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9. ABSTRACT

To determine the relationships between nutritional status and economic productivity of Colombian manual workers, two sets of studies were conducted. In the first, laboratory studies of body composition, nutritional status, and physical condition (work capacity) were conducted with 49 undernourished and normal adult males. Nineteen of the most severely malnourished of this group were also studied during a 2.5 month dietary repletion period in which the daily protein intake was increased from 28 gms/day to 100 gms/day. The second set of studies was performed on 61 well-nourished male sugar cane cutters and 28 sugar cane loaders in whom nutritional status, body composition, physical work capacity, energy expenditure during work, and work productivity were determined under laboratory and field conditions. These workers were compared with 18 other agricultural workers in Colombia who were not engaged in harvesting sugar cane, with a group of 20 civil service laborers in Milwaukee, and with 15 Mexican-American migrant workers in Wisconsin. Some measurements of maximum oxygen consumption were also performed on 42 six-year-old children of differing nutritional and ethnic backgrounds to obtain some preliminary data on the effects of early malnutrition on some of the work parameters studied in the adults. Results showed that physical work capacity is directly related to nutritional status, and that productivity is directly related to maximum oxygen consumption capacity as well as to other nutritionally related parameters.

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CLINICAL AND SUBCLINICAL MALNUTRITION:

Their influence on the capacity to do work

FINAL PROGRESS REPORT TO

Agency for International Development
Project No. AID/CSD 2943
For the period: Jan. 1, 1971 - Nov. 30, 1975

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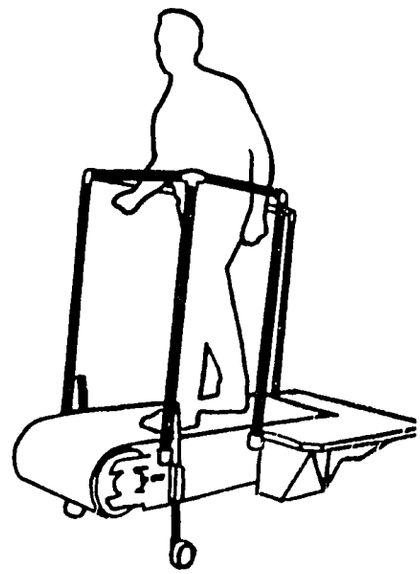

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May, 1976

REPORT SUMMARY

A. 1. Project Title and Contract Number

Clinical and Subclinical Malnutrition:
Their Influence on the Capacity to Do Work

AID/CSD-2943

2. Principal Investigator

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3. Contract Period

June 30, 1971 to November 30, 1975

4. Period Covered by Report

January 1, 1971 to November 30, 1975

5. Total AID Funding of Contract

$195,376

6. Total Expenditures and Obligations through Previous Contract Year

$128,797

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$66,579

8. Estimated Expenditures for Next Contract Year

Not applicable

B. Narrative Summary of Accomplishments and Utilization

1. April 1, 1974 to November 30, 1975

Since April 1, 1974, when the last progress report was filed, the data collection has been completed and the analysis of the data largely completed. These included studies on 7 additional hospitalized malnourished patients during dietary (100 gms protein/day) repletion, the completion of measurements on 21 borderline malnourished patients, observations on 28 sugar cane loaders in the field and under laboratory conditions, and preliminary studies in 42 children from upper and lower socioeconomic strata. In addition, studies were made on 18 general farm laborers in Colombia and on 20 civil service workers and 15 Mexican-American migrant workers in this country for purposes of comparison with the Colombian sugar cane workers.

The detailed results of all of these studies are presented in the appended final progress report.

2. During the Life of the Project

In order to determine the relationship(s) between nutritional status and economic productivity, two sets of studies have been performed. In the first, laboratory studies of body composition, nutritional status and physical condition (work capacity) have been done on 49 undernourished and normal adult males in Colombia, South America. Nineteen of the most severely malnourished of this group were also studied during a 2.5 month dietary repletion period in which the daily protein intake was increased from 28 gms/day to 100 gms/day.

The second set of studies was performed on 61 well nourished male sugar cane cutters and 28 sugar cane loaders in whom nutritional status, body composition, physical work capacity, energy expenditure during work and work productivity were determined under laboratory and field conditions. Sugar cane workers were chosen because of the relative ease in measuring productivity. These workers were compared with 18 other agricultural workers in Colombia not engaged in the harvesting of sugar cane, with a group of 20 civil service laborers in Milwaukee and with 15 Mexican-American migrant workers at the end of a harvest season in Wisconsin.

Finally, some measurements of maximum oxygen consumption were also done on 42 6-year-old children of differing nutritional and ethnic backgrounds to give some preliminary results of the effects of early malnutrition on some of the work parameters studied in the adults.

ANNUAL RESEARCH REPORT

A. General Background

Research on the physical work capacity of malnourished human adults had previously been limited to studies on experimentally induced malnutrition of relatively short duration. From studies published in the literature there was ample reason to believe that there was considerable physiological difference between acute malnutrition and the chronic malnutrition which might have existed since birth in undernourished populations.

Out of our interest in studying malnourished subjects from an exercise point of view and AID's interest in assessing the influence of poor nutrition on the ability of such people to work and therefore contribute to the economy of undernourished nations came a proposal from us to the Office of Nutrition in 1970.

B. Statement of Project Objectives as Stated in the Contract

The objectives as stated in the contract and subsequently modified are as follows:

"To measure the increase of productivity that can result from alleviating chronic malnutrition. The physical work capacity and cardiovascular reactivity in chronically malnourished patients in various stages of malnutrition will be determined. The changes in work capacity will then be quantified and related to the initial severity of malnutrition.

The specific aims of the project are (1) to determine the ability of malnourished subjects to respond to superimposed stress (exercise); (2) to determine if physical exercise will reveal the subclinical malady (malnutrition); (3) to determine the feasibility of quantifying the reduction in work capacity and/or efficiency and relating this to the nutritional status of an individual; and (4) to develop, if possible, a simple work test for revealing malnutrition in apparently healthy individuals."

Subsequently it was determined that studies were needed on workers in whom productivity could be measured in order to relate laboratory findings to economic terms. Therefore, the aims were modified to the following questions:

1. Does the nutritional state influence the maximal aerobic power of the subject?
2. Does the nutritional state influence the fatigability (maximal endurance time at the same <u>relative</u> work load)?
3. Is productivity related to the work capacity as measured by the maximum ability of the subject to consume oxygen (aerobic power)?
4. Since these studies are to be performed in Colombian agricultural workers, what are the normal values for maximal oxygen consumption in Colombians as compared to laborers in other ethnic groups?
5. Does malnutrition early in life affect the maximal oxygen consumption?

C. Continued Relevance of Objectives

The overall objectives of the research have been accomplished, i.e., to quantitate the impairment in physical work capacity of undernourished subjects, relate it to the degree of malnourishment, measure its change as clinically malnourished patients go through a dietary repletion regime and attempt to relate the laboratory findings to the degree of impact on the economy.

D. Accomplishments to Date

1. Findings

The results to date are presented in detail in the accompanying Final Progress Report in Appendix II (Section H).

The studies in the Colombian adults were carried out: (a) to establish a relationship between physical work capacity, as measured by the maximal oxygen consumption, and nutritional status in the undernourished subjects; and (b) to establish a relationship between physical work capacity and productivity in the nutritionally normal sugar cane workers.

The establishment of (a) and (b) above would allow for the indirect establishment of a relationship between nutritional status and productivity.

The results have been grouped into studies of the physical work capacity as related to nutritional status, nutritional repletion and productivity, and can be summarized as follows:

Nutritional status: Of the 49 subjects in this group, 79% exhibited some form of intestinal parasitism and 69% some level of vitamin deficiency. The severity of malnutrition was associated with progressively more severe anemia (decreased hematocrit and blood hemoglobin) and a slight increase in plasma volume, which in the face of a decreased red cell volume resulted in no difference in blood volume expressed in terms of body weight. Total body water (ml/kg) was increased due to an elevated extracellular fluid volume. No significant difference in intracellular volume (ml/kg) was detected as a result of differences in nutritional status. Body composition (fat weight, fat free weight, fat free solids, body cell mass, cell solids, support tissue solids, muscle cell mass and visceral cell mass) was markedly influenced by nutritional status when expressed in absolute terms (kg), but only muscle cell mass was significantly related to nutritional status when body composition was expressed in terms of % body weight. Differences in body fat derived from body fluid compartment calculations and those based on skinfold measurements raise the question of the accuracy of both methods when applied to malnourished subjects.

The maximum oxygen consumption, expressed as L/min or after normalization for various parameters of body composition and nutritional status, exhibited a marked dependency on nutritional status. It was severely depressed in the malnourished subjects. There were highly significant

statistical correlations between $\dot{V}O_2$ max and numerous measures of nutritional status, with the highest being with creatinine excretion, total body hemoglobin and extracellular fluid volume. These were sufficiently high to permit the development of predictive equations for $\dot{V}O_2$ max and aerobic capacity. On the other hand, maximum heart rate was not correlated with nutritional status.

The maximal endurance time at 80% of $\dot{V}O_2$ max (T_{80}) was not related to the nutritional status.

Nutritional repletion: The studies of the influence of dietary protein repletion consisted initially of a basal period which endured an average of 45 days and during which the protein intake was the same as that taken prior to entering the hospital, i.e., 28 gms/day. Following the basal period there ensued a 2-1/2 month dietary repletion period in which the protein intake was 100 gms/day. Measurements of body composition, nutritional status and physical work capacity (maximal oxygen consumption) were made at the beginning and end of the basal period and at 1.5 and 2.5 months after beginning the protein repletion.

The increased protein intake resulted in statistically significant increases in body weight, serum albumin, plasma proteins, plasma cholesterol and creatinine excretion. There was a slight decrease in plasma volume as part of an overall decrease in extracellular volume. Blood hematocrit and hemoglobin were initially unchanged by protein repletion but exhibited a significant increase at the end of the high protein diet.

The maximum oxygen consumption did not change in the basal period but showed a progressive and statistically significant increase during protein repletion. This increase was not only the result of the change in body weight since it was present after normalization of $\dot{V}O_2$ max for weight. An important observation was the significant improvement in this parameter before significant changes in blood hemoglobin concentration or total body hemoglobin content were observed. There was no significant alteration in maximum heart rate throughout the entire experiment in these subjects, indicating the lack of a training effect as a result of the several exercise tests performed.

An interesting observation in these subjects was the significant decrease in maximum endurance time on the treadmill when the subjects were working at 80% of the $\dot{V}O_2$ max. This may be related to the substitution of carbohydrate calories by protein calories in the daily diet. This observation has also been made by others in animal experiments.

Body compositional changes were also statistically significant and in general showed an increase in most components, with changes in muscle cell mass being the most outstanding.

Productivity: The studies on the sugar cane cutters showed clearly that in heavy physical work the productivity is related to body size (height and weight) as well as to physical condition as determined by the $\dot{V}O_2$ max measured in the laboratory and heart rates measured during work in the field. These findings are those intuition would predict.

Multiple regression analysis resulted in the following equation which contains those factors which contribute significantly to productivity:

$$P = 0.81V - 0.14F + 0.03H - 1.96$$

wherein P = productivity (tons of sugar cane cut/day), V = $\dot{V}O_2$ max (L/min STPD), F = % body fat, and H = height (cm).

However, since the equation accounts for only about 50% of the variability in productivity, it cannot be used as a predictor of productivity. The data indicate that productivity is affected indirectly by nutritional status through the influence of the latter on height, fat content and $\dot{V}O_2$ max.

Evidence is also presented that as the worker ages, a higher percentage of the $\dot{V}O_2$ max has to be utilized in order to maintain productivity.

Among the cane cutters there was a group of men who were inefficient in the work performed and therefore had to utilize an inordinately high fraction of their $\dot{V}O_2$ max to maintain normal productivity. This raises questions about the effects of motivation and habitual alcohol consumption (since the latter has been shown to affect efficiency) on daily productivity in these subjects. Answers are not available since these variables were not measured in the present studies.

It would seem, then, that productivity is the result of many factors, such as body size and composition, physical condition, nutritional status, motivation, habitual alcohol

consumption and, perhaps, even weather conditions. We have measured daily productivity over a 3-month period and taken an average for purposes of these studies. However, the daily values for productivity show a marked variability which the 3-month average was designed to minimize. It may be that one of the newer approaches of mathematics described by Zeeman (82) will find application in quantitating the complex relationships between productivity and the multitude of variables which can affect it.

In comparing the Colombian sugar cane workers (cutters and loaders) with other agricultural workers in Colombia and with laborers and migrant workers in the United States, it was found that the Colombian workers had values for $\dot{V}O_2$ max significantly larger than the U.S. subject. These findings were probably related to greater physical fitness associated with the physical demands of their occupations.

Finally, the preliminary studies on 6-year-old children indicate that malnutrition early in life (up to 3 years of age) results in depressed $\dot{V}O_2$ max values and that subsequent nutritional supplementation for 3 years improves physical condition but does not return the children to normal levels. These results are preliminary and suggest the need for a larger study on the influence of malnutrition on the growth and development of work capacity in children.

2. Interpretation of Data and Supporting Evidence

The specific conclusions to be drawn are stated simply and largely restricted, in this section, to the specific questions asked of the experiments performed as stated in the introduction to the appended progress report. A broader statement of the findings and conclusions is found in the summary of the appended progress report.

a. Does the nutritional state influence the maximal aerobic power of the subject?

The results show clearly that $\dot{V}O_2$ max is significantly related to various measures of nutritional status and that some of these have high enough correlations to be utilizable in predicting $\dot{V}O_2$ max, particularly when several are combined.

b. Does the nutritional state influence the fatigability (maximal endurance time at the same relative work load)?

The results obtained on this point are ambivalent. When maximal endurance time at a work load of 80% of $\dot{V}O_2$ max (T_{80}) was related to nutritional status of the 49 subjects in the nutritional status (vertical) study, there was no statistically significant correlation with any of the parameters which measure nutritional status (e.g., serum albumin or (creatinine excretion x total hemoglobin)/extracellular fluid volume). However, the 19 subjects studied during nutritional repletion with dietary protein exhibited a significant decrease in endurance time at the end of the

2.5 month repletion period. This may be related to the substitution of protein for carbohydrate in the isocaloric diet consumed by the subjects.

c. Is productivity related to the work capacity as measured by the maximum ability of the subject to consume oxygen (aerobic power)?

The answer to this question is "yes." While the degree of statistical correlation of productivity with aerobic power was not high ($r = 0.34$), it was statistically significant.

d. Since these studies were performed in Colombian agricultural workers, what were the normal values for maximal oxygen consumption in Colombian workers as compared to laborers in other ethnic groups?

Normal values of $\dot{V}O_2$ max for Colombian sugar cane cutters and loaders and general farm workers have been established and found to be higher than Milwaukee County civil service laborers and Mexican-American migrant farm workers. The difference is probably related to the severity of daily work tasks.

e. Does malnutrition early in life affect the maximal oxygen consumption?

Undernutrition in 6-year-old children results in severe depression of $\dot{V}O_2$ max. Children who were undernourished at age 3 and received dietary supplementation for the 3 years prior to being studied at 6 years showed some recuperation of physical condition but were still in poorer

physical condition than children from upper socioeconomic groups who had never been exposed to undernutrition.

In general, it has been found that physical work capacity ($\dot{V}O_2$ max) is directly related to nutritional status. It has also been established that productivity is directly related to $\dot{V}O_2$ max as well as to other nutritionally related parameters. By inference, then, the productivity of workers engaged in physically taxing occupations is directly related to the nutritional status of the individual.

E. Dissemination and Utilization of Research Results

1. During the life of the project several presentations were made in seminar form and at scientific meetings in this country, Mexico, Nicaragua and Colombia (see Appendix I). Manuscripts for publication in leading scientific journals are presently in preparation.
2. At a meeting on February 22, 1974, in the office of Dr. Guillermo Varela, Chief of the Social Demographic Division of the National Department of Planning, an agency of the Colombian government, we discussed our findings at length with Dr. Varela and his aides. They were most interested and claimed that the information would be very useful in convincing government officials of the economic impact of undernutrition.
3. We believe that a widespread distribution of our final progress report will be helpful to various officials in the Colombian government.

4. The major portion of this work was done at the Universidad del Valle in Cali, Colombia. There were three professional people and three technicians involved in the work who were Colombians working at the University. One of them, Dr. Mario Barac-Nieto, is a co-investigator and so was involved in all aspects of the project from the beginning.

F. Statement of Expenditures and Obligations

	Total Funding from 6/30/71	Expenditures to 11/30/75
Salaries and Wages	$80,279	$74,044
Fringe Benefits	11,474	10,304
Overhead	21,691	17,713
Travel, Transportation and Allowances	20,851	21,122
Other Direct Costs	25,745	33,878
Equipment, Vehicles, Materials and Supplies	34,286	38,315
Consultants	1,050	0
TOTAL	$195,376	$195,376

G. Work Plan and Budget Forecast for Coming Year

Not applicable.

H. Appendices

Please see following pages.

APPENDIX I

LIST OF SEMINARS, PRESENTATIONS AT NATIONAL AND INTERNATIONAL SCIENTIFIC MEETINGS, AND MANUSCRIPTS

Seminars

1. Spurr, G. B.: Clinical and Subclinical Malnutrition: Their Influence on the Capacity to Do Work. Presented at the University of Wisconsin-Green Bay, May 1973.

2. Spurr, G. B.: Desnutrición Clínica y Subclínica: Su Influencia sobre la Capacidad para Trabajo. Presented at the Escuela de Medicina, Universidad de Guanajuato, León, Guanajuato, México, June 1973.

3. Spurr, G. B.: Influencia de Desnutrición sobre Estado Físico y la Productividad. Presented at the Universidad Nacional Autónoma de Nicaragua, León, Nicaragua, February 1975.

4. Spurr, G. B.: Relaciones entre Estado Nutricional, Estado Físico y Productividad. Presented at the Universidad de Cartagena, Cartagena, Colombia, March 1975.

5. Several seminars of work in progress have been presented by Dr. Barac-Nieto at the Universidad del Valle and other universities in Colombia during the course of the investigations. A list is not presently available.

Presentations at National and International Scientific Meetings

1. Barac-Nieto, M., Lotero, H. and Spurr, G. B.: Capacidad de Trabajo y Desnutrición. Presented at the VIII Annual Congress, Colombian Association of Biological Sciences, Cali, Colombia, October 1973.

2. Barac-Nieto, M., Spurr, G. B. and Maksud, M. G.: Productividad y Aptitud Física en Corteros de Caña. Presented at the VIII Annual Congress, Colombian Association of Biological Sciences, Cali, Colombia, October 1973.

3. Barac-Nieto, M., Spurr, G. B., Maksud, M. G. and Lotero, H.: Nutrición, Aptitud Física y Productividad. Presented at the II Convention, Colombian Association for the Advancement of Science, Bogotá, Colombia, November 1973.

4. Spurr, G. B., Barac-Nieto, M. and Maksud, M. G.: Productivity and Aerobic Power of Sugar Cane Cutters. Presented at the 58th Annual Meeting of the Federation of American Societies for Experimental Biology (FASEB), Atlantic City, New Jersey, April 1974. Fed. Proc. 33:328, 1974 (abstract).

5. Barac-Nieto, M., Spurr, G. B., Lotero, H. and Maksud, M. G.: Physical Work Capacity, Endurance and Undernutrition in Colombian Rural Dwellers. Presented at the 58th Annual Meeting of the Federation of American Societies for Experimental Biology (FASEB), Atlantic City, New Jersey, April 1974. Fed. Proc. 33:678, 1974 (abstract).

6. Spurr, G. B., Maksud, M. G. and Barac-Nieto, M.: Energy cost of cutting sugar cane. Presented at the 21st Annual Meeting of the American College of Sports Medicine, Knoxville, Tennessee, May 1974. Med. Sci. Sports 6:83-84, 1974 (abstract).

7. Spurr, G. B., Barac-Nieto, M. and Maksud, M. G.: Relationships among Productivity, Aerobic Power and Energy Cost in Heavy Physical Labor. Presented at the XXVI International Congress of Physiological Sciences, New Delhi, India, October 1974. Proc. Int. Union Physiol. Sci. 10:92, 1974 (abstract).

