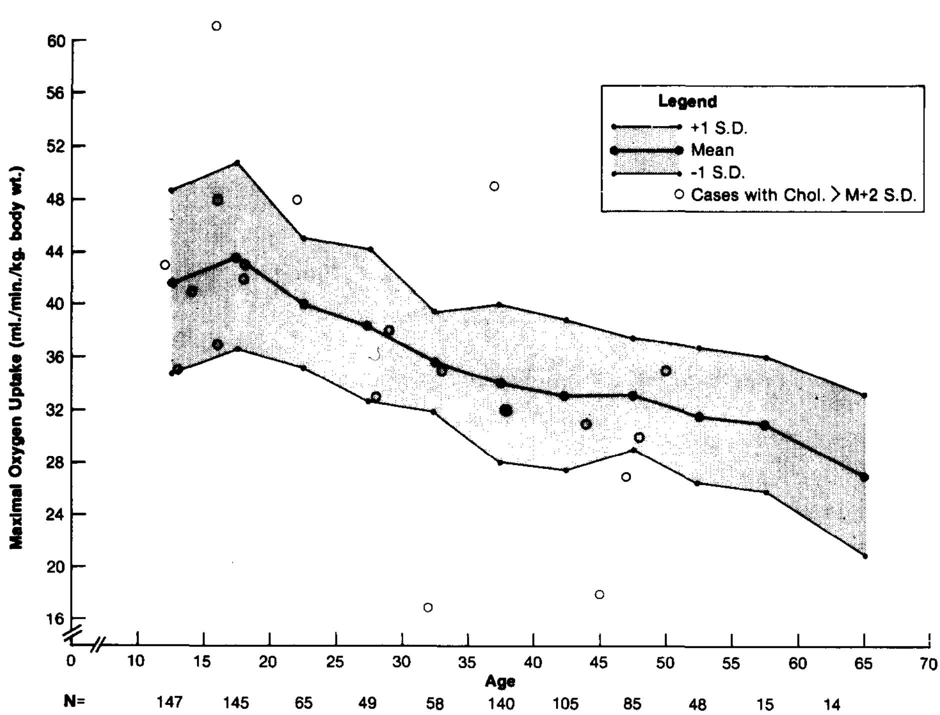

FIG. 1. Maximal oxygen uptake of subjects with high serum total cholesterol compared to $\dot{V}O_2$ max for the rest of the population. Numbers of subjects listed below were used to calculate means and S.D. for $\dot{V}O_2$ max and exclude high cholesterol subjects.

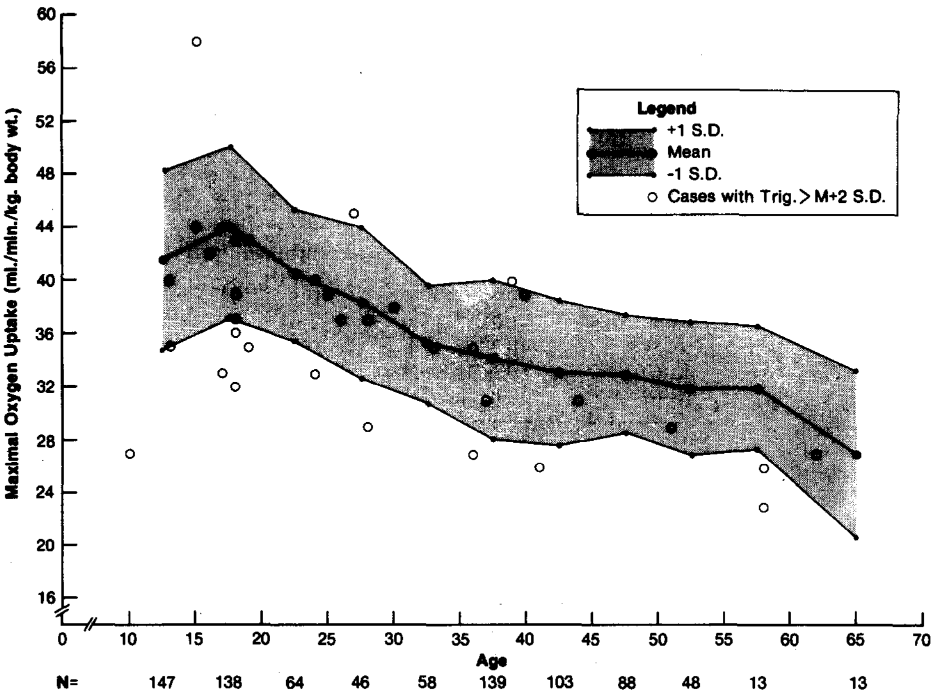

FIG. 2. Maximal oxygen uptake of subjects with high serum triglycerides compared to $\dot{V}O_2$ max for the rest of the population. Numbers of subjects listed below were used to calculate means and S.D. for $\dot{V}O_2$ max and exclude high triglycerides subjects.