8. Barac-Nieto, M., Spurr, G. B., Maksud, M. G. and Lotero, H.: Effects of Protein-Calorie Repletion on Maximal Oxygen Consumption and Endurance in Malnourished Subjects. Presented at the XXVI International Congress of Physiological Sciences, New Delhi, India, October 1974. Proc. Int. Union Physiol. Sci. 10:103, 1974 (abstract).

9. Spurr, G. B., Maksud, M. G. and Barac-Nieto, M.: Maximal Oxygen Consumption in Colombian and U.S. Laborers. Presented at the 26th Annual Fall Meeting of the American Physiological Society, San Francisco, California, October 1975. Physiologist 18:404, 1975 (abstract).

Manuscripts

1. Spurr, G. B., Barac-Nieto, M. and Maksud, M. G.: Energy expenditure cutting sugarcane. J. Appl. Physiol. 39:990-996, 1975.

2. Maksud, M. G., Spurr, G. B. and Barac-Nieto, M.: The aerobic power of several groups of laborers in Colombia and the United States. Eur. J. Appl. Physiol. Occup. Physiol. (In press)

3. Spurr, G. B., Barac-Nieto, M. and Maksud, M. G.: Productivity and maximal oxygen consumption in sugar cane cutters. (Submitted for publication)

4. Spurr, G. B., Barac-Nieto, M. and Maksud, M. G.: Efficiency and daily work effort in sugar cane cutters. (Submitted for publication)

5. Barac-Nieto, M., Spurr, G. B. and Maksud, M. G.: Body composition and nutritional status. (In preparation)

6. Spurr, G. B., Barac-Nieto, M. and Maksud, M. G.: Energy expenditure, productivity and physical work capacity of sugar cane loaders. (In preparation)

7. Barac-Nieto, M., Spurr, G. B. and Maksud, M. G.: Influence of nutritional status on physical work capacity. (In preparation)

8. Spurr, G. B., Barac-Nieto, M. and Maksud, M. G.: Predictability of work $\dot{V}O_2$ under field conditions from telemetered heart rates. (In preparation)

9. Barac-Nieto, M., Spurr, G. B. and Maksud, M. G.: Changes in body composition of malnourished subjects during dietary repletion. (In preparation)

10. Barac-Nieto, M., Spurr, G. B. and Maksud, M. G.: Physical work capacity changes during dietary repletion. (In preparation)

APPENDIX II

FINAL PROGRESS REPORT

ACKNOWLEDGEMENT

The authors wish to express their deep appreciation for the outstanding cooperation granted to them by the management of Central Castilla, Ltd., during the summers of 1972, 1973 and 1974. The willing participation of the hospital patients, sugar cane cutters, and loaders, who took part in these studies is acknowledged with gratitude. Workers from the Centro Internacional de Agricultura Tropical (C.I.A.T.) were also willing subjects and the cooperation of the directors is appreciated.

The following personnel participated with distinction in various phases of the work:

Universidad del Valle

(A) Participating Investigators: Hernan Lotero, M.D.
Jaime Quintero C., M.D.

(B) Technical Staff: Angela de Arango, Martha de Barona, Carmen Elvira Gonzalez, Alba de Lotero, Zoila de Maldonado, Maria Cristina Narvaez, Julia Maria Tascon, Myriam Valencia

(C) Secretary: Emilia Delgado

Medical College of Wisconsin and Wood V.A. Center

(A) Professional and Technical Staff: John H. Kalbfleisch, Ph.D., Ms. Judith Hoernke, James O. Blanck

(B) Secretaries: Ms. Judith Broaddrick, Ms. Sylvia E. Welytok, Ms. Susan Westphal

(C) Medical Artist: Ms. Carole Russell Hilmer

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Dr. K. Tripathy was one of the scientists who participated in the development of the original protocol prior to his departure from Cali.

Finally, the support of the Office of Nutrition, Agency for International Development, is acknowledged with gratitude. The Tulane University ICMR Program in Cali has collaborated in several aspects of the present research.

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INTRODUCTION

Widespread undernutrition has been cited as contributing to reduced productivity, particularly in developing nations where the use of heavy physical labor is common (1). Direct evidence for this concept has been lacking. Indirect measurements of the relationship between nutrition and productivity based on economic considerations have been attempted (2), and Viteri and Torun (3) have shown that the work intensity and leisure activity levels were higher in nutritionally supplemented agricultural workers than in their non-supplemented counterparts.

Keys et al. (4), in the Minnesota experiment, demonstrated that acute starvation of previously well nourished subjects resulted in a decrease in work capacity. Presumably, therefore, physical work capacity, as measured by the maximum ability of the individual to consume oxygen ($\dot{V}_{O_2}$max) (5), would also be related to nutritional status in chronically undernourished patients. However, to date there have been few studies which have attempted to quantitate such a proposed decrement in work capacity in chronic, severe undernutrition (6), to relate it to the nutritional status (i.e., the degree of undernutrition), or to follow its changes during dietary repletion.

The proposed relationship(s) among productivity, nutritional status, physical work capacity ($\dot{V}_{O_2}$ max) and endurance are summarized in Figures 1-3. Figure 1 illustrates the $\dot{V}_{O_2}$ max (L/min) of three hypothetical normal subjects and their relation to the energy cost of a given task expressed in terms of $\dot{V}_{O_2}$ as well as the theoretical $\dot{V}_{O_2}$ max of a severely malnourished subject. The variation of $\dot{V}_{O_2}$ max in the three normal subjects could be the result of age, sex, body size, physical training, etc. (5). Whatever the reason, the O_2 cost of a given task is relatively fixed (if the efficiency with which it is done is not considered) and represents from 50 to 75% of the $\dot{V}_{O_2}$ max of the three normal subjects and 100% of the $\dot{V}_{O_2}$max of the proposed undernourished patient.

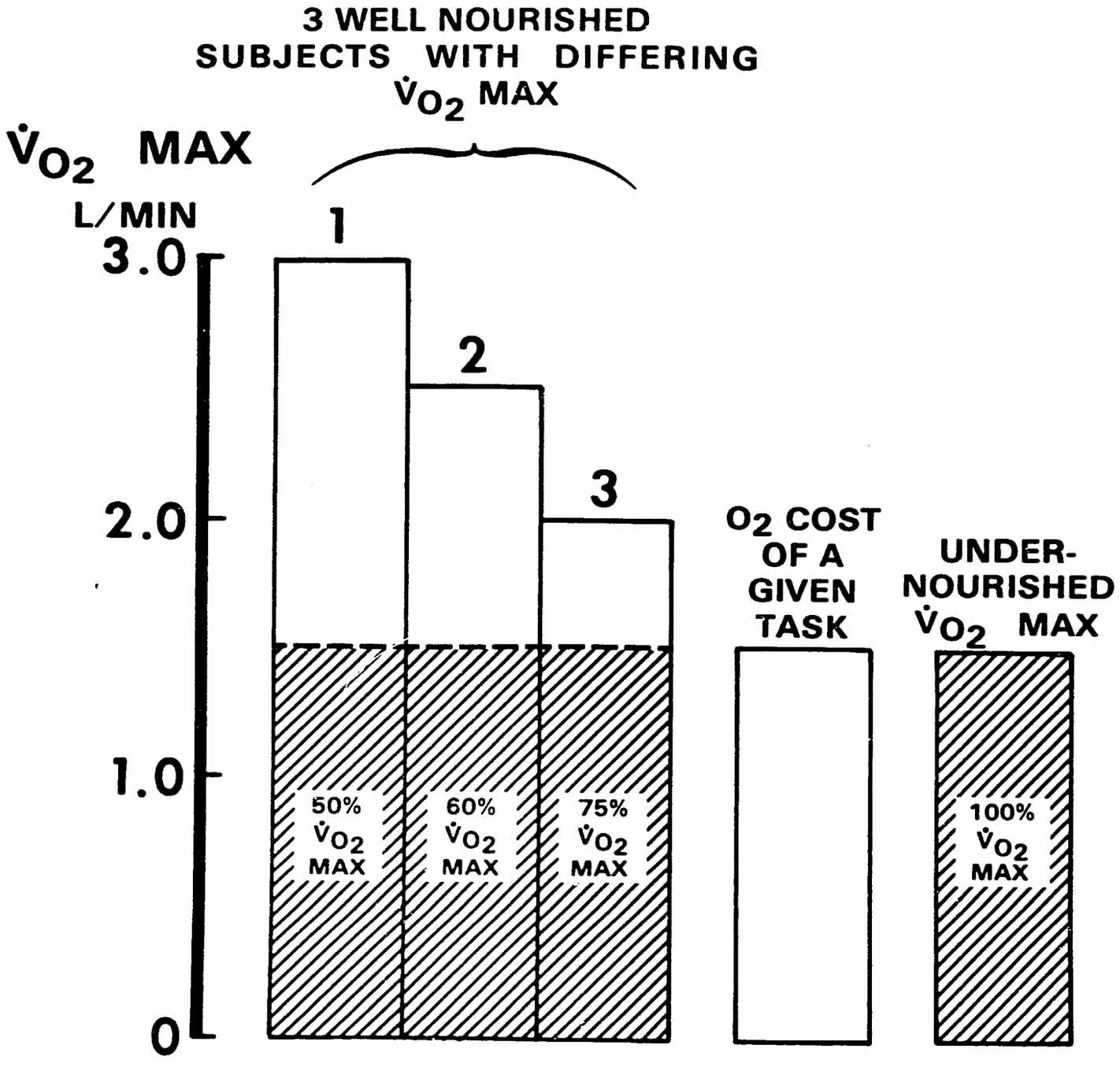

FIG. 1. Hypothetical $\dot{V}_{O_2}$ max of 3 normal subjects compared to oxygen cost of a task and the theoretical $\dot{V}_{O_2}$ max of a malnourished subject.

Figure 2 expresses these ideas in terms of the percentage of the $\dot{V}_{O_2}$ max utilized to maintain three levels of productivity. From a number of sources it is known that the maximum effort a well trained individual can sustain for an 8-hour working day is one which utilizes about 35-40% of the $\dot{V}_{O_2}$ max (7). Figure 2 shows the theoretical per cent effort which would have to be sustained at three different productivity levels and points out that there are at least two factors involved in productivity:

(1) variations in absolute $\dot{V}_{O_2}$ max (Fig. 1), and therefore in the amount of effort which an individual can expend when utilizing 40% of that available to him.

(2) willingness (motivation) to utilize increasing fractions of the $\dot{V}_{O_2}$ max to produce a given product.

Figure 2 shows that a malnourished person with a severely reduced $\dot{V}_{O_2}$ max might be able to maintain the lowest productivity level while making a maximum (40% $\dot{V}_{O_2}$ max) effort. However, the per cent $\dot{V}_{O_2}$ max which an undernourished person can sustain during 8 hours has not been determined.

Figure 3 is a modification of Åstrand and Rodahl's (5) relationship between relative intensity of work (expressed as a percentage of the maximum work load) and endurance. Endurance at a given load depends on (a) the relative intensity of the work for the subjects as measured by the fraction of the $\dot{V}_{O_2}$ max which is being taxed, and (b) the ability of the subject to sustain (endure) loads at that given relative intensity. It seems logical that productivity at a given work load would be higher, the more the subject can endure working. Decreases in endurance time at a given load would affect productivity either by obliging the subject to work at a lower rate and/or by more frequent rest stops.

If a change in endurance time can be quantitated, it could be translated either as salaries lost (when salary depends on productivity) or as time (and money) wasted for the employer (when salary is on a time basis). The

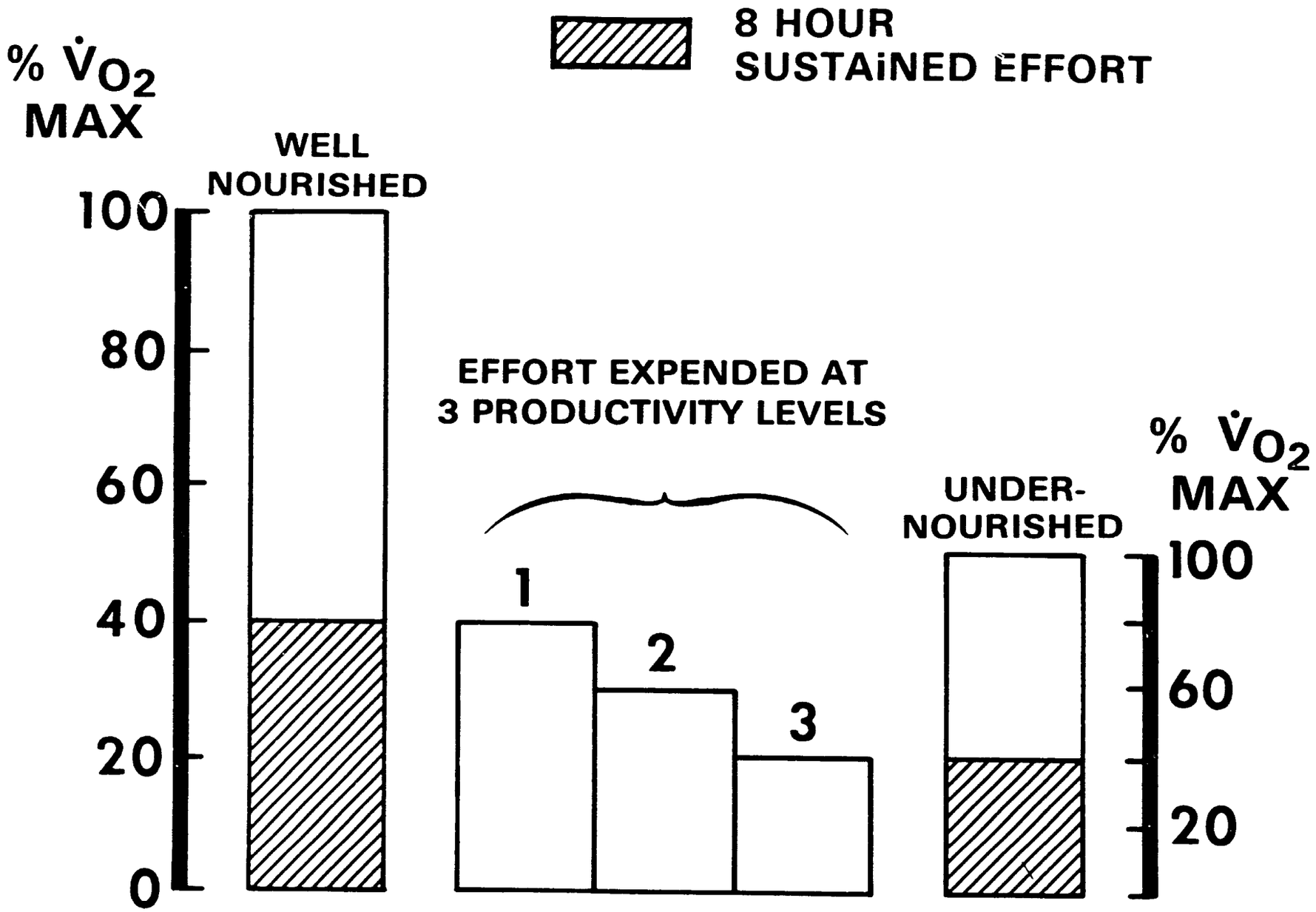

FIG. 2. Per cent $\dot{V}_{O_2}$ max related to effort expended in achieving 3 hypothetical productivity levels in normal and malnourished subjects.

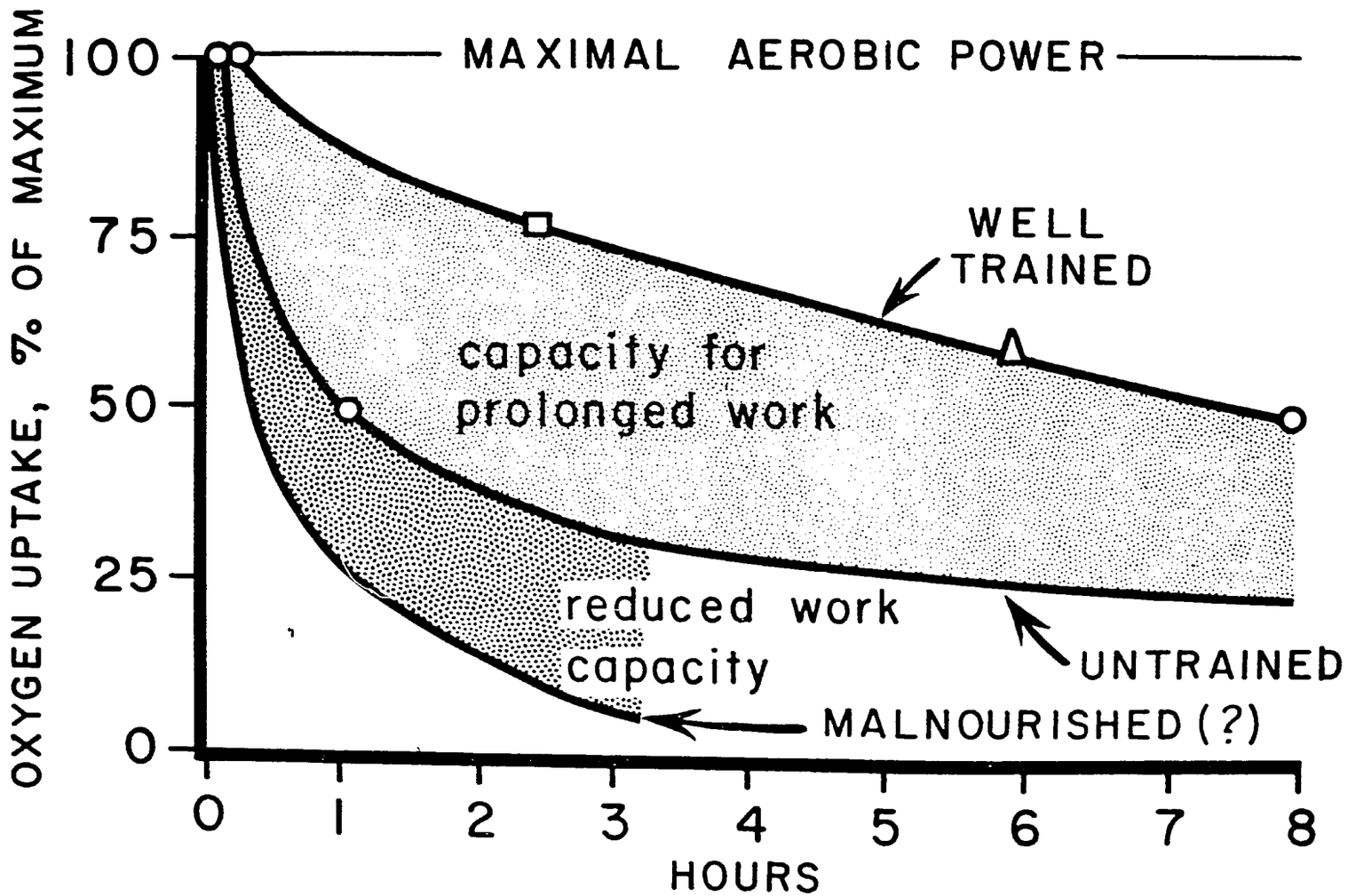

FIG. 3. Proposed relation of per cent $\dot{V}O_2$ max to endurance time in malnourished subjects (modified from Astrand and Rodahl (5)).

relationship between relative work loads and maximal endurance times can be described by a first order exponential:

$$\% \ \dot{V}_{O_2} \max = e^{-kt}$$

The slope (k) of the semilog plot of endurance versus $\dot{V}_{O_2}$ max estimates the fatigability of the subject and depends on the "motivation," training, etc., of the subject in the specific type of work.

Changes in endurance time at a given work task can thus occur as a function of differences in maximal aerobic power (Fig. 1), resulting in different degrees of taxation on the subject's aerobic reserves (Fig. 2), or in changes in endurance time at the same relative work load (Fig. 3).

Furthermore, it has been suggested that a man's maximum capacity to do physical work--expressed in terms of the rate of oxygen consumption per unit of body weight or simply as $\dot{V}_{O_2}$ max in L/min--is related to his productivity when performing hard physical labor. In support of this concept, Hansson (8) reported that lumberjacks who have higher $\dot{V}_{O_2}$ max's earned more money. These men are paid by piecework.

If a relationship can be established between physical work capacity and productivity, one would then have a way of translating the laboratory findings on malnourished subjects into the economic impact of undernutrition on productivity. The specific questions to be asked are:

(1) Does the nutritional state influence the maximal aerobic power of the subject?

(2) Does the nutritional state influence the fatigability (maximal endurance time at the same <u>relative</u> work load)?

(3) Is productivity related to the work capacity as measured by the maximum ability of the subject to consume oxygen (aerobic power)?

(4) Since these studies are to be performed in Colombian agricultural workers, what are the normal values for maximal oxygen

consumption in Colombians as compared to laborers in other ethnic groups?

5) Does malnutrition early in life affect the maximal oxygen consumption?

MATERIALS AND METHODS

I. SUBJECT GROUPS

The answers to these questions were investigated in several groups of subjects.

(A) Nutritional Status (Vertical) Study

These are patients covering a range of nutritional states and maximal aerobic power. They are the so-called "subclinically" malnourished subjects, although at the low extreme of the range, values from subjects who were entering the second group, described below, were included. At the high end of the scale normal subjects were also included to increase the range of nutritional states studied.

(B) Nutritional Repletion (Longitudinal) Study

In this group of severely malnourished patients the results of nutritional (protein) repletion on physical work capacity, body composition and blood chemistry were studied.

(C) Productivity Study (Sugar Cane Workers)

Sugar cane raising and processing constitute one of the largest agricultural endeavors in the Valle del Cauca. The harvesting is done by hand and sugar cane cutters and loaders form a large part of the agricultural work force in this region. The men are paid by the metric ton of sugar cane they cut each day and so accurate records are kept of their productivity.

(D) Laborers in Colombia and the United States

The subjects in (C) above were engaged in a specific kind of agricultural activity. We were interested in obtaining a comparison of their work capacities with others in Colombia who had a similar socio-economic background and who were also engaged in agriculture not related to the sugar cane industry. The three groups were then compared with two groups of laborers in the United States.

(E) Children

Because of the obvious question about early nutritional effects on work capacity, some pilot studies were done on children with both a good and a poor nutritional history, the latter with and without nutritional repletion and supplementation.

II. STUDIES IN MALNOURISHED ADULTS

(A) Patient Selection Procedure

A total of 49 male subjects (18-56 years of age) were selected for this study from among more than 400 rural dwellers interviewed in the northern part of the state of Cauca, Colombia, South America. They belonged to the indigenous or mixed indigenous-white population of the area. Social workers thoroughly informed the subjects of the objective of the study and the methods and procedures to be employed. A venous blood sample was obtained from those willing to cooperate and their heights and weights were measured. Hematocrit and blood hemoglobin concentration were determined immediately in an aliquot and the remainder centrifuged and the plasma frozen for later determination of plasma protein and serum albumin concentrations. Subjects with weight/height ratios below 32 kg/m and plasma albumin less than 4 gms % were invited to stay for 15-20 days in the metabolic ward of the University Hospital in Cali, Colombia, for further study and evaluation. Some subjects exceeding the above mentioned limits were also invited in order to include a few representative "normal" subjects in the study. Eighteen subjects had serum albumin levels of 2.2 gms % or below and weight/height ratios below 30 kg/m. These were invited for a longer stay in the ward for purposes of the nutritional repletion study. All the subjects received weekly allowances of food for their families during their stay in the hospital. Those found to be in a marginal state of nutrition were advised nutritionally and referred to their rural health center for follow-up upon discharge from the metabolic ward.

At the University Hospital in Cali the subjects underwent a complete clinical history and physical examination including a resting EKG and chest x-rays. Samples were obtained for coproanalysis, serology, routine urine analysis, fasting blood glucose level and blood urea N_2 level. If no pathology was found except for the nutritional compromise, the patient was included in the study. However, intestinal parasites (Ascaris, hookworm, Entamoeba histolytica, Giardia lamblia, Trichocephalus, Strongyloides) and anemias (iron and folic acid deficiencies) are frequently associated with undernutrition. It was thus impossible to exclude those patients from the study.

(B) Biochemical Assessment of Nutritional Status

This included a 3-4 day pooled collection of urine and feces for determination of N_2 balance (9) and urinary creatinine excretion (10). The collection period was preceded by at least one week on a constant diet. Environmental temperature was kept as constant as possible. The subjects stayed in air conditioned rooms at 22°-24°C during the entire experiment. A 24-hr urine sample was obtained on the day of entry into the hospital for assay of urinary thiamine (11) riboflavin (11), ascorbic acid (11) and N-methylnicotinamide (11). Erythrocyte transketolase activity (12) plasma proteins, serum albumin (9) and cholesterol levels (13) were determined on a blood sample obtained on the day of entry into the hospital.

(C) Hematological Assessment

In addition to blood hemoglobin concentration (11), hematocrit (14) and a blood smear (11), samples were obtained for determination of serum Vit B_{12} (15), folic acid (16), total serum iron (17), iron binding capacity (18), and percent transferrin saturation (19). A bone marrow aspirate (iliac) was obtained in most cases.

(D) Body Composition Studies

After an overnight fast during which the subjects had free access to water, body weight was determined to the nearest 25 gm on a Homs beam balance and height measured to the nearest millimeter.

Right subscapular and triceps skinfold thicknesses were taken by triplicate independent determinations with a Lange caliper (20). The same person always made the measurements. Total body water was measured (21) using tritiated water (HTO) dilution: A dose of 0.2 mC of HTO in approximately 10 ml of sterile saline solution containing 60 mg/ml of sodium thiocyanate was administered IV, by a syringe weighed before and after the injection. Blood samples were taken after 3 hrs equilibration, during which no ingestion of water was allowed. Concentration of tritium in plasma was determined in a protein free filtrate of plasma, using Bray's solution (22) and a liquid scintillation counter (Packard Model 2110). Counting efficiency for ^3H was approximately 25% and was measured in each sample using automatic external standardization (23). Plasma water was estimated from the protein concentration in plasma (% water = 100 -% protein). Total body solids were estimated as the difference between body weight and total body water. Extracellular fluid volume was estimated from the space of distribution of the injected thiocyanate (24). Thiocyanate was determined spectrophotometrically in samples of protein free filtrate of plasma obtained after 3 hrs equilibration (24). Plasma volume was estimated by dilution of Evans blue, in plasma samples obtained 10 min after IV injection of 25 mg of the dye (25). Blood volume was calculated from the estimated plasma volume and the venous hematocrit, correcting by 0.92, the ratio between whole body and large vessel hematocrit (26). Intracellular water was estimated as the difference between TBW and thiocyanate space. When pertinent, fat free weight was estimated from the HTO space and the hydration coefficient of fat free body, estimated in turn from the ratio of intracellular to total body water and the ratio of measured to predicted extracellular

space, according to Moore (27). Predicted extracellular fluid volume was estimated from the age, weight and sex of the subjects (27). Fat weight and fat free solids were calculated by differences (27). Body cell mass was estimated from intracellular water using the regressions described by Moore (27) between intracellular water and total body exchangeable K and between total body K and body cell mass. Cell body solids were calculated as the difference between cell body mass and intracellular water. Extracellular solids were calculated as the difference between fat free solids and cell body solids.

Muscle cell mass was estimated from the measured daily creatinine excretion and an assumed rate of creatinine production per Kg of muscle cells (80 mg/Kg day). Fisceral cell mass was calculated as the difference between cell body mass and muscle cell mass. Total body hemoglobin was calculated from the estimated blood volume and the measured concentration of hemoglobin in venous blood.

(E) Dietary Intake

Table 1 presents the dietary composition during the basal period and dietary repletion for those subjects who subsequently entered the repletion study. Subjects in the nutritional status study consumed only the basal diet during their hospital stay. Subjects were provided with an adequate caloric intake for the sedentary conditions prevailing in the ward (2240 ± 357 kcal /day). Fat provided approximately 30% of the calories, averaging 76 ± 15.74 g/day; 70% of the fat derived from corn oil, the rest from cream.

Protein intake was maintained at a level approximating that reported by the subjects to be eaten at their homes according to data obtained in a nutritional inquiry (24 hr recall method) and averaged 28.84 ± 12.76 g/day. Ninety percent of the protein was of vegetable origin (colombiaharina, bienestarina) but with high biological value while 10% was of animal origin. The diet provided all recommended allowances of vitamins and minerals (28).

TABLE 1

HOSPITAL DIETS

	Basal	Repletion
Calories	2240 ± 357 kcal/day	Same as basal
CHO	64.33% of calories	50.35% of calories
Fat	30% of calories 70% of all fat from corn oil 30% of all fat from cream	Same as basal Same as basal Same as basal
Protein	28.84 ± 12.76 gm/day (5.66% of calories) 10% of animal origin 90% Colombiaharina	100 gm/day (19.65% of calories) Same as basal Same as basal

TABLE 2

N_2 BALANCES (GM/DAY) BEFORE, DURING AND AFTER A $\dot{V}_{O_2}$ MAX TEST

Patient	Days		
	1,2 & 3	4*,5 & 6	7,8 & 9
A. Gue	+4.61	+5.14	+4.55
B. Barona	+1.00	+4.53	+2.66
Mean	+2.80	+4.84	+3.60

*Exercise day

(F) Nutritional Repletion (Longitudinal) Study

In patients included in the longitudinal study (severely malnourished) a pooled 4-day collection of urine and feces was done after one week on the low protein hospital diet for N_2 balance and urinary creatinine output determinations.

A one week period was allowed to establish a steady state in N_2 input and output. Exercise testing or training was avoided in this period, since experiments with two patients showed that nitrogen balance became more positive when performed on a 3-day pooled collection started the day after a $\dot{V}_{O_2}$ max test was performed (20-25 min duration) (Table 2). Upon termination of balance studies, body composition studies were initiated as described above.

After exercise testing (to be described), the patients continued for four weeks on a low protein (basal) diet. At the end of these four weeks, the nutritional evaluation protocol, body composition and exercise studies were repeated. This one month period has been included so as to evaluate the possible effects of training or inactivity due to the sedentary life in the metabolic ward on the physical work capacity of the subjects.

Upon completion of the second battery of studies during the basal (low protein) period, nutritional repletion was started with an isocaloric diet providing 100 gms of protein per day (Table 1). Four weeks after the start of nutritional repletion the testing protocol was repeated. The same protocol was repeated 8 weeks after the start of nutritional repletion.

(G) Nutritional Status (Vertical) Study

When the same criteria for admission had been met as described for patients in the longitudinal study, processing of urinary and blood vitamins was ordered and a low protein (20 gm/day) diet started.

In a first group of nine patients, a 3-day pooled collection of urine and feces was started on day 2 for N_2 balance and creatinine output

determinations. However, it was found that negative N_2 balances were frequently encountered in these patients, probably reflecting the adjustment to the low protein (20-25 gm/day) diet they were receiving in the metabolic ward (Table 3). Thus a longer period of adjustment to the hospital diet seemed to be required in these patients to obtain valid measurements of N_2 balance in a steady state.

Since it was felt that one additional week in the hospital was not justified for this group of patients and we knew that N_2 balances taken immediately after exercise testing resulted in falsely positive balances, we have tested (using the patients in the longitudinal study) whether N_2 balances taken 3 days after exercise testing give the same results as N_2 balances taken before exercise testing (Table 4).

(H) Summary of Criteria for Patient Selection

The original selection of patients was based on weight/height ratios less than 32 kg/m and serum albumin of < 4 gms%. In the final analysis, the 49 subjects who became subjects were divided into three groups as summarized in Table 5. Using the weight/height ratio, the serum albumin and the creatinine/height index a point system was devised. The patients with 8-9 points were those in the best nutritional condition (Group A, n = 11); those with 5-7 points were below normal nutritionally (Group B, n = 20); and those with 3-4 points were considered to be severely malnourished (Group C, n = 18). The subjects in Group C were the ones who subsequently participated in the nutritional repletion study. Table 6 presents the means and standard deviations of the parameters used to define the three groups.

III. STUDIES IN SUGAR CANE WORKERS

(A) Type of Work

The measurements to be reported were obtained on sugar cane cutters in the Valley of the Cauca River in Colombia. In this region, sugar

TABLE 3

N_2 BALANCES (GM/DAY) IN SUBJECTS IN VERTICAL STUDY

Patient	N_2 Balance
M.T.	-1.36
M.A.C.	-.97
R.Ch.	-2.11
R.I.	-.29
M.T.	-1.87
Mean	-1.32
S.D.	0.73

TABLE 4

N_2 BALANCES (GM/DAY) BEFORE AND AFTER EXERCISE

Patient	Before	Before	3 Days After	15-20 Days After
I.M.	+.892	+1.189	+1.080	+1.110
R.U.	+1.323	+.661	+1.230	+1.310
R.C.	+1.850	+.795	+1.037	+.605
Mean	+1.355	+0.882	+1.116	+1.008
S.D.	0.480	0.274	0.101	0.363

TABLE 5

POINT SYSTEM FOR CLASSIFYING SUBJECTS BASED ON WEIGHT/HEIGHT RATIO, SERUM ALBUMIN CONCENTRATION AND CREATININE/HEIGHT INDEX (Cr/Ht)

Weight/Height		Serum Albumin		Creatinine		Total Points	Group
kg/m	Points	gm %	Points	Height (mg/day/m)	Points		
>32	3	>3.5	3	>600	3	8-9	A
29-32	2	2.5-3.5	2	450-600	2	5-7	B
<29	1	<2.5	1	<450	1	3-4	C

TABLE 6

MEANS AND STANDARD DEVIATIONS OF VARIABLES USED IN CLASSIFYING SUBJECTS INTO GROUPS A, B AND C (TABLE 5)

	Group A (n = 11)	Group B (n = 20)	Group C (n = 18)
Weight/Height (kg/m) $F = 30.12$ ($P < 0.001$)	33.29 ± 2.09	30.81 ± 2.02	27.38 ± 2.09
Creatinine/Height ($mg/day \cdot m^{-1}$) $F = 50.19$ ($P < 0.001$)	660 ± 67	559 ± 75	391 ± 76
Serum Albumin (gm %) $F = 30.03$ ($P < 0.001$)	3.83 ± .46	3.05 ± .70	2.14 ± .50

cane cutting occurs during 12 months of the year. The subjects had been cutting cane full-time for at least 9 months prior to the study. The men commence work at about 6:30 AM and continue, with only brief breaks for water, until noon. They then take an hour for lunch, which consists of a hot meal of soup, rice, some meat, potatoes, casava (yucca) or other vegetables. They return to work at about 1:00 PM and cut until 3:30 or 4:00 PM, when they stop for the day.

Each man is assigned a line about 15 feet wide. Cutting commences at the edge of the field and moves toward the center. It is done with a 75 cm machette weighing about 700 gm. Each stalk weighs approximately 1-2 kg and is usually cut individually and deleafed before being thrown on a pile which follows the cutter across the field. The pile is marked with the worker's identification number for later collection by separate gangs of loaders. The collected cane is weighed and accurate records are kept of the productivity, since the men are paid by the metric ton of cane cut.

In the case of the sugar cane loaders, work is intermittant depending on the availability of wagons. However, when wagons are available the work is intense because of the desire to load as many wagons as possible while they are available. These men are also paid by the metric ton of cane loaded.

(B) Subject Selection

All the subjects were male employees (18-56 years of age) of a large sugar cane growing and processing firm (Central Castilla, Ltda.). They were selected from company records to give representative age and productivity. In order to rule out chronic diseases, no subject was chosen who had been absent from work for more than 2 days in the previous 3 mos. The work history of the men in cutting cane varied from 9 months to 17 yrs, with the majority reported 2-6 yrs of experience. Data for experience of the sugar cane loaders was not available.

(C) Measurements in the Field

Oxygen consumption and pulmonary ventilation were measured with a Kofranyi-Michaelis (K-M) respirometer (Zentralwerkstatt Gottigen) which was calibrated and used as described by Consolazio (29). The K-M meter weighs about 3 kg and offers minimal interference to cutting sugar cane (Fig. 4). Aliquot samples of expired air were taken in a rubber balloon attached to the respirometer. Immediately following termination of a measurement, 50 cc of the sample were transferred to an oiled, glass syringe for later analysis. During the collection periods the three-way respiratory valve (QuinTron Instruments) and mouthpiece were supported by a headpiece worn by the subject and connected to the respirometer on his back by flexible tubing to allow free movement of his arms and shoulders (Fig. 4).

Heart rates were determined with a Parks Telemetry System, using two precordial leads. Counts were made for the last 30 sec of each min during the 5-min data collection periods, averaged and expressed as beats/min.

Prior to each experiment the equipment and its use was carefully explained to each subject. He was instructed to cut or load cane as was his custom, neither faster nor slower. After positioning the equipment he was allowed to respire quietly for 10 min while seated in order to flush the instrument and to become accustomed to the mouthpiece and nose clamp; then a 5-10 min collection period ensued to determine resting values.

(1) Cutters

Following the resting measurements the subjects began work on signal, and the first collection of data was made between the 5th and 10th min of work. It has been shown that at submaximal work loads the heart rate and oxygen consumption plateau after about 2 min of work (30). At the end of the 5-min collection period the subjects stopped for removal of the sampling balloon and mouthpiece and recording of ventilation values from

A. Subject at rest.

B. Subject cutting sugar cane.

FIG. 4

the respirometer. The subjects then continued working and during the 16-17 min the mouthpiece and collection bag were replaced. A second collection was made between the 20 and 25 min. Following the second collection period the apparatus was removed and the subjects returned to their work.

During each period of testing, the cane cut was carefully collected and the stalks counted and weighed on a Detector Scale Balance having a 500 kg capacity. The accuracy of the balance was checked at frequent intervals with 50 and 100 pound standard weights.

Measurements were made during July and August of 1972 and 1973. Three subjects were measured each day in the field. Testing began on the first man at 7:00 AM and finished on the third at approximately 10:00 AM. Consequently, the first man had not been working prior to the test, whereas the second and third had been working about 1 and 2 hr, respectively, before undergoing the testing procedure. In 58 of 61 subjects, repeat measurements were made in the afternoon of the same day between 1:00 and 4:00 PM, using the same testing procedure as in the morning.

Ambient air temperatures were measured with an unshielded thermometer during each work period and averaged. Humidity was determined with a sling psychrometer. Sweat rates were measured in 20 of the men by obtaining body weights on a Homs Beam Scale accurate to ± 25 gm, while clad in shorts, before and immediately after the 25 min period of cutting.

Oxygen debt determinations were made on five men, utilizing the K-M meter, by collecting 5-min samples continuously for 30 min following the termination of work.

(2) Loaders

The measurements of $\dot{V}_{O_2}$ and f_H in the sugar cane loaders was done with the same equipment and techniques as in the cutters. The determinations were done during the summer of 1974. The collection periods

were between 10-15 min, 25-30 min and 40-45 min following commencement of work. Loading of the wagons occurred in approximately 1 hr (50-70 min). The weight of cane loaded was subsequently obtained at the weighing station.

(D) Analysis of Gas Samples

At the end of a day of testing, the stored expiratory gas samples were transported back to the Exercise Laboratory at the Universidad del Valle in Cali for analysis. Oxygen and carbon dioxide concentrations were measured in duplicate by a gas chromatograph (model H-3, QuinTron Instruments). The instrument was calibrated with standard gases, the concentrations of which were established with a Scholander apparatus (20). All gas analyses were done on the day of collection.

(E) Testing in the Laboratory

Later in the same week in which the field studies were done, the men were transported to Cali for the laboratory studies. At the laboratory, scapular and triceps skinfold thicknesses were obtained with Lange skinfold calipers (Cambridge Scientific Instruments, Inc.) and body weight (± 25 gm) and height (± 1 mm) measured. Body density was estimated by the formulae of Pascale et al. (31) and body fat by the formula of Brozek, et al. (32). A 4-5 hr postabsorptive venous blood sample was taken for serum albumin (9), total proteins (9), hematocrit and hemoglobin (14) determinations in most of the subjects.