significant. It is possible that $\dot{V}O_2$ max and serum cholesterol are related at only one end of the distribution. The $\dot{V}O_2$ max of those male subjects whose cholesterol was more than two standard deviations (S.D.) above the mean is compared with the rest of the population in Fig. 1. There is no indication that the $\dot{V}O_2$ max of males with high cholesterol is different from other subjects.

The results in Table 2 are based on all subjects for whom blood lipids and treadmill performance data were available. One can hypothesize that if data from only the subjects who exercised to exhaustion were included, the relationship between serum cholesterol and $\dot{V}O_2$ max might be stronger. This did not prove to be the case. When the analyses were repeated using (1) total sample excluding subjects who were uncooperative or complained of leg cramps, and (2) only those subjects who exercised to exhaustion, the partial correlation coefficients for the modified samples are virtually identical to those for the total sample (i.e. those in Table 2).

Serum triglycerides

Partial correlation coefficients similar to those in Table 2 were calculated for non-fasting serum triglycerides. As before, the influence of age, wt, skinfolds was removed by regression analysis. The results appear in Table 3. There is essentially no correlation between non-fasting serum triglycerides and $\dot{V}O_2$ max. The $\dot{V}O_2$ max of subjects whose triglycerides were more than two S.D. above the mean are compared to the rest of the population in Fig. 2. There is a tendency for the high triglyceride subjects to have slightly lower $\dot{V}O_2$ max. $\dot{V}O_2$ max is expressed per unit body wt, which eliminates the effect of body wt, but not the effect of body fatness. Therefore, the skinfold values of these same high triglycerides were plotted against the mean and S.D. of the rest of the population as in Figs. 1 and 2. Almost all of these subjects whose $\dot{V}O_2$ max was low also were fatter than average. Hence the slight tendency for the $\dot{V}O_2$ max of high triglyceride subjects can be explained by their greater fatness.

As in the cholesterol analysis, partial correlation coefficients were calculated for modified samples. Again, the results for the modified samples are virtually the same as those for the total sample.

TABLE 3. PARTIAL CORRELATION COEFFICIENTS: SERUM TOTAL TRIGLYCERIDES VS $\dot{V}O_2$ MAX (EFFECTS OF AGE, WEIGHT AND SUM OF SKINFOLDS REMOVED)

	Males		Females	
Age group	N	Partial correlation coefficient*	N	Partial correlation coefficient*
10–19	285	0.05	44	−0.05
20–29	103	−0.01	15	0.18
30–39	189	−0.11	16	0.05
40–49	189	−0.06		
50–59	53	−0.23	8	0.09
60–69	8	0.21		
10–69	827	−0.05	83	−0.05

*None of the correlation coefficients was statistically significant, $P < 0.01$.

There is another problem in analyzing the triglycerides data. The distribution of serum triglycerides is positively skewed, as pointed out earlier. It is possible for this to affect the correlation coefficient. Therefore, the nonparametric Kendall Rank Correlation Coefficient (or tau) was calculated in place of the Pearson Correlation Coefficient whenever triglycerides were involved [11]. Additionally, Kendall Partial Rank Correlation Coefficients were computed for the non-fasting serum triglycerides relationships. The calculation of tau does not require a normal or even symmetrical distribution. These analyses produced values for tau and partial tau almost identical to the r and partial r values.

DISCUSSION

It would have been desirable to obtain fasting rather than casual blood samples. Probably this would not have changed the serum cholesterol relationships. However, food consumed in the hours before the blood sample was obtained can be expected to affect the concentration of chylomicrons in the blood, and hence perhaps the triglycerides concentration since chylomicrons contain mostly triglycerides. The laboratory procedures were such that it is unlikely that any meal was consumed more recently than 2 hr beforehand.