The subjects then underwent a maximum oxygen uptake determination as described below. Expired gas samples were taken in oiled glass syringes from a mixing chamber in the expiratory line and analyzed as described above. $\dot{V}_E$ was measured by means of a Parkinson-Cowan dry gas meter (Model CD4). Heart rates were recorded on a Grass Polygraph, using lead CV_5.

(F) Dietary and Activity Questionnaires

In 27 of the sugar cane cutters, dietary information was obtained from each subject by a trained nutritionist utilizing the 24 hr recall technique. Activity levels were estimated in 59 of 61 subjects by the procedure described by Saltin and Grimby (33).

IV. COMPARATIVE STUDIES IN COLOMBIAN AND U.S. LABORERS

The subjects for this study were three groups of adult males from Colombia and two groups from the United States. The Colombian populations included the sugar cane cutters and loaders and 18 agricultural workers engaged in general farming. The two United States populations involved 20 Milwaukee County civil service laborers and 15 Mexican-American migrant farm workers. The civil service laborers worked at a variety of tasks including golf course maintenance, snow shoveling, etc. The migrant workers were studied while in Wisconsin during the latter part of the harvest season.

The studies in Colombia and the United States were done by the same investigators utilizing similar equipment. The men reported to the laboratory in small groups. All subjects were given an orientation to treadmill walking and the overall experimental procedure. Heights and weights were measured with the subjects dressed in shorts. Skinfold measurements were made in triplicate at two sites, triceps and subscapular, using a Lange skinfold caliper.

The exercise testing was done as described below for adult subjects. Venous blood samples were also obtained from the Colombian subjects engaged in general farming but not from the U.S. populations.

V. STUDIES IN CHILDREN

In order to obtain some preliminary information on the influence of early undernutrition on physical work capacity, we have studied 36 children

participating in a program conducted by the "Human Ecology Research Station" under the direction of Drs. H. McKay, A. McKay and L. Sinisterra during the past six years (34) and six American children residing in Cali for at least one year prior to the performance of the studies.

Thirty children in Groups 1, 4 and 6 (the group numbers 1, 4, 5 and 6 are those assigned in the McKay-Sinisterra study (34)) were the lowest in terms of heights and weights in a population of 469 - 3 yr old children born during a 6-mo period in one of the poorest barrios in the city of Cali. This population contrasted sharply in terms of distribution of heights and weights for age with a sample of Colombian children from high income families living in the same city (Group 5). This last group did not differ significantly from normative populations (Boston, Iowa or Mexican norms).

All 30 children chosen from Groups 1, 4 and 6 belonged to the lower 10 percentiles of the normative populations and to the lower 25 percentiles of the population of 469 children screened. In the studies performed in our laboratory, Group 1 was composed of 10 children who, during the 3 yrs prior to our measurement, received nutritional supplementation (mostly vegetable proteins and all mineral and vitamin requirements), health care and psychoeducational stimulation in a special school run by the program. Group 6 was made up to 10 children who received the nutritional supplementation (mostly animal protein) and health care in a supervised home-based program. Group 4 consisted of 10 children who did not enter the program (i.e., receive nutritional supplementation) until they entered the school shortly before the measurements to be described were done. Group 5 was composed of 6 children from advantaged (high income) Colombian families and like Group 4 were observed only (i.e., no intervention) during the 3 yr period prior to determination of their $\dot{V}_{O_2}$ max. The means and standard deviations of the body weights and heights at the beginning, middle and end of this period are presented in Table 1. The subjects in Group 7 (our group number) are the 6 volunteer American children mentioned above and were measured only at the time of the $\dot{V}_{O_2}$ max determination.

When the children were 6 yrs old (approximately 80 mos), they were all evaluated in terms of physical fitness, utilizing the treadmill (Figs. 5 and 6) and a modification of the procedure used in the adults (see below).

VI. EXERCISE TESTING

The exercise protocol was designed (a) to determine maximal aerobic power and (b) to determine maximal endurance time at submaximal loads.

(A) Reproducibility of Exercise Tests

In 10 voluntary medical students we have carried on test-retest correlations for $\dot{V}_{O_2}$ max and endurance tests (a) to assess the limits of confidence of the experimental procedures in our hands, and (b) to determine possible training effects of the first exercise sessions on the last ones.

After a warmup period the subjects underwent a continuous treadmill test at 3 or 3.5 mph; starting at 2.5% grade and elevating 2.5% grade each 2 min up to exhaustion. This was done on two occasions separated by one week. Results were expressed as the ratio (r) of the $\dot{V}_{O_2}$ max determined in the second test to the $\dot{V}_{O_2}$ max determined in the first test ($\bar{r} \pm SE = 1.05 \pm .07$, $n = 10$).

In 9 subjects maximal endurance times were determined at the same submaximal load on two occasions separated by two days. Results were expressed as the ratio of the endurance time in the second test to the endurance time in the first test. For 5 subjects working at more than 90% of their $\dot{V}_{O_2}$ max and enduring less than 1 hr, reproducibility was good: ($\bar{r} \pm SE = 1.02 \pm .15$, $n = 5$).

In 4 subjects working at less than 90% of their $\dot{V}_{O_2}$ max and enduring for more than 1 hr in the first test, a training effect occurs ($\bar{r} \pm SE = 1.38 \pm .17$, $n = 4$).

FIG. 5. Six year old boy walking on treadmill during $\dot{V}O_2$ max test.

FIG. 6. Six year old girl on treadmill showing safety harness.

Thus, the exercise protocol was devised so as to avoid training effects of one session on the next: (a) The less intense and more prolonged test was done last in the series; (b) Submaximal tests were performed at high intensities, the first at 90-95% of $\dot{V}_{O_2}$ max, the second at 80-85% of $\dot{V}_{O_2}$ max.

As already mentioned, the possible effects of one battery of tests (or the resting period) on the results obtained in the next battery, performed four weeks after, are being studied in malnourished patients in the longitudinal study by testing them twice during the basal (low protein) period. Malnourished patients served as subjects because of the possible effects of the sedentary activity and bed rest in the metabolic ward in addition to any effect of training on the aerobic capacity and endurance time of the patients under study (35). These conditions would be difficult to reproduce in "normal" subjects.

To compare the "efficiency" of our subjects with previously reported data the relationship between treadmill grade and oxygen uptake was determined for 24 subjects who walked at 3.0 mph. These data are shown in Fig. 7 along with data reported by Fox (36). The calculated regression lines are very similar.

(B) <u>Exercise Protocol in Malnourished Subjects</u>

(1) Training 3 mph - 2.5% grade - 5-10 min

(2) Training 3 mph - 2.5% grade - 5-10 min

(3) Training 3 mph - 2.5% grade - 5-10 min

(4) $\dot{V}_{O_2}$ max test

Rest Collect $\dot{V}_E$ x 1' and measure $F_{E_{O_2}}$ and $F_{E_{CO_2}}$, heart rate, respiratory frequency.

Calculate $\dot{V}_{O_2}$, $\dot{V}_{CO_2}$, R, $\dot{V}_E$, V_T, $\dot{V}_{O_2}$/hr, $\dot{V}_E/\dot{V}_{O_2}$.

EKG at rest.

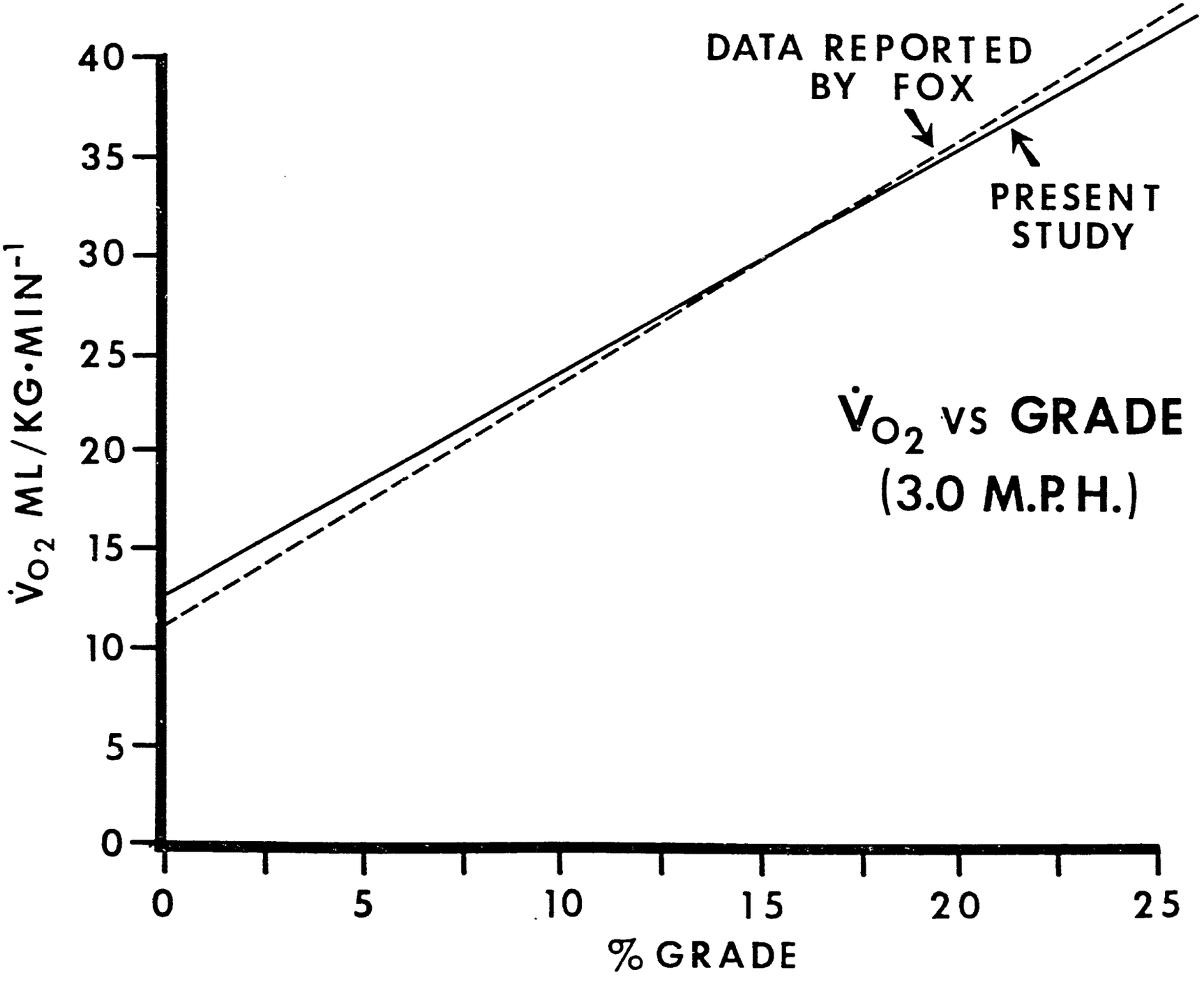

FIG. 7. Comparison of results obtained in this laboratory with those reported by Fox (36).

Warmup 3 mph - 2.5% grade

Exercise EKG

Choose testing speed:

$f_H < 100$	speed 3.5 mph
$100 < f_H < 120$	speed 3.0 mph
$f_H > 120$	speed 2.5 mph

Rest 2 min

Test Start at 2.5% grade

Increase grade 2.5% each 2' up to exhaustion. Sample from 1:30" to 2' at each work load.

(5) Active recovery at 2 mph 0% grade for 2 min. Rest.

(6) Submax test I

Work at 90-95% of $\dot{V}_{O_2}$ max.

Push to maximal endurance time.

Measure $\dot{V}_{O_2}$, etc., at 2.5, 5, 10, 15 min and thereafter each 15 min; also upon reaching exhaustion.

Watch heart rate up to maximal.

(7) Recovery

(8) Rest

(9) $\dot{V}_{O_2}$ submax II

Work at 80-85% of $\dot{V}_{O_2}$ max.

Same as submaximal test I.

Although initially proposed, venipuncture, cardiac output and breath-holding D_{LCO} determination during exercise were eliminated from the protocol since we found them to interfere with the willingness of the subjects to reach exhaustion, either in the maximal test or in the endurance tests.

(C) Exercise Protocol in Adults and Children

The testing procedure for these subjects was essentially the same as for the malnourished subjects except that training in the normal adults was

done on the day of the test and endurance studies were not generally performed.

(D) Criteria for Maximal Exercise

A controversial point is the criteria for maximum in exercise testing of patients (37).

(1) In the $\dot{V}_{O_2}$ max test, we have always reached plateau or decreases in the rate of oxygen consumption when reaching a supra-maximal load. Also, heart rate plateaus generally faster than $\dot{V}_{O_2}$ max so that the relationship between $\dot{V}_{O_2}$ and heart rate is not linear at near maximal loads. Finally, we have always observed an abrupt increase in $\dot{V}_E$ and a decrease in $F_{E_{O_2}}$ upon reaching maximal $\dot{V}_{O_2}$.

(2) At submaximal loads the criteria for exhaustion and maximal endurance are:

(a) Heart rate within 5 beats of maximal as determined in the maximal test.

(b) Inability to follow the treadmill.

(c) Abrupt increases in $\dot{V}_E$.

In one severely malnourished patient we observed frequent AV blocks (first degree) upon reaching maximal work load; in a second one, a small ST segment depression (2 mm) at maximal work loads; and in still another, occasional PVC's were observed at maximal load and frequent PVC's immediately upon recovery.

VII. DETERMINATION OF T_{80}

The maximum endurance time at 80% of the maximum oxygen consumption (T_{80}) was determined by two tests of maximal endurance while walking on the treadmill. The first was performed at an intensity equivalent to 92-98% of maximal (2.5% grade below th
in the progressive, $\dot{V}_{O_2}$ max test). Two days afte

second was done at 80-90% of maximal (5% grade below the maximal grade in the progressive test). On the basis of the endurances observed during these submaximal tests and assuming an exponential relationship between % effort and maximal endurance, we calculated the maximal endurance time for 80% effort, in each case (T_{80}). An exponential relationship is assumed between relative intensity, that is the fraction of the $\dot{V}_{O_2}$ max at which the submaximal test is performed and endurance time. With maximal endurances measured during both submaximal tests and the fractional intensities of each test, the slope K and intercept log A of the line are calculated for each subject. Then the endurance at 80% effort (.8 fractional intensity) is calculated as follows:

$$(1)\quad F_i\ \dot{V}_{O_2}\max = A\,e^{-KT_i}$$

$$(2)\quad 2.3\ \mathrm{LOG}\ F_i\ \dot{V}_{O_2}\max = -KT_i + 2.3\ \mathrm{LOG}\ A$$

$$(3)\quad K = \frac{2.3\,(\mathrm{LOG}\ F_{II}\ \dot{V}_{O_2}\max - \mathrm{LOG}\ F_I\ \dot{V}_{O_2}\max)}{T_I - T_{II}}$$

$$(4)\quad \mathrm{LOG}\ A = \frac{KT_{II}}{2.3} + \mathrm{LOG}\ F_{II}\ \dot{V}_{O_2}\max$$

$$(5)\quad T_{80} = \frac{2.3\,(\mathrm{LOG}\ A - \mathrm{LOG}\ 0.80)}{K}$$

Wherein:

T_i = Maximal endurance time in min. at load i

$\dot{V}_{O_{2_i}}$ = Steady state oxygen consumption at load i

$\dot{V}_{O_2}$ max = Maximal rate of oxygen consumption

$$F_i\ \dot{V}_{O_2}\max = \frac{\dot{V}_{O_{2_i}}}{\dot{V}_{O_2}\max}$$

T_{80} = Maximal endurance time in min. at load 80% of maximal.

VIII. STATISTICAL ANALYSES

The statistical comparisons between groups were made on an unpaired basis and within groups on a paired basis. In the student "t" and, where appropriate, F-ratio analyses, the null hypothesis was rejected at the 5% level. These and the analyses of regression, correlation, and multiple step-wise regression of data were performed as described by Snedecor (38). All data are presented as means and standard deviations unless indicated otherwise.

RESULTS

I. MALNOURISHED ADULTS

(A) Nutritional Status (Vertical) Study

The subjects were classified into one of three groups as described in Tables 5 and 6.

Intestinal parasitism was commonplace in the three subject groups. Seventy nine per cent of all subjects had some form of parasitism. The most common types and their distribution within groups are given in Table 7.

Assays of urinary vitamin excretion rates and erythrocyte transketolase revealed 34 subjects with some kind of vitamin deficiency. Their overall incidence according to the type and their group distribution are given in Table 8.

The hematological characteristics of the subjects in each group are shown in Table 9. Average plasma volume in Group A was not significantly lower than values in Groups B and C. Average blood volumes were not significantly different. Blood hematocrit and hemoglobin concentration showed pronounced and significant differences between groups. Total body hemoglobin correlated significantly (Table 10) with body weight, ($r = 0.628$), fat free weight estimated from skinfolds ($r = 0.67$), creatinine output ($r = 0.495$), total body water ($r = 0.494$) and intracelullar water ($r = 0.492$). Thus, the total hemoglobin mass in the body seemed to vary with the nutritional status. Since, in this population total body hemoglobin correlated highly with hemoglobin concentration ($r = 0.906$), the severity of the anemia in these subjects was well correlated with their nutritional status.

Table 11 shows the incidence of folic acid and Vitamin B_{12} deficiencies in the different groups. Also shown in the incidence of low per cent transferrin saturation values and of absences or decreases in hemosiderin depots in the bone marrow. The frequency of folic acid deficiencies increased with increasing severity of nutritional compromise. Iron deficiency seemed widespread in all groups.

TABLE 7

FREQUENCY OF INTESTINAL PARASITISM

Parasites	Group A (n = 10)		Group B (n = 18)		Group C (n = 16)		All Groups (n = 44)	
	Number Positive	Per Cent Positive	Number Positive	Per Cent Positive	Number Positive	Per Cent Positive	Number Positive	Per Cent Positive
Hookworm	5	50.0	10	55.5	7	43.75	22	50
Amoebas (histolytica)	7	70.0	9	50.0	5	31.25	21	47.7
Trichocephalus	2	20.0	5	27.7	4	25.0	11	25.0
Ascaris	3	30.0	5	27.7	2	12.5	10	22.7
Strongiloids	0	0	1	5.5	2	12.5	3	6.8
Giardia lamlia	1	10.0	0	0	0	0	1	2.3
Any parasite (pathogens)	9	90.0	16	88.8	10	62.5	35	79.5

$x^2 = 6.81$ ($P > 0.05$)

TABLE 8

URINARY VITAMIN EXCRETION AND ERYTHROCYTE TRANSKETOLASE ACTIVITY

		Group A	Group B	Group C	All
	Riboflavin (mcg/12 hrs.)				
F = 1.33	n	11	16	17	44
P < 0.25	Mean	207.8	104.6	173.7	157.1
	S.D.	182.7	82.3	216.7	171.4
	n < 50 mcg/12 hrs.	2	5	2	9
	% < 50 mcg/12 hrs.	18.2	31.3	11.8	20.5
	N-methyl nicotinamide (mg/12 hrs.)				
F = 0.11	n	11	17	17	45
P > 0.80	Mean	4.68	4.29	3.89	4.24
	S.D.	2.98	4.21	5.04	4.27
	n < 2 mg/12 hrs.	1	7	8	16
	% < 2 mg/12 hrs.	9.1	47.1	47.1	35.5
	Ascorbic acid (mg/12 hrs.)				
F = 2.42	n	10	15	17	42
P > 0.05	Mean	14.91	10.72	3.30	8.72
	S.D.	23.02	13.93	2.44	14.42
	n < 2 mg/12 hrs.	2	4	7	13
	% < 2 mg/12 hrs.	20.0	26.7	41.1	30.9
	Erythrocyte transketolase activity (%)				
F = 4.27	n	11	19	14	44
P = 0.02	Mean	11.89	5.02	10.29	8.41
	S.D.	7.12	4.66	8.89	7.36
	n < 5%	1	10	3	14
	% < 5%	9.1	52.6	21.4	31.8
	Number of subjects with above vitamin deficiencies				
	n	6	15	13	34
	%	54.5	78.9	76.5	75.5

TABLE 9

HEMATOLOGY OF SUBJECTS IN NUTRITIONAL STATUS (VERTICAL) STUDY

Variable	Group A			Group B			Group C			Analysis of Variance	
	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	F Ratio	P
Hematocrit (%)	10	44.4	2.6	20	37.2	8.7	18	32.0	4.9	11.66	<0.001
Hemoglobin (gm %)	10	15.0	1.2	20	12.2	3.4	18	10.0	1.7	12.90	<0.001
Total hemoglobin (gm)	10	655	134	19	516	172	18	355	103	15.36	<0.001
Total hemoglobin (gm/kg)	10	12.7	2.3	19	10.7	3.5	18	8.3	2.0	8.61	<0.001
Plasma volume (ml/kg)	10	49.5	6.0	19	56.7	8.9	18	57.7	7.9	3.71	<0.04
Blood volume (ml/kg)	10	84.3	10.3	19	86.9	11.4	18	82.3	11.2	0.78	N.S.

TABLE 10

CORRELATIONS OF 27 MEASURED AND DERIVED VARIABLES

IN 49 SUBJECTS OF THE NUTRITIONAL STATUS (VERTICAL) STUDY

COMPARISON		CORRELATION COEFF.	N	P VALUE
ALBUMIN-GMS %	VS TOT. PROT. GMS.%	0.7518	49	0.000000
ALBUMIN-GMS %	VS PLASMA VOL.-L.	-0.3451	47	0.024160
ALBUMIN-GMS %	VS HEMATOCRIT-%	0.4766	49	0.000[illegible]
ALBUMIN-GMS %	VS HEMOGLOBIN-GMS%	0.4209	49	0.003201
ALBUMIN-GMS %	VS TOT.BODY WATER-L	0.4421	47	0.002209
ALBUMIN-GMS %	VS EXTRACELL WATER-	-0.2954	47	0.049005
ALBUMIN-GMS %	VS CREAT. MG/24 HRS	0.7689	49	0.000000
ALBUMIN-GMS %	VS MAX.HEART RATE	0.0727	49	0.625219
ALBUMIN-GMS %	VS MAX VENT.-L/MIN	0.2425	49	0.089453
ALBUMIN-GMS %	VS MAX O2 ML/MIN	0.5335	49	0.000019
ALBUMIN-GMS %	VS INTRACELL WATER-	0.5394	47	0.000021
ALBUMIN-GMS %	VS PRED. EXCELL H2O	0.4559	49	0.001332
ALBUMIN-GMS %	VS HYDRAT.COEFF.	-0.5105	47	0.000043
ALBUMIN-GMS %	VS FAT FREE WT-KG	0.5312	47	0.000289
ALBUMIN-GMS %	VS FAT WEIGHT-KG	0.0154	47	0.914492
ALBUMIN-GMS %	VS FAT FREE SOLIDS-	0.5500	47	0.000016
ALBUMIN-GMS %	VS BODY CELL MASS-K	0.5392	47	0.000021
ALBUMIN-GMS %	VS CELL SOLIDS-KG	0.5395	47	0.000021
ALBUMIN-GMS %	VS SUPPORT SOLIDS-K	0.5447	47	0.000019
ALBUMIN-GMS %	VS MUSCLE CELL MASS	0.7690	49	0.000000
ALBUMIN-GMS %	VS VISC CELL MASS-K	0.2952	47	0.156671
ALBUMIN-GMS %	VS BLOOD VOL-L	0.2715	47	0.061666
ALBUMIN-GMS %	VS TOTAL HB-GMS	0.4293	47	0.002921
ALBUMIN-GMS %	VS SUM 5SKINFOLDS-CM	0.2195	43	0.153727
ALBUMIN-GMS %	VS %FAT-5SKINFOLDS	0.3439	43	0.022565
ALBUMIN-GMS %	VS LEAN BODY MASS-K	0.5062	43	0.000820
TOT. PROT. GMS.%	VS PLASMA VOL.-L.	0.1256	47	0.595344
TOT. PROT. GMS.%	VS HEMATOCRIT-%	0.3612	49	0.011235
TOT. PROT. GMS.%	VS HEMOGLOBIN-GMS%	0.3555	49	0.012613
TOT. PROT. GMS.%	VS TOT.BODY WATER-L	0.3144	47	0.029499
TOT. PROT. GMS.%	VS EXTRACELL WATER-	-0.3610	47	0.012161
TOT. PROT. GMS.%	VS CREAT. MG/24 HRS	0.6327	49	0.000019
TOT. PROT. GMS.%	VS MAX.HEART RATE	0.0676	49	0.648555
TOT. PROT. GMS.%	VS MAX VENT.-L/MIN	0.1286	49	0.518759
TOT. PROT. GMS.%	VS MAX O2 ML/MIN	0.5286	49	0.000244
TOT. PROT. GMS.%	VS INTRACELL WATER-	0.5521	47	0.000176
TOT. PROT. GMS.%	VS PRED. EXCELL H2O	0.3416	49	0.015481
TOT. PROT. GMS.%	VS HYDRAT.COEFF.	-0.5190	47	0.000034
TOT. PROT. GMS.%	VS FAT FREE WT-KG	0.4197	47	0.004367
TOT. PROT. GMS.%	VS FAT WEIGHT-KG	0.0151	47	0.915992
TOT. PROT. GMS.%	VS FAT FREE SOLIDS-	0.5575	47	0.000155
TOT. PROT. GMS.%	VS BODY CELL MASS-K	0.5521	47	0.000176
TOT. PROT. GMS.%	VS CELL SOLIDS-KG	0.5526	47	0.000174
TOT. PROT. GMS.%	VS SUPPORT SOLIDS-K	0.5499	47	0.000186
TOT. PROT. GMS.%	VS MUSCLE CELL MASS	0.6328	49	0.000019
TOT. PROT. GMS.%	VS VISC CELL MASS-K	0.1991	47	0.175902
TOT. PROT. GMS.%	VS BLOOD VOL-L	0.3499	47	0.015176
TOT. PROT. GMS.%	VS TOTAL HB-GMS	0.4159	47	0.003521
TOT. PROT. GMS.%	VS SUM 5SKINFOLDS-CM	0.1091	43	0.507297

CORRELATION MATRIX

COMPARISON			CORR. COEFF.	N	P VALUE
TOT. PROT. GMS.%	VS	%FAT-SKINFOLDS	0.2272	43	0.139094
TOT. PROT. GMS.%	VS	LEAN BODY MASS-K	0.4109	43	0.006254
PLASMA VOL.-L.	VS	HEMATOCRIT-%	-0.1702	47	0.251386
PLASMA VOL.-L.	VS	HEMOGLOBIN-GMS%	-0.0961	47	0.527385
PLASMA VOL.-L.	VS	TOT.BODY WATER-L	0.3944	45	0.007300
PLASMA VOL.-L.	VS	EXTRACELL WATER-	0.3769	45	0.010373
PLASMA VOL.-L.	VS	CREAT. MG/24 HRS	0.1191	47	0.569294
PLASMA VOL.-L.	VS	MAX.HEART RATE	0.0107	47	0.941137
PLASMA VOL.-L.	VS	MAX VENT.-L/MIN	0.4517	47	0.001786
PLASMA VOL.-L.	VS	MAX O2 ML/MIN	0.2199	47	0.133765
PLASMA VOL.-L.	VS	INTRACELL WATER-	0.1704	45	0.262066
PLASMA VOL.-L.	VS	PRED. EXCELL H2O	0.4383	47	0.002403
PLASMA VOL.-L.	VS	HYDRAT.COEFF.	0.0459	45	0.762552
PLASMA VOL.-L.	VS	FAT FREE WT-KG	0.3511	45	0.017094
PLASMA VOL.-L.	VS	FAT WEIGHT-KG	0.2181	45	0.146343
PLASMA VOL.-L.	VS	FAT FREE SOLIDS-	0.2246	45	0.134285
PLASMA VOL.-L.	VS	BODY CELL MASS-K	0.1704	45	0.261912
PLASMA VOL.-L.	VS	CELL SOLIDS-KG	0.1705	45	0.261645
PLASMA VOL.-L.	VS	SUPPORT SOLIDS-K	0.2660	45	0.071556
PLASMA VOL.-L.	VS	MUSCLE CELL MASS	0.1192	47	0.569852
PLASMA VOL.-L.	VS	VISC CELL MASS-K	0.1191	45	0.554399
PLASMA VOL.-L.	VS	BLOOD VOL-L	0.8051	47	0.000000
PLASMA VOL.-L.	VS	TOTAL HB-GMS	0.3120	47	0.030812
PLASMA VOL.-L.	VS	SUM SKINFOLDS-CM	0.3751	41	0.014915
PLASMA VOL.-L.	VS	%FAT-SKINFOLDS	0.4435	41	0.003930
PLASMA VOL.-L.	VS	LEAN BODY MASS-K	0.4252	41	0.005692
HEMATOCRIT-%	VS	HEMOGLOBIN-GMS%	0.9606	48	0.000000
HEMATOCRIT-%	VS	TOT.BODY WATER-L	0.3436	46	0.018339
HEMATOCRIT-%	VS	EXTRACELL WATER-	-0.1546	46	0.305546
HEMATOCRIT-%	VS	CREAT. MG/24 HRS	0.4712	48	0.001041
HEMATOCRIT-%	VS	MAX.HEART RATE	0.1067	48	0.531616
HEMATOCRIT-%	VS	MAX VENT.-L/MIN	0.1937	46	0.184065
HEMATOCRIT-%	VS	MAX O2 ML/MIN	0.7257	48	0.000001
HEMATOCRIT-%	VS	INTRACELL WATER-	0.4436	46	0.002112
HEMATOCRIT-%	VS	PRED. EXCELL H2O	0.4376	48	0.002214
HEMATOCRIT-%	VS	HYDRAT.COEFF.	-0.4357	46	0.002802
HEMATOCRIT-%	VS	FAT FREE WT-KG	0.4033	46	0.005573
HEMATOCRIT-%	VS	FAT WEIGHT-KG	0.1027	46	0.503756
HEMATOCRIT-%	VS	FAT FREE SOLIDS-	0.4739	46	0.001208
HEMATOCRIT-%	VS	BODY CELL MASS-K	0.4484	46	0.002121
HEMATOCRIT-%	VS	CELL SOLIDS-KG	0.4483	46	0.002129
HEMATOCRIT-%	VS	SUPPORT SOLIDS-K	0.4849	46	0.000941
HEMATOCRIT-%	VS	MUSCLE CELL MASS	0.4711	48	0.001042
HEMATOCRIT-%	VS	VISC CELL MASS-K	0.1789	46	0.232106
HEMATOCRIT-%	VS	BLOOD VOL-L	0.4405	47	0.002289
HEMATOCRIT-%	VS	TOTAL HB-GMS	0.8385	47	0.000000
HEMATOCRIT-%	VS	SUM SKINFOLDS-CM	0.0892	42	0.580812
HEMATOCRIT-%	VS	%FAT-SKINFOLDS	0.2243	42	0.149649
HEMATOCRIT-%	VS	LEAN BODY MASS-K	0.4878	42	0.001381
HEMOGLOBIN-GMS%	VS	TOT.BODY WATER-L	0.3490	46	0.016541

CORRELATION MATRIX

COMPARISON			CORR. COEFF.	N	P VALUE
HEMOGLOBIN-GMS%	VS	EXTRACELL WATER-	-0.1255	46	0.589593
HEMOGLOBIN-GMS%	VS	CREAT. MG/24 HRS	0.4453	48	0.001867
HEMOGLOBIN-GMS%	VS	MAX.HEART RATE	0.0899	48	0.550170
HEMOGLOBIN-GMS%	VS	MAX VENT.-L/MIN	0.2419	48	0.093769
HEMOGLOBIN-GMS%	VS	MAX O2 ML/MIN	0.7725	48	0.000000
HEMOGLOBIN-GMS%	VS	INTRACELL WATER-	0.4362	46	0.002772
HEMOGLOBIN-GMS%	VS	PRED. EXCELL H2O	0.4432	48	0.001957
HEMOGLOBIN-GMS%	VS	HYDRAT.COEFF.	-0.4136	46	0.004496
HEMOGLOBIN-GMS%	VS	FAT FREE WT-KG	0.4036	46	0.005543
HEMOGLOBIN-GMS%	VS	FAT WEIGHT-KG	0.1231	46	0.579933
HEMOGLOBIN-GMS%	VS	FAT FREE SOLIDS-	0.4639	46	0.001509
HEMOGLOBIN-GMS%	VS	BODY CELL MASS-K	0.4360	46	0.002784
HEMOGLOBIN-GMS%	VS	CELL SOLIDS-KG	0.4358	46	0.002795
HEMOGLOBIN-GMS%	VS	SUPPORT SOLIDS-K	0.4775	46	0.001111
HEMOGLOBIN-GMS%	VS	MUSCLE CELL MASS	0.4452	48	0.001869
HEMOGLOBIN-GMS%	VS	VISC CELL MASS-K	0.1813	46	0.225836
HEMOGLOBIN-GMS%	VS	BLOOD VOL-L	0.4930	47	0.000702
HEMOGLOBIN-GMS%	VS	TOTAL HB-GMS	0.9053	47	0.000000
HEMOGLOBIN-GMS%	VS	SUM SKINFOLDS-CM	0.0592	42	0.708241
HEMOGLOBIN-GMS%	VS	%FAT-SKINFOLDS	0.2079	42	0.183419
HEMOGLOBIN-GMS%	VS	LEAN BODY MASS-K	0.5072	42	0.000904
TOT.BODY WATER-L	VS	EXTRACELL WATER-	0.3706	47	0.010032
TOT.BODY WATER-L	VS	CREAT. MG/24 HRS	0.5774	47	0.000096
TOT.BODY WATER-L	VS	MAX.HEART RATE	-0.0359	47	0.805351
TOT.BODY WATER-L	VS	MAX VENT.-L/MIN	0.2802	47	0.053463
TOT.BODY WATER-L	VS	MAX O2 ML/MIN	0.5800	47	0.000099
TOT.BODY WATER-L	VS	INTRACELL WATER-	0.8201	47	0.000000
TOT.BODY WATER-L	VS	PRED. EXCELL H2O	0.7826	47	0.000000
TOT.BODY WATER-L	VS	HYDRAT.COEFF.	-0.2547	47	0.089375
TOT.BODY WATER-L	VS	FAT FREE WT-KG	0.9919	47	0.000000
TOT.BODY WATER-L	VS	FAT WEIGHT-KG	-0.2064	47	0.160491
TOT.BODY WATER-L	VS	FAT FREE SOLIDS-	0.8370	47	0.000000
TOT.BODY WATER-L	VS	BODY CELL MASS-K	0.8201	47	0.000000
TOT.BODY WATER-L	VS	CELL SOLIDS-KG	0.8200	47	0.000000
TOT.BODY WATER-L	VS	SUPPORT SOLIDS-K	0.8315	47	0.000000
TOT.BODY WATER-L	VS	MUSCLE CELL MASS	0.5774	47	0.000096
TOT.BODY WATER-L	VS	VISC CELL MASS-K	0.5851	47	0.000080
TOT.BODY WATER-L	VS	BLOOD VOL-L	0.5614	45	0.000181
TOT.BODY WATER-L	VS	TOTAL HB-GMS	0.4943	45	0.000851
TOT.BODY WATER-L	VS	SUM SKINFOLDS-CM	0.2184	41	0.166771
TOT.BODY WATER-L	VS	%FAT-SKINFOLDS	0.4474	41	0.003627
TOT.BODY WATER-L	VS	LEAN BODY MASS-K	0.8130	41	0.000000
EXTRACELL WATER-	VS	CREAT. MG/24 HRS	-0.0115	47	0.936545
EXTRACELL WATER-	VS	MAX.HEART RATE	0.0603	47	0.689478
EXTRACELL WATER-	VS	MAX VENT.-L/MIN	0.1707	47	0.249797
EXTRACELL WATER-	VS	MAX O2 ML/MIN	0.0060	47	0.966944
EXTRACELL WATER-	VS	INTRACELL WATER-	-0.2274	47	0.120454
EXTRACELL WATER-	VS	PRED. EXCELL H2O	0.2906	47	0.044843
EXTRACELL WATER-	VS	HYDRAT.COEFF.	0.7610	47	0.000000
EXTRACELL WATER-	VS	FAT FREE WT-KG	0.1962	47	0.182992

CORRELATION MATRIX

COMPARISON	CORR. COEFF.	N	P VALUE
EXTRACELL WATER- VS FAT WEIGHT-KG	0.1617	47	0.276871
EXTRACELL WATER- VS FAT FREE SOLIDS-	-0.1753	47	0.236662
EXTRACELL WATER- VS BODY CELL MASS-K	-0.2273	47	0.120462
EXTRACELL WATER- VS CELL SOLIDS-KG	-0.2274	47	0.120313
EXTRACELL WATER- VS SUPPORT SOLIDS-K	-0.1257	47	0.595967
EXTRACELL WATER- VS MUSCLE CELL MASS	-0.0117	47	0.935709
EXTRACELL WATER- VS VISC CELL MASS-K	-0.2795	47	0.054995
EXTRACELL WATER- VS BLOOD VOL-L	0.2442	45	0.102110
EXTRACELL WATER- VS TOTAL HB-GMS	0.0236	45	0.872220
EXTRACELL WATER- VS SUM SKINFOLDS-CM	0.2936	41	0.059336
EXTRACELL WATER- VS %FAT-SKINFOLDS	0.3242	41	0.036432
EXTRACELL WATER- VS LEAN BODY MASS-K	0.2431	41	0.121793
CREAT. MG/24 HRS VS MAX.HEART RATE	0.0382	49	0.759826
CREAT. MG/24 HRS VS MAX VENT.-L/MIN	0.3779	49	0.007404
CREAT. MG/24 HRS VS MAX O2 ML/MIN	0.7440	49	0.000001
CREAT. MG/24 HRS VS INTRACELL WATER-	0.6125	47	0.000041
CREAT. MG/24 HRS VS PRED. EXCELL H2O	0.6621	49	0.000009
CREAT. MG/24 HRS VS HYDRAT.COEFF.	-0.4644	47	0.000654
CREAT. MG/24 HRS VS FAT FREE WT-KG	0.6279	47	0.000028
CREAT. MG/24 HRS VS FAT WEIGHT-KG	0.1939	47	0.213332
CREAT. MG/24 HRS VS FAT FREE SOLIDS-	0.6589	47	0.000012
CREAT. MG/24 HRS VS BODY CELL MASS-K	0.6124	47	0.000041
CREAT. MG/24 HRS VS CELL SOLIDS-KG	0.6128	47	0.000040
CREAT. MG/24 HRS VS SUPPORT SOLIDS-K	0.6847	47	0.000006
CREAT. MG/24 HRS VS MUSCLE CELL MASS	0.9999	49	0.000000
CREAT. MG/24 HRS VS VISC CELL MASS-K	-0.0096	47	0.952997
CREAT. MG/24 HRS VS BLOOD VOL-L	0.4037	47	0.005068
CREAT. MG/24 HRS VS TOTAL HB-GMS	0.4947	47	0.000675
CREAT. MG/24 HRS VS SUM SKINFOLDS-CM	0.3694	43	0.014109
CREAT. MG/24 HRS VS %FAT-SKINFOLDS	0.5410	43	0.000373
CREAT. MG/24 HRS VS LEAN BODY MASS-K	0.6980	43	0.000008
MAX.HEART RATE VS MAX VENT.-L/MIN	0.2927	49	0.038839
MAX.HEART RATE VS MAX O2 ML/MIN	0.1381	49	0.654034
MAX.HEART RATE VS INTRACELL WATER-	-0.0749	47	0.622556
MAX.HEART RATE VS PRED. EXCELL H2O	-0.0231	49	0.868785
MAX.HEART RATE VS HYDRAT.COEFF.	0.0919	47	0.545503
MAX.HEART RATE VS FAT FREE WT-KG	-0.0507	47	0.734543
MAX.HEART RATE VS FAT WEIGHT-KG	0.0527	47	0.725023
MAX.HEART RATE VS FAT FREE SOLIDS-	-0.0745	47	0.624133
MAX.HEART RATE VS BODY CELL MASS-K	-0.0750	47	0.621908
MAX.HEART RATE VS CELL SOLIDS-KG	-0.0749	47	0.622987
MAX.HEART RATE VS SUPPORT SOLIDS-K	-0.0728	47	0.632021
MAX.HEART RATE VS MUSCLE CELL MASS	0.0384	49	0.789224
MAX.HEART RATE VS VISC CELL MASS-K	-0.1142	47	0.549565
MAX.HEART RATE VS BLOOD VOL-L	0.0755	47	0.619663
MAX.HEART RATE VS TOTAL HB-GMS	0.1016	47	0.503389
MAX.HEART RATE VS SUM SKINFOLDS-CM	0.2354	43	0.124732
MAX.HEART RATE VS %FAT-SKINFOLDS	0.1897	43	0.223464
MAX.HEART RATE VS LEAN BODY MASS-K	-0.0405	43	0.791925
MAX VENT.-L/MIN VS MAX O2 ML/MIN	0.4621	49	0.001156