Table 4 contains a summary of previous reports in which the relation of serum total cholesterol concentration and work capacity have been studied. $\dot{V}O_2$ max was measured in these investigations. Shane [16] reported a low but statistically significant correlation coefficient (−0.20) between work capacity on a treadmill and serum cholesterol but the effects of age and body fatness were not removed. In two other similar treadmill studies [17, 18] no correlation between work capacity and serum cholesterol was observed. On the other hand, Cooper *et al.* [19] reported lower serum cholesterol in men whose treadmill performance was excellent compared to those rated "very poor." The difference, after adjusting for height, wt, age and body fitness, was only 9 mg%!!

TABLE 4. RELATIONSHIP OF SERUM TOTAL CHOLESTEROL CONCENTRATION TO MEASURED $\dot{V}O_2$ MAX (REVIEW OF PREVIOUS STUDIES)

Population	Relationship of cholesterol to $\dot{V}O_2$ max	Other factors	Reference
11 Soccer players	N.R.		Nayman *et al.* [12]
19 Medical students	N.R.		Akgun [13]
86 Males age 40–69	N.R.	Effect of age, fatness and other variables removed	McDonough *et al.* [14]
531 Males age 54*	N.R.		Grimby *et al.* [15]

*In some cases $\dot{V}O_2$ max was estimated rather than measured.
N.R. = not related.

Similarly, there was little or no correlation between serum cholesterol and work performance on a bicycle ergometer [20, 21]. In another report [22] time required to run 1.5 miles was related to serum cholesterol ($r = 0.30$) but the relationship was not corrected for any influence of age and body fatness.

Heart rate response to a standard work task has often been employed as an estimate of work or metabolic capacity; low heart rates reflecting greater capacity. In a number of investigations, this estimate of fitness was studied in relation to serum cholesterol. The relationship, without adjusting for other factors such as age and fatness, was weak but statistically significant [21–28]. In other studies of this kind, when the influence of age and fatness were removed, the relationship of heart rate response to exercise (physical fitness) and serum cholesterol was statistically insignificant [29, 30].

Oxygen uptake at a heart rate of 180 while exercising on a treadmill has also been used as an estimate of metabolic capacity. The correlation of this measurement with serum cholesterol was low and statistically significant ($r = -0.18$) but again the relationship was not adjusted for the influence of age and body fatness [16].

Fifty middle-aged faculty members served as subjects in another study [31]. Their fitness was measured by scores on a number of tests including maximal oxygen uptake. When the most fit 12 men were compared with the least fit 12, there was no significant difference in serum cholesterol. On the other hand, Ekelund and Olsson [32], after correcting for age and wt, found that males with types IIA and IV hyperlipidaemia had lower work performance at a heart rate of 150.

Clearly from our results and those of other investigators there is little evidence of a significant association between serum total cholesterol and fitness expressed as work capacity or measured or estimated $\dot{V}O_2$ max, provided that the influence of confounding variables is eliminated.

To our knowledge, serum concentration of triglycerides has not been previously studied in relation to measured $\dot{V}O_2$ max, and only to a limited extent in relation to estimated $\dot{V}O_2$ max or work capacity. Oberman in 1965 in his Thousand Aviator Study [25] reported a statistically significant correlation between heart rate response to a modified Harvard Step Test and serum triglycerides in approximately 600 men, age 42–62. The coefficient was only 0.094 and probably would be even lower, if the effects of body fatness were eliminated. Two years later Allard *et al.* [20], reported a significant negative relationship between work accomplished on a bicycle ergometer at a heart rate of 150 and serum triglycerides. The relationship was weak and probably also contained the confounding effects of age and body fatness. Cooper *et al.* [19] reported large and statistically significant differences in serum triglycerides among males of different work capacity; high triglycerides concentrations being associated with poor work capacity. The relationships were adjusted for the influence of age, height, wt and body fatness and all of the men were in a postabsorptive state when blood was drawn. The subjects composed a self-selected population of predominantly high socio-economic level; hence, it is difficult to generalize to other populations.

In conclusion, it appears clear from our data and other studies that maximal oxygen uptake or work capacity is not significantly related to non-fasting serum cholesterol or triglycerides concentration. It is possible that had fasting blood samples been drawn the relationship of maximal oxygen uptake to serum triglycerides might have been different.

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