CORRELATION MATRIX

COMPARISON			CORR. COEFF.	N	P VALUE
MAX VENT.-L/MIN	VS	INTRACELL WATER-	0.1885	47	0.201584
MAX VENT.-L/MIN	VS	PRED. EXCELL H2O	0.4042	49	0.004217
MAX VENT.-L/MIN	VS	HYDRAT.COEFF.	-0.1132	47	0.545170
MAX VENT.-L/MIN	VS	FAT FREE WT-KG	0.2776	47	0.055815
MAX VENT.-L/MIN	VS	FAT WEIGHT-KG	0.2926	47	0.043323
MAX VENT.-L/MIN	VS	FAT FREE SOLIDS-	0.2409	47	0.099005
MAX VENT.-L/MIN	VS	BODY CELL MASS-K	0.1885	47	0.201713
MAX VENT.-L/MIN	VS	CELL SOLIDS-KG	0.1884	47	0.201837
MAX VENT.-L/MIN	VS	SUPPORT SOLIDS-K	0.2825	47	0.051387
MAX VENT.-L/MIN	VS	MUSCLE CELL MASS	0.3778	49	0.007396
MAX VENT.-L/MIN	VS	VISC CELL MASS-K	-0.0733	47	0.629691
MAX VENT.-L/MIN	VS	BLOOD VOL-L	0.5392	47	0.000239
MAX VENT.-L/MIN	VS	TOTAL HB-GMI	0.4260	47	0.003143
MAX VENT.-L/MIN	VS	SUM SKINFOLDS-CM	0.4463	43	0.003011
MAX VENT.-L/MIN	VS	%FAT-SKINFOLDS	0.4950	43	0.001051
MAX VENT.-L/MIN	VS	LEAN BODY MASS-K	0.3994	43	0.007573
MAX O2 ML/MIN	VS	INTRACELL WATER-	0.6045	47	0.000050
MAX O2 ML/MIN	VS	PRED. EXCELL H2O	0.7205	49	0.000001
MAX O2 ML/MIN	VS	HYDRAT.COEFF.	-0.4961	47	0.000654
MAX O2 ML/MIN	VS	FAT FREE WT-KG	0.6316	47	0.000025
MAX O2 ML/MIN	VS	FAT WEIGHT-KG	0.2938	47	0.050313
MAX O2 ML/MIN	VS	FAT FREE SOLIDS-	0.6645	47	0.000011
MAX O2 ML/MIN	VS	BODY CELL MASS-K	0.6043	47	0.000050
MAX O2 ML/MIN	VS	CELL SOLIDS-KG	0.6040	47	0.000050
MAX O2 ML/MIN	VS	SUPPORT SOLIDS-K	0.7024	47	0.000004
MAX O2 ML/MIN	VS	MUSCLE CELL MASS	0.7440	49	0.000001
MAX O2 ML/MIN	VS	VISC CELL MASS-K	0.1823	47	0.217729
MAX O2 ML/MIN	VS	BLOOD VOL-L	0.6473	47	0.000017
MAX O2 ML/MIN	VS	TOTAL HB-GMI	0.6339	47	0.000000
MAX O2 ML/MIN	VS	SUM SKINFOLDS-CM	0.3606	43	0.016618
MAX O2 ML/MIN	VS	%FAT-SKINFOLDS	0.5573	43	0.000257
MAX O2 ML/MIN	VS	LEAN BODY MASS-K	0.7673	43	0.000001
INTRACELL WATER-	VS	PRED. EXCELL H2O	0.6415	47	0.000020
INTRACELL WATER-	VS	HYDRAT.COEFF.	-0.7359	47	0.000001
INTRACELL WATER-	VS	FAT FREE WT-KG	0.9096	47	0.000000
INTRACELL WATER-	VS	FAT WEIGHT-KG	-0.3160	47	0.028640
INTRACELL WATER-	VS	FAT FREE SOLIDS-	0.9856	47	0.000000
INTRACELL WATER-	VS	BODY CELL MASS-K	0.9999	47	0.000000
INTRACELL WATER-	VS	CELL SOLIDS-KG	0.9999	47	0.000000
INTRACELL WATER-	VS	SUPPORT SOLIDS-K	0.9494	47	0.000000
INTRACELL WATER-	VS	MUSCLE CELL MASS	0.6127	47	0.000040
INTRACELL WATER-	VS	VISC CELL MASS-K	0.7850	47	0.000000
INTRACELL WATER-	VS	BLOOD VOL-L	0.4241	45	0.003948
INTRACELL WATER-	VS	TOTAL HB-GMI	0.4924	45	0.000888
INTRACELL WATER-	VS	SUM SKINFOLDS-CM	0.0163	41	0.770308
INTRACELL WATER-	VS	%FAT-SKINFOLDS	0.2563	41	0.088706
INTRACELL WATER-	VS	LEAN BODY MASS-K	0.6975	41	0.000011
PRED. EXCELL H2O	VS	HYDRAT.COEFF.	-0.3682	47	0.010529
PRED. EXCELL H2O	VS	FAT FREE WT-KG	0.8023	47	0.000000
PRED. EXCELL H2O	VS	FAT WEIGHT-KG	0.4123	47	0.004217

CORRELATION MATRIX

COMPARISON			CORR. COEFF.	N	P VALUE
PRED. EXCELL H2O	VS	FAT FREE SOLIDS-	0.7523	47	0.000001
PRED. EXCELL H2O	VS	BODY CELL MASS-K	0.6415	47	0.000020
PRED. EXCELL H2O	VS	CELL SOLIDS-KG	0.6414	47	0.000020
PRED. EXCELL H2O	VS	SUPPORT SOLIDS-K	0.8326	47	0.000000
PRED. EXCELL H2O	VS	MUSCLE CELL MASS	0.6621	49	0.000009
PRED. EXCELL H2O	VS	VISC CELL MASS-K	0.2831	47	0.050930
PRED. EXCELL H2O	VS	BLOOD VOL-L	0.6625	47	0.000011
PRED. EXCELL H2O	VS	TOTAL HB-GMS	0.6020	47	0.000053
PRED. EXCELL H2O	VS	SUM 3SKINFOLDS-CM	0.5197	43	0.000606
PRED. EXCELL H2O	VS	%FAT-3SKINFOLDS	0.7548	43	0.000001
PRED. EXCELL H2O	VS	LEAN BODY MASS-K	0.9854	43	0.000000
HYDRAT.COEFF.	VS	FAT FREE WT-KG	-0.4303	47	0.002963
HYDRAT.COEFF.	VS	FAT WEIGHT-KG	0.0396	47	0.792444
HYDRAT.COEFF.	VS	FAT FREE SOLIDS-	-0.7345	47	0.000001
HYDRAT.COEFF.	VS	BODY CELL MASS-K	-0.7359	47	0.000001
HYDRAT.COEFF.	VS	CELL SOLIDS-KG	-0.7359	47	0.000001
HYDRAT.COEFF.	VS	SUPPORT SOLIDS-K	-0.7164	47	0.000002
HYDRAT.COEFF.	VS	MUSCLE CELL MASS	-0.4946	47	0.000851
HYDRAT.COEFF.	VS	VISC CELL MASS-K	-0.5512	47	0.000180
HYDRAT.COEFF.	VS	BLOOD VOL-L	-0.2192	45	0.144339
HYDRAT.COEFF.	VS	TOTAL HB-GMS	-0.3916	45	0.009458
HYDRAT.COEFF.	VS	SUM 3SKINFOLDS-CM	-0.0097	41	0.950396
HYDRAT.COEFF.	VS	%FAT-3SKINFOLDS	-0.1445	41	0.629680
HYDRAT.COEFF.	VS	LEAN BODY MASS-K	-0.4175	41	0.006638
FAT FREE WT-KG	VS	FAT WEIGHT-KG	-0.1987	47	0.177319
FAT FREE WT-KG	VS	FAT FREE SOLIDS-	0.9254	47	0.000000
FAT FREE WT-KG	VS	BODY CELL MASS-K	0.9096	47	0.000000
FAT FREE WT-KG	VS	CELL SOLIDS-KG	0.9096	47	0.000000
FAT FREE WT-KG	VS	SUPPORT SOLIDS-K	0.9177	47	0.000000
FAT FREE WT-KG	VS	MUSCLE CELL MASS	0.6279	47	0.000028
FAT FREE WT-KG	VS	VISC CELL MASS-K	0.6575	47	0.000013
FAT FREE WT-KG	VS	BLOOD VOL-L	0.5584	45	0.000194
FAT FREE WT-KG	VS	TOTAL HB-GMS	0.5294	45	0.000372
FAT FREE WT-KG	VS	SUM 3SKINFOLDS-CM	0.2000	41	0.207438
FAT FREE WT-KG	VS	%FAT-3SKINFOLDS	0.4413	41	0.004116
FAT FREE WT-KG	VS	LEAN BODY MASS-K	0.9400	41	0.000000
FAT WEIGHT-KG	VS	FAT FREE SOLIDS-	-0.1624	47	0.274713
FAT WEIGHT-KG	VS	BODY CELL MASS-K	-0.3161	47	0.028613
FAT WEIGHT-KG	VS	CELL SOLIDS-KG	-0.3161	47	0.028599
FAT WEIGHT-KG	VS	SUPPORT SOLIDS-K	-0.0219	47	0.878632
FAT WEIGHT-KG	VS	MUSCLE CELL MASS	0.1939	47	0.213560
FAT WEIGHT-KG	VS	VISC CELL MASS-K	-0.5441	47	0.000213
FAT WEIGHT-KG	VS	BLOOD VOL-L	0.2558	45	0.086156
FAT WEIGHT-KG	VS	TOTAL HB-GMS	0.2029	45	0.178128
FAT WEIGHT-KG	VS	SUM 3SKINFOLDS-CM	0.5744	41	0.000225
FAT WEIGHT-KG	VS	%FAT-3SKINFOLDS	0.6131	41	0.000091
FAT WEIGHT-KG	VS	LEAN BODY MASS-K	0.3754	41	0.014843
FAT FREE SOLIDS-	VS	BODY CELL MASS-K	0.9954	47	0.000000
FAT FREE SOLIDS-	VS	CELL SOLIDS-KG	0.9956	47	0.000000
FAT FREE SOLIDS-	VS	SUPPORT SOLIDS-K	0.9987	47	0.000000

CORRELATION MATRIX

COMPARISON	CORR. COEFF.	N	P VALUE
FAT FREE SOLIDS- VS MUSCLE CELL MASS	0.6590	47	0.000012
FAT FREE SOLIDS- VS VISC CELL MASS-K	0.7307	47	0.000001
FAT FREE SOLIDS- VS BLOOD VOL-L	0.4873	45	0.000995
FAT FREE SOLIDS- VS TOTAL HB-GMS	0.5397	45	0.000301
FAT FREE SOLIDS- VS SUM SKINFOLDS-CM	0.1410	41	0.617372
FAT FREE SOLIDS- VS %FAT-SKINFOLDS	0.3795	41	0.013762
FAT FREE SOLIDS- VS LEAN BODY MASS-K	0.7991	41	0.000000
BODY CELL MASS-K VS CELL SOLIDS-KG	0.9999	47	0.000000
BODY CELL MASS-K VS SUPPORT SOLIDS-K	0.9494	47	0.000000
BODY CELL MASS-K VS MUSCLE CELL MASS	0.6125	47	0.000041
BODY CELL MASS-K VS VISC CELL MASS-K	0.7851	47	0.000000
BODY CELL MASS-K VS BLOOD VOL-L	0.4240	45	0.003956
BODY CELL MASS-K VS TOTAL HB-GMS	0.4922	45	0.000892
BODY CELL MASS-K VS SUM SKINFOLDS-CM	0.0462	41	0.770493
BODY CELL MASS-K VS %FAT-SKINFOLDS	0.2652	41	0.088760
BODY CELL MASS-K VS LEAN BODY MASS-K	0.6974	41	0.000011
CELL SOLIDS-KG VS SUPPORT SOLIDS-K	0.9494	47	0.000000
CELL SOLIDS-KG VS MUSCLE CELL MASS	0.6129	47	0.000040
CELL SOLIDS-KG VS VISC CELL MASS-K	0.7849	47	0.000000
CELL SOLIDS-KG VS BLOOD VOL-L	0.4240	45	0.003957
CELL SOLIDS-KG VS TOTAL HB-GMS	0.4921	45	0.000894
CELL SOLIDS-KG VS SUM SKINFOLDS-CM	0.0464	41	0.770965
CELL SOLIDS-KG VS %FAT-SKINFOLDS	0.2663	41	0.088638
CELL SOLIDS-KG VS LEAN BODY MASS-K	0.6973	41	0.000011
SUPPORT SOLIDS-K VS MUSCLE CELL MASS	0.6848	47	0.000006
SUPPORT SOLIDS-K VS VISC CELL MASS-K	0.6645	47	0.000011
SUPPORT SOLIDS-K VS BLOOD VOL-L	0.5326	45	0.000354
SUPPORT SOLIDS-K VS TOTAL HB-GMS	0.5695	45	0.000149
SUPPORT SOLIDS-K VS SUM SKINFOLDS-CM	0.2200	41	0.163550
SUPPORT SOLIDS-K VS %FAT-SKINFOLDS	0.4690	41	0.002317
SUPPORT SOLIDS-K VS LEAN BODY MASS-K	0.8692	41	0.000000
MUSCLE CELL MASS VS VISC CELL MASS-K	-0.0034	47	0.953314
MUSCLE CELL MASS VS BLOOD VOL-L	0.4038	47	0.005059
MUSCLE CELL MASS VS TOTAL HB-GMS	0.4947	47	0.000675
MUSCLE CELL MASS VS SUM SKINFOLDS-CM	0.3693	43	0.014121
MUSCLE CELL MASS VS %FAT-SKINFOLDS	0.5410	43	0.000374
MUSCLE CELL MASS VS LEAN BODY MASS-K	0.6990	43	0.000008
VISC CELL MASS-K VS BLOOD VOL-L	0.2105	45	0.161711
VISC CELL MASS-K VS TOTAL HB-GMS	0.2159	45	0.150673
VISC CELL MASS-K VS SUM SKINFOLDS-CM	-0.2313	41	0.142020
VISC CELL MASS-K VS %FAT-SKINFOLDS	-0.0933	41	0.610442
VISC CELL MASS-K VS LEAN BODY MASS-K	0.3509	41	0.023059
BLOOD VOL-L VS TOTAL HB-GMS	0.8010	47	0.000000
BLOOD VOL-L VS SUM SKINFOLDS-CM	0.3778	41	0.014194
BLOOD VOL-L VS %FAT-SKINFOLDS	0.5337	41	0.000569
BLOOD VOL-L VS LEAN BODY MASS-K	0.6990	41	0.000011
TOTAL HB-GMS VS SUM SKINFOLDS-CM	0.1946	41	0.220605
TOTAL HB-GMS VS %FAT-SKINFOLDS	0.3751	41	0.014923
TOTAL HB-GMS VS LEAN BODY MASS-K	0.6697	41	0.000023
SUM SKINFOLDS-CM VS %FAT-SKINFOLDS	0.9438	43	0.000000

CORRELATION MATRIX

COMPARISON	CORR. COEFF.	N	P VALUE
SUM SKINFOLDS-CM VS LEAN BODY MASS-K	0.4099	43	0.006526
%FAT-SKINFOLDS VS LEAN BODY MASS-K	0.6721	43	0.000016

TABLE 11

FOLIC ACID, VITAMIN B_{12}, TRANSFERRIN SATURATION AND HEMOSIDERIN

		Group A	Group B	Group C	All
	Folic acid (mg/ml)				
F = 4.83	n	11	20	18	49
P < 0.02	Mean	12.26	7.90	6.58	8.38
	S.D.	5.73	4.75	4.41	5.24
	n < 5 mg/ml	2	5	9	16
	% < 5 mg/ml	18.2	25	50	32.7
	Vitamin B_{12} (pcg/ml)				
F = 0.79	n	11	20	18	49
P < 0.50	Mean	561.51	491.75	608.5	550.3
	S.D.	269.7	327.75	244.6	285.7
	n < 200 pcg/ml	1	3	0	4
	% < 200 pcg/ml	9.1	15	0	8.2
	Transferrin saturation (%)				
F = 1.19	n	8	15	13	36
P < 0.30	Mean	35.93	30.83	25.31	29.97
	S.D.	13.80	16.24	15.64	15.61
	n < 15%	0	2	5	7
	% < 15%	0	13.3	38.5	19.4
	Hemosiderin				
	n	8	18	17	43
	n absent or diminished	7	15	13	35
	% absent or diminished	87.5	83.3	76.5	81.4

Average values of serum and plasma analyses are illustrated in Table 12. While average serum albumin levels differed significantly in all three groups, only Group C showed a significant decrease in average serum protein levels. Serum cholesterol levels were highly variable in all three groups, the incidence of low values being somewhat higher in Group C. However, extremely high values were encountered occasionally in all three groups.

Nitrogen balance and creatinine output studies are summarized in Tables 13 and 14. Valid nitrogen balance data were obtained only in some of the subjects, all measurements being made while administering a low protein diet. Nitrogen balance was frankly positive only in Group 1. Significant differences in creatinine output (mg/day or mg/kg day) were found between all three groups (Table 14). The average anthropometric characteristics of the three groups are shown in Table 15. Average heights were similar in all groups. Group A was on the average significantly younger than the other two. Highly significant differences in average weight, weight/height, weight$^{1/3}$/height and weight/height^{3} were found between all groups. Average triceps skinfold thickness in Groups B and C were significantly different from that in Group A. Average scapular skinfold thickness was significantly decreased only in Group C. In general, % body fat calculated from the skinfolds was low in all three groups, but Group C had significantly lower % body fat than Groups A and B.

The body fluid compartments are presented in Table 16 as total volumes and after normalization for body weight the total volumes of body water were progressively and significantly less as the nutritional status became progressively worse. This was due to a change in the intracellular volume since total extracellular water did not exhibit significant differences in the three groups. When expressed in terms of body weight, however, it is clear that there is a relative overhydration in the subjects in Group C which is apparently due to an extracellular edema.

TABLE 12

BLOOD CHEMISTRIES

Variable	Group A			Group B			Group C			Analysis of Variance	
	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	F Ratio	P
Serum albumin (gm %)	11	3.83	0.46	20	3.05	0.70	18	2.14	0.50	30.03	<0.001
Total proteins (gm %)	11	7.09	0.65	20	6.68	0.72	18	5.64	0.70	17.47	<0.001
Serum cholesterol	11	149	35	20	148	42	18	135	39	0.65	N.S.

TABLE 13

NITROGEN BALANCE

	Group A (n = 5)	Group B (n = 14)	Group C (n = 17)
Dietary N_2			
g/day	5.01 ± .69	4.70 ± 1.08	4.30 ± 1.16
g/kg·day	.098 ± .013	.097 ± .022	.101 ± .027
N_2 balance			
g/day	-.69 ± .083	-.07 ± 1.69	+.91 ± 1.1
% N_2 retention	-13.77	-1.40	+21.16

TABLE 14

CREATININE EXCRETION

	Group A			Group B			Group C			Analysis of Variance	
	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	F Ratio	P
mg/24 hrs.	11	1030	87	20	874	113	18	605	108	60.65	<0.001
Creatinine/Ht. index	11	660	67	20	559	75	18	391	76	50.19	<0.001
mg/24 hrs/kg	11	19.84	2.00	20	18.16	2.48	18	14.24	2.56	21.62	<0.001
mg/24 hrs/kg TBS	11	50.13	5.03	18	44.15	9.53	18	38.87	8.91	6.13	<0.005
mg/24 hrs/kg ICM	11	61.67	11.95	18	61.91	12.91	18	50.65	8.82	5.46	<0.01

TABLE 15

ANTHROPOMETRY

Variable	Group A			Group B			Group C			Analysis of Variance	
	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	F Ratio	P*
Age (yrs)	11	32.5	10.6	20	40.0	6.7	20	38.2	9.3	2.73	N.S.
Height (cm)	11	156.3	6.7	20	156.6	5.4	20	155.5	7.7	0.14	N.S.
Weight (kg)	11	52.03	3.99	20	48.24	3.2	18	42.52	4.27	23.06	<0.001
Weight/height ratio (kg/m)	11	33.3	2.1	20	30.8	2.0	18	27.4	2.1	30.12	<0.001
Weight$^{1/3}$/height	11	2.39	0.08	20	2.33	0.08	18	2.25	0.08	11.12	<0.001
Weight/height^3	11	13.69	1.35	20	12.62	1.27	18	11.43	1.28	10.84	<0.001
Surface area (m^2)	11	1.50	0.08	20	1.45	0.06	18	1.37	0.10	9.55	<0.001
Triceps skinfolds (cm)	11	.572	.195	20	.453	.245	18	.448	.19		
Subscapular skinfolds (cm)	11	.774	.270	20	.742	.222	18	.576	.20		
% body fat**	8	4.9	1.0	17	4.1	1.1	18	3.4	0.9	6.93	<0.003
Lean body mass (kg)**	8	48.8	3.0	17	44.0	2.8	18	39.1	3.5	27.44	<0.001

*Probability

**Derived from skinfold measurements

TABLE 16

BODY FLUID COMPARTMENTS

Variable	Group A			Group B			Group C			Analysis of Variance	
	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	F Ratio	P
Total Volumes (L):											
Body water	11	31.374	2.710	18	28.314	2.322	18	26.554	3.540	9.23	<0.001
Extracellular water	11	14.140	1.876	18	13.861	1.438	18	14.425	2.568	0.34	N.S.
Intracellular water	11	17.233	3.338	18	14.453	2.468	18	12.129	2.347	12.79	<0.001
Plasma	10	2.548	0.366	19	2.724	0.413	18	2.456	0.451	1.92	N.S.
Blood	10	4.337	0.614	19	4.178	0.571	18	3.507	0.666	7.86	<0.002
Volumes/kg Body Weight (ml/kg):											
Body water	11	603	25	18	585	42	18	624	52	3.79	<0.003
Extracellular water	11	273	36	18	286	27	18	339	45	13.94	<0.001
Intracellular water	11	330	50	18	299	50	18	286	49	2.78	N.S.
Plasma	10	49.5	6.0	19	56.7	8.9	18	57.7	7.9	3.71	<0.04
Blood	10	84.3	10.3	19	86.9	11.4	18	82.3	11.2	0.78	N.S.

Tables 17 and 18 show body composition in Kg and as % of body weight. All the calculated components of body composition except visceral cell mass show highly significant differences related to the three nutritional groups. However, when these variables are expressed as % of the body weight, only muscle cell mass continues to show a statistically significant variation with nutritional status. The relatively high % of body fat (Table 18) obtained by this method as compared with that observed by the skinfold method (Table 15), raises the question about the applicability of either method to the determination of body fat of malnourished subjects. A third, more reliable determination (underwater weighing?) may be necessary to resolve this question.

Table 19 illustrates the ratios of the differences in total body water and in body weight between any two groups, an index of the hydration of the mass deficit shown by any one group. Group B showed deficit of a water rich (80.7% water) mass with respect to Group A. Group C showed an average deficit of body mass with very low water content with respect to Group B (18.48% water) and with about 50% water if compared with Group A. It thus appears that the deficit in Group B was one involving water rich compartments (cells and/or extracellular fluid), while that in Group C involved in addition to cell losses, a deficit of water poor tissues (fat or others).

This is confirmed by an analysis of the ratios of the differences in intracellular water to the differences in the sum of body solids and cell water, an estimate of the intracellular hydration of the tissue deficits in the body (Table 19). The tissue hydration of the deficit shown by Group B with respect to Group A as evaluated by the ratio $_{\Delta}ICW/_{\Delta}(TBS+ICW)$ had a 79% content of water, indicating deficit of pure cells and even suggesting a disproportionately excessive loss of cell water over that in cell solids. The hydration of the additional tissue deficit in Group C, estimated by the ratio $_{\Delta}ICW / _{\Delta}(ICW + TBS)$ in Groups B and C, showed a low water content (36.88% water), consistent with a deficit of water poor tissue (fat or others) in addition to the further loss of water rich cells evident in the lower average intracellular water content in Group C (Table 16).

TABLE 17

BODY COMPOSITION IN KILOGRAMS

Variable	Group A			Group B			Group C			Analysis of Variance	
	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	F Ratio	P
Fat free weight	11	42.8	4.3	18	38.3	3.3	18	35.1	4.4	12.59	<0.001
Fat weight	11	9.2	2.4	18	10.1	3.3	18	7.4	3.0	3.75	<0.05
Fat free solids	11	11.4	1.8	18	10.0	1.1	18	8.5	1.2	17.24	<0.001
Body cell mass	11	22.0	4.2	18	18.6	3.0	18	15.6	2.9	12.78	<0.001
Cell solids	11	4.8	0.8	18	4.1	0.6	18	3.5	0.6	12.79	<0.001
Support tissue solids	11	6.6	0.9	18	5.9	0.5	18	5.0	0.6	21.19	<0.001
Muscle cell mass	11	12.9	1.1	20	10.9	1.4	18	7.6	1.4	60.59	<0.001
Visceral cell mass	11	9.2	4.6	18	7.7	3.0	18	8.1	2.3	0.74	N.S.

TABLE 18

BODY COMPOSITION AS % BODY WEIGHT

Variable	Group A			Group B			Group C			Analysis of Variance	
	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	F Ratio	P
Fat free weight	11	82.2	4.5	18	79.1	6.1	18	82.5	6.6	1.66	N.S.
Fat weight	11	17.7	4.5	18	20.8	6.1	18	17.4	6.6	1.66	N.S.
Fat free solids	11	21.9	2.4	18	20.7	2.2	18	20.1	2.1	2.29	N.S.
Body cell mass	11	42.2	6.2	18	38.3	6.2	18	36.9	6.1	2.57	N.S.
Cell solids	11	9.2	1.2	18	8.5	1.3	18	8.3	1.2	1.83	N.S.
Support tissue solids	11	12.7	1.2	18	12.2	9.0	18	11.8	9.2	3.06	N.S.
Muscle cell mass	11	24.8	2.5	20	22.7	3.1	18	17.8	3.2	21.18	<0.001
Visceral cell mass	11	17.4	7.9	18	15.8	6.2	18	19.0	5.0	1.19	N.S.

TABLE 19

DIFFERENCES OF THE RATIOS OF BODY WATER, BODY WEIGHT AND CREATININE EXCRETION

	Groups		
	A - C	B - C	A - B
$\frac{\Delta \text{ Total Body Water}}{\Delta \text{ Body Weight}}$	.5063	.1848	.8074
$\frac{\Delta \text{ Intracellular Water}}{\Delta \text{ (Total Body Solids + Intracellular Water)}}$	.5204	.3688	.7920
$\frac{\Delta \text{ Creatinine Excretion}}{\Delta \text{ Total Body Solids}}$	90.36	67.80	213.01
$\frac{\Delta \text{ Creatinine Excretion}}{\Delta \text{ Intracellular Water}}$	83.27	116.03	55.93

Table 19 also shows the ratios of the differences in creatinine output to the differences in total body solids between any two groups. Creatinine producing solids are confined to the intracellular solids and among them to the solids within muscle cells. The significantly lower values of the ratios in groups B and C (Table 14) indicate progressively severe deficit of muscle cell solids within the total mass of solids remaining in the body. Comparison of Groups A and B reveals deficit of solids with a very high creatinine production capacity in Group B. Thus the deficit of solids in Group B must include a high proportion of solids from muscle cells. By contrast comparison of Groups B and C reveals that the large deficit of solids in Group C had a much lower creatinine producing capacity than the deficit in Group B and thus must include a large proportion of nonmuscle solids.

Only in Group C was the average ratio of creatinine output to intracellular water significantly lower than in the other two groups (Table 19). Decreases in the creatinine output/ICW ratio can be due to a decrease in the proportion of muscle within the cell body mass, to a decrease in the creatinine producting capacity per unit of muscle mass or to increases in cell hydration. None of these phenomena seemed to have occurred to a significant extent in Group B. Any one or several of them could have occurred in Group C. The ratio of the differences in creatinine output and intracellular water between any two groups (Table 19) reveals that only in Group C the deficit of cell mass had a very high ratio of creatinine output to intracellular water, indicative of a disproportionate large deficit of creatinine producing cells in their body cell masses.

To summarize, in Group B muscle solids and other cell solids were lost in approximately equal proportion to that in which they usually occur within the body cell mass, but much out of proportion to losses of fat and/or extracellular solids. In Group C, loss of cellular solids represented a lower fraction of the total solid loss, probably due to large deficits in solids such as fat. Loss of muscle cells probably exceed that in visceral

cells resulting in a high Δ creatinine output/Δ intracellular water, ratio within the tissue deficit shown by this group either when compared with Group B or with Group A.

The maximum oxygen consumption and endurance times at 80% $\dot{V}_{O_2}$ max (T_{80}) are presented in Tables 20 and 21. $\dot{V}_{O_2}$ max (L/min) and maximum pulmonary ventilation (L/min) were significantly different in each of the three nutritional groups (Table 20). However, there were no differences in maximum heart rates (f_H) or endurance times (T_{80}). When $\dot{V}_{O_2}$ max was normalized for weight (aerobic capacity), height, fat free weight, cell body mass, muscle cell mass and creatinine excretion, the one way analyses of variance of these variables in the three groups all gave statistically significant F-ratio values (Table 21).

Using $\dot{V}_{O_2}$ max (ml/min) and aerobic capacity (ml/kg $\cdot$ min^{-1}) as the measures of physical working capacity (5), the regression and correlation analyses of these two variables with a number of independent indices of nutritional status are presented in Figs. 8-15. All are statistically significant at $P < 0.001$. The relationships of physical work capacity to nutritional status as measured by a factor derived from the creatinine excretion, total body hemoglobin and extracellular water ((mg/24 hr $\cdot$ gms)/(ECW ml/kg $\cdot$ 100)) are presented in Figs. 16 and 17. These emphasize the very high degree of correlation between nutritional status and physical work capacity. These correlations are sufficiently high for the regression equations to be utilizable as predictive formulae.

The relationship of muscle cell mass to serum albumin and then of $\dot{V}_{O_2}$ max to muscle cell mass are shown in Figs. 18 and 19. Figs. 20 and 21 show the scattergrams of T_{80} on serum albumin and the factor (Cr $\cdot$ Hb)/ECW, mentioned above. In both cases there was no statistically significant relationship.

TABLE 20

MAXIMUM OXYGEN CONSUMPTION AND ENDURANCE TIME AT 80% $\dot{V}O_2$ MAX

Variable	Group A			Group B			Group C			Analysis of Variance	
	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	F Ratio	P
$\dot{V}O_2$ max (L/min)	11	2.17	0.40	20	1.71	0.34	18	1.05	0.31	39.67	<0.001
f_H max (/min)	11	185	8	20	182	11	18	185	9	0.41	N.S.
$\dot{V}_E$ max (L/min)	11	91.62	15.60	20	82.92	20.58	18	74.09	17.17	3.19	<0.05
T_{80} (min)	11	91	102	15	95	71	16	103	77	0.07	N.S.

TABLE 21

NORMALIZATION OF $\dot{V}_{O_2}$ MAX FOR VARIOUS PARAMETERS

Variable	Group A			Group B			Group C			Analysis of Variance	
	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	F Ratio	P
Weight[1]	11	41.7	6.9	20	35.4	6.6	18	24.5	5.9	27.17	<0.001
Height[2]	11	13.9	2.6	20	10.9	2.1	18	6.8	1.9	39.36	<0.001
Fat free weight[1]	11	51.0	9.9	18	44.7	8.8	18	29.7	6.9	25.66	<0.001
Cell body mass[1]	11	101.4	25.6	18	93.7	19.7	18	67.2	14.7	13.05	<0.001
Muscle cell mass[1]	11	169.4	31.0	20	159.1	37.9	18	138.9	29.5	3.20	<0.05
Creatinine excretion[3]	11	2.12	0.39	20	1.99	0.47	18	1.74	0.37	3.21	<0.05

[1] $ml/kg \cdot min^{-1}$

[2] $ml/cm \cdot min^{-1}$

[3] $ml/cm \cdot 24\ hrs \cdot min^{-1}$

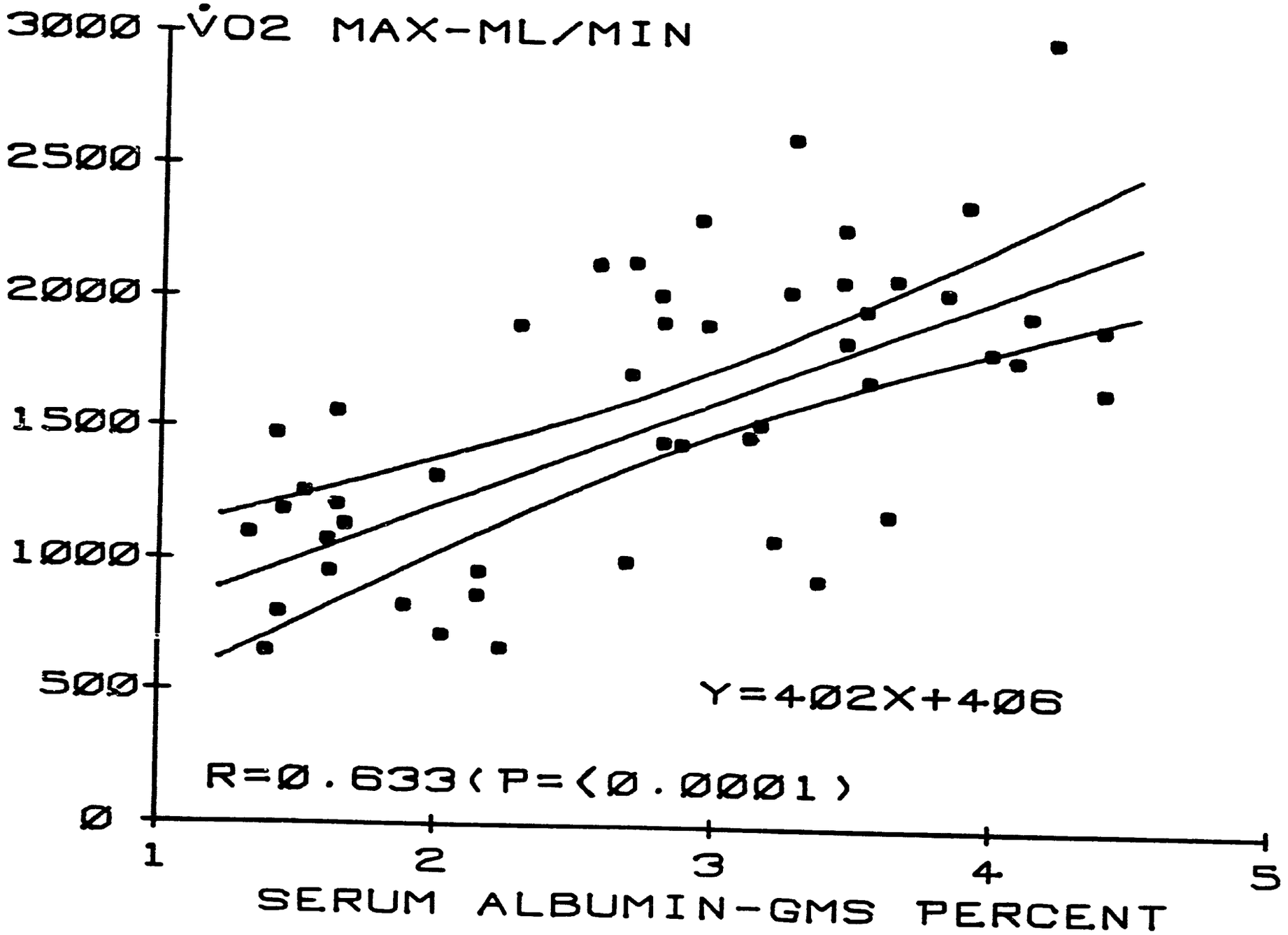

FIG. 8. Regression of $\dot{V}_{O_2}$ max on serum albumin with 95% confidence limits.

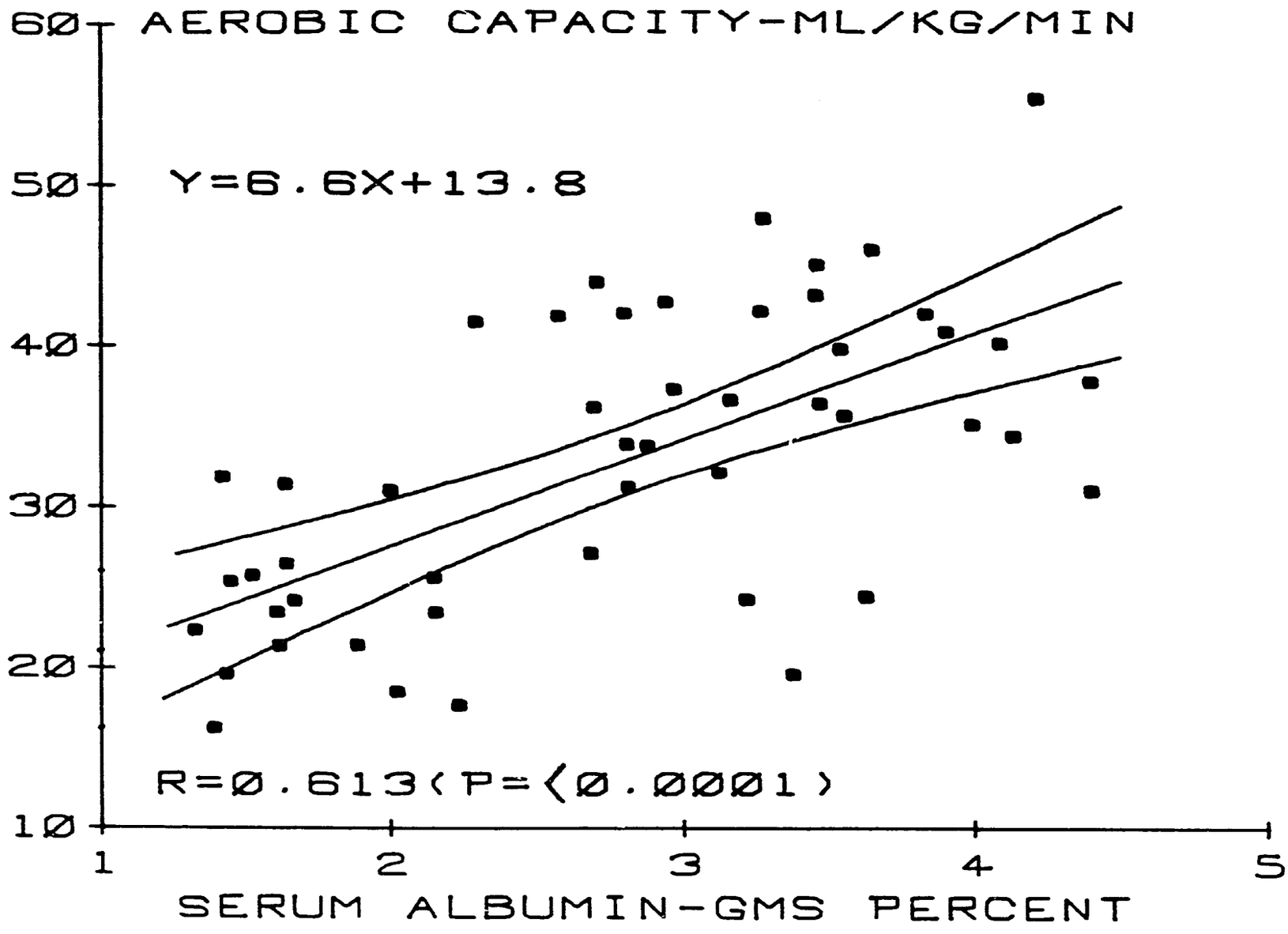

FIG. 9. Regression of aerobic capacity on serum albumin with 95% confidence limits.

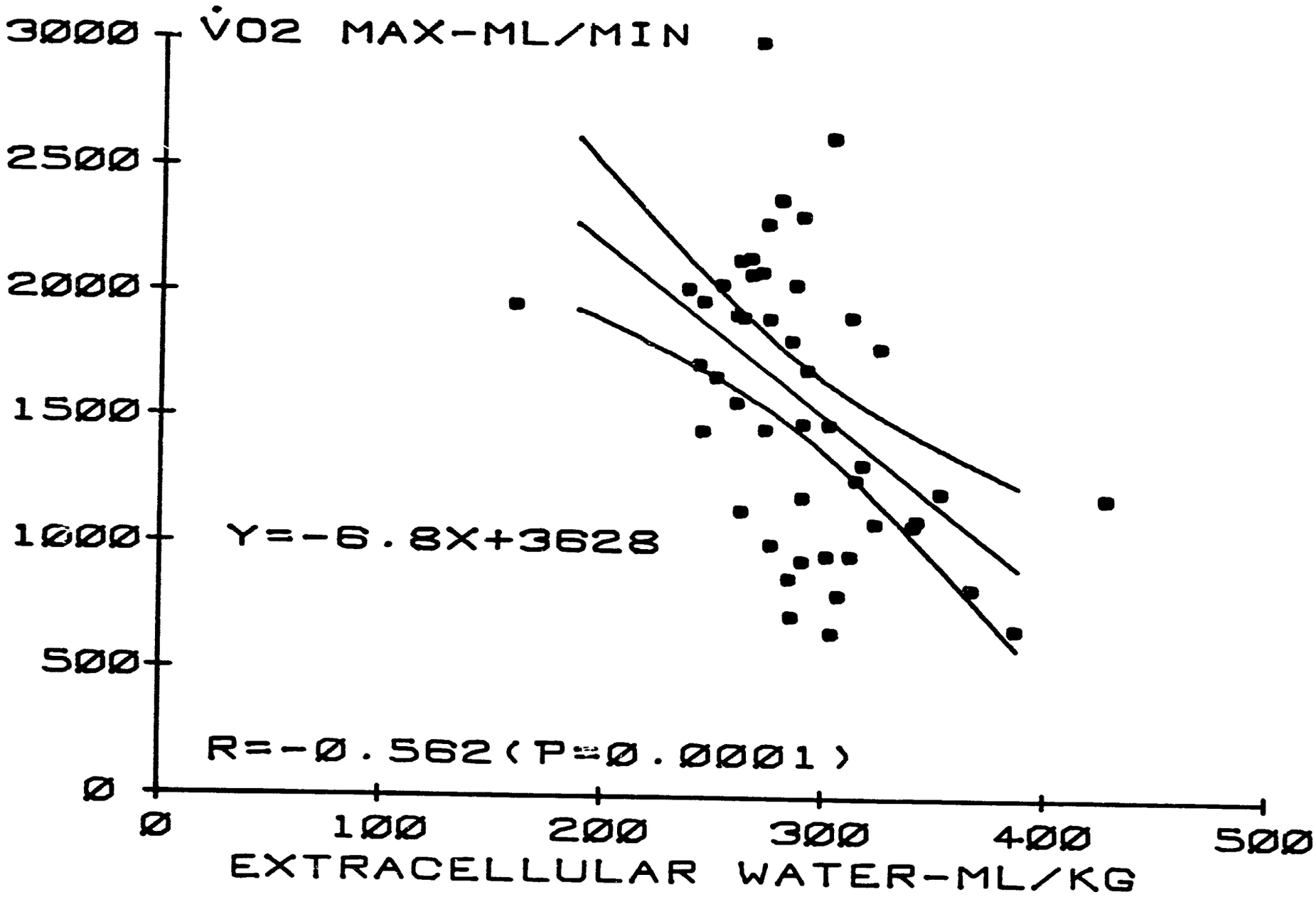

FIG. 10. Regression of $\dot{V}_{O_2}$ max on extracellular water with 95% confidence limits.

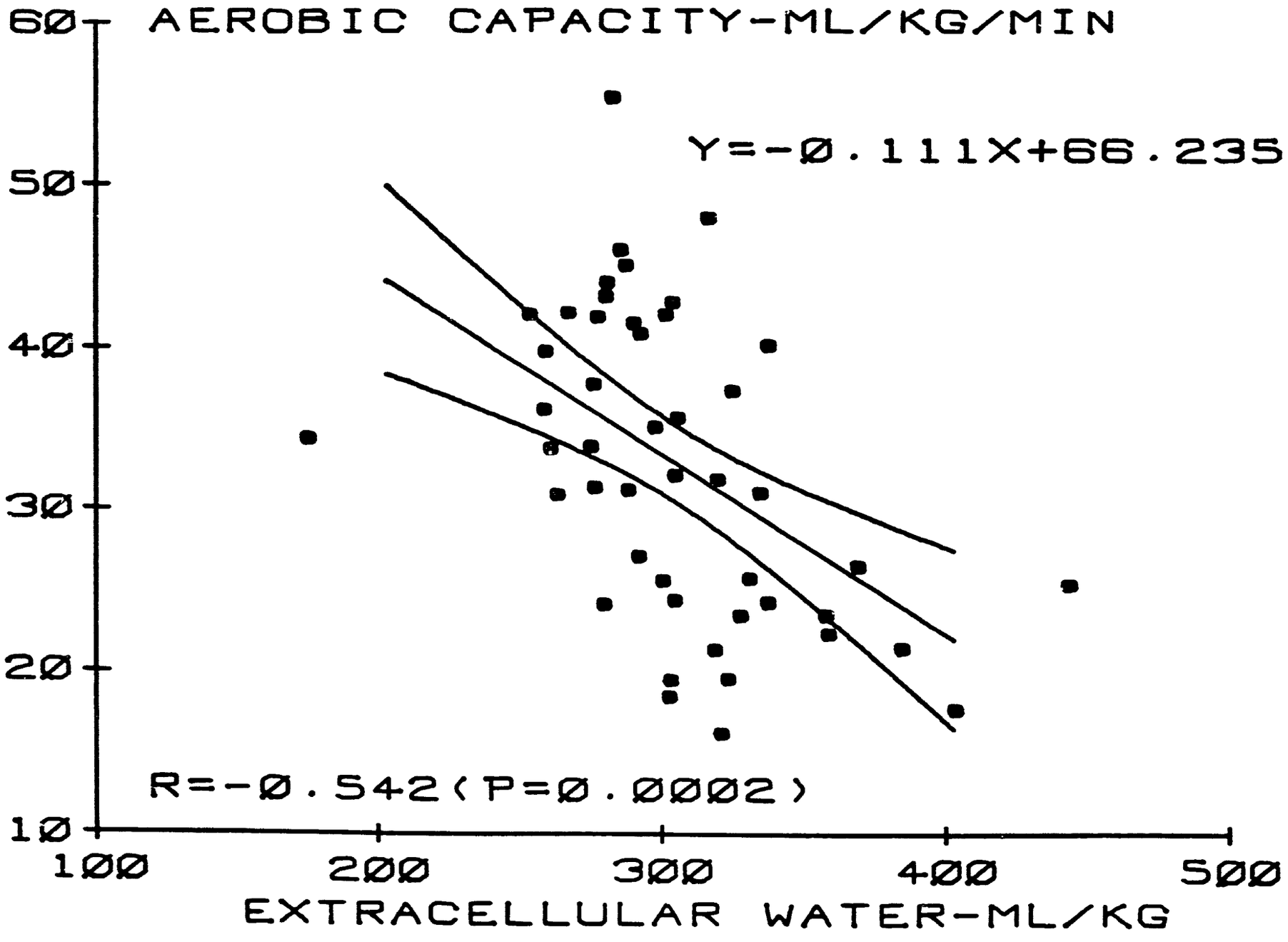

FIG. 11. Regression of aerobic capacity on extracellular water with 95% confidence limits.

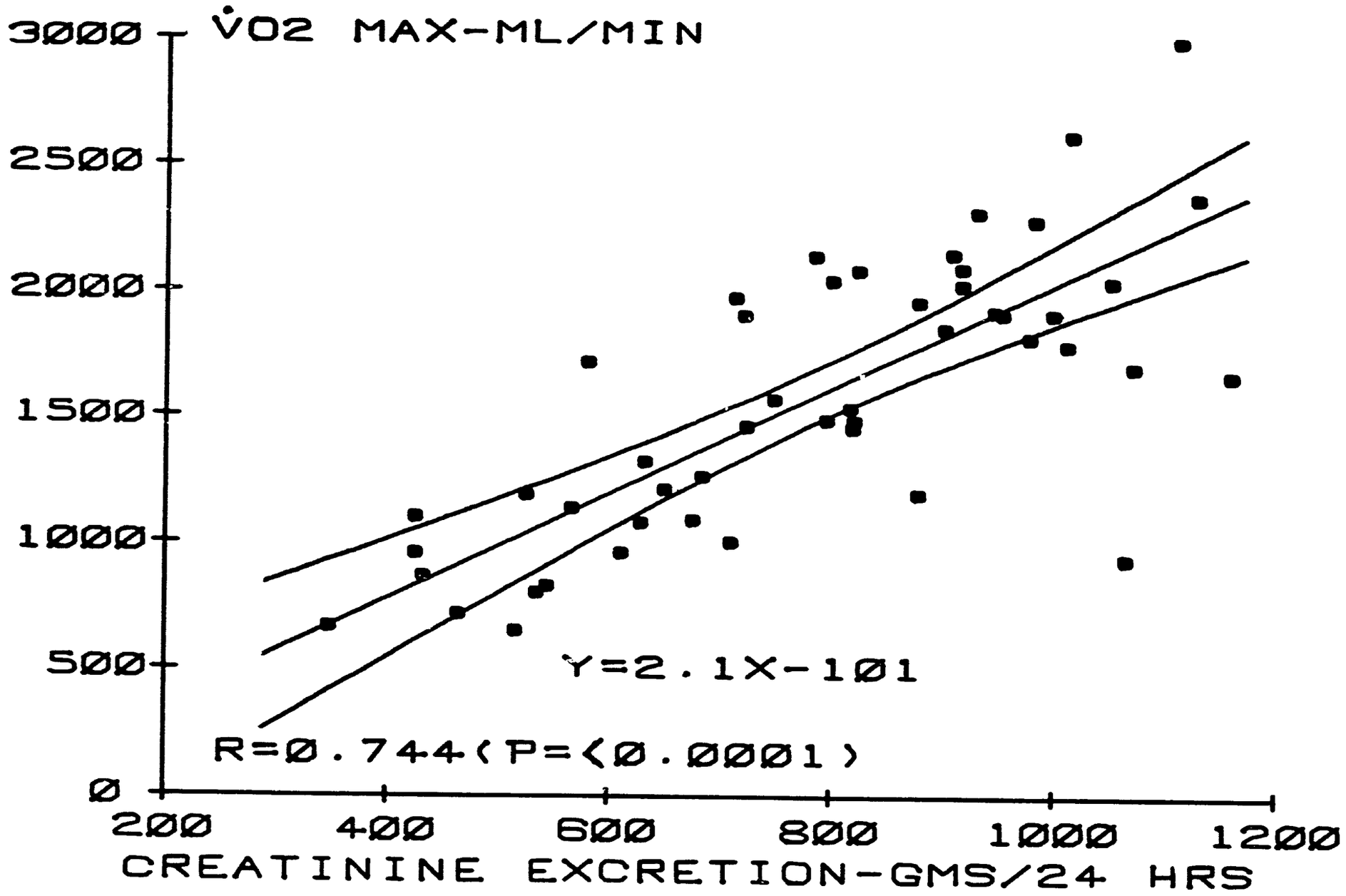

FIG. 12. Regression of $\dot{V}_{O_2}$ max on creatinine excretion with 95% confidence limits.

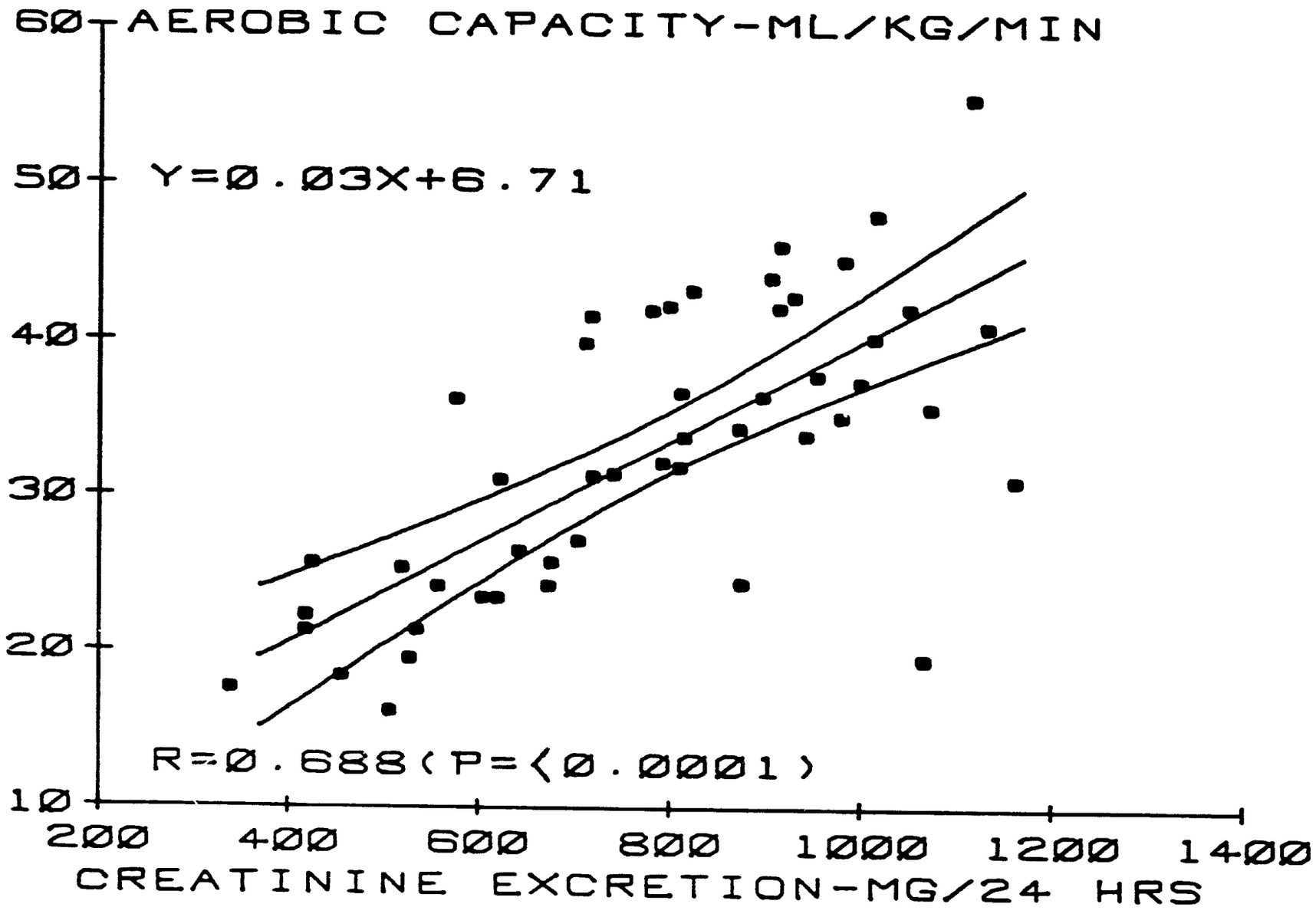

FIG. 13. Regression of aerobic capacity on creatinine excretion with 95% confidence limits.

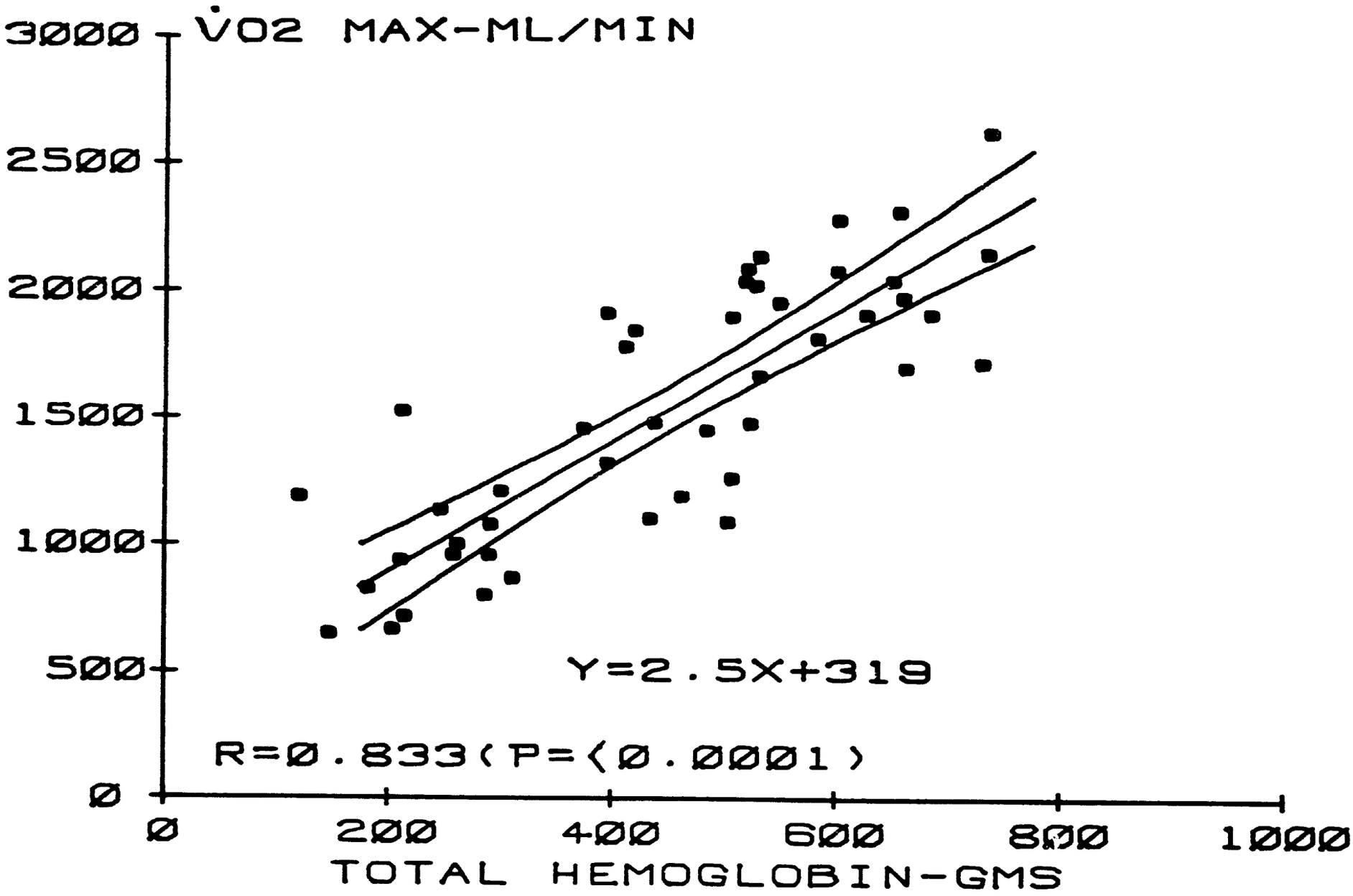

FIG. 14. Regression of $\dot{V}_{O_2}$ max on total hemoglobin with 95% confidence limits.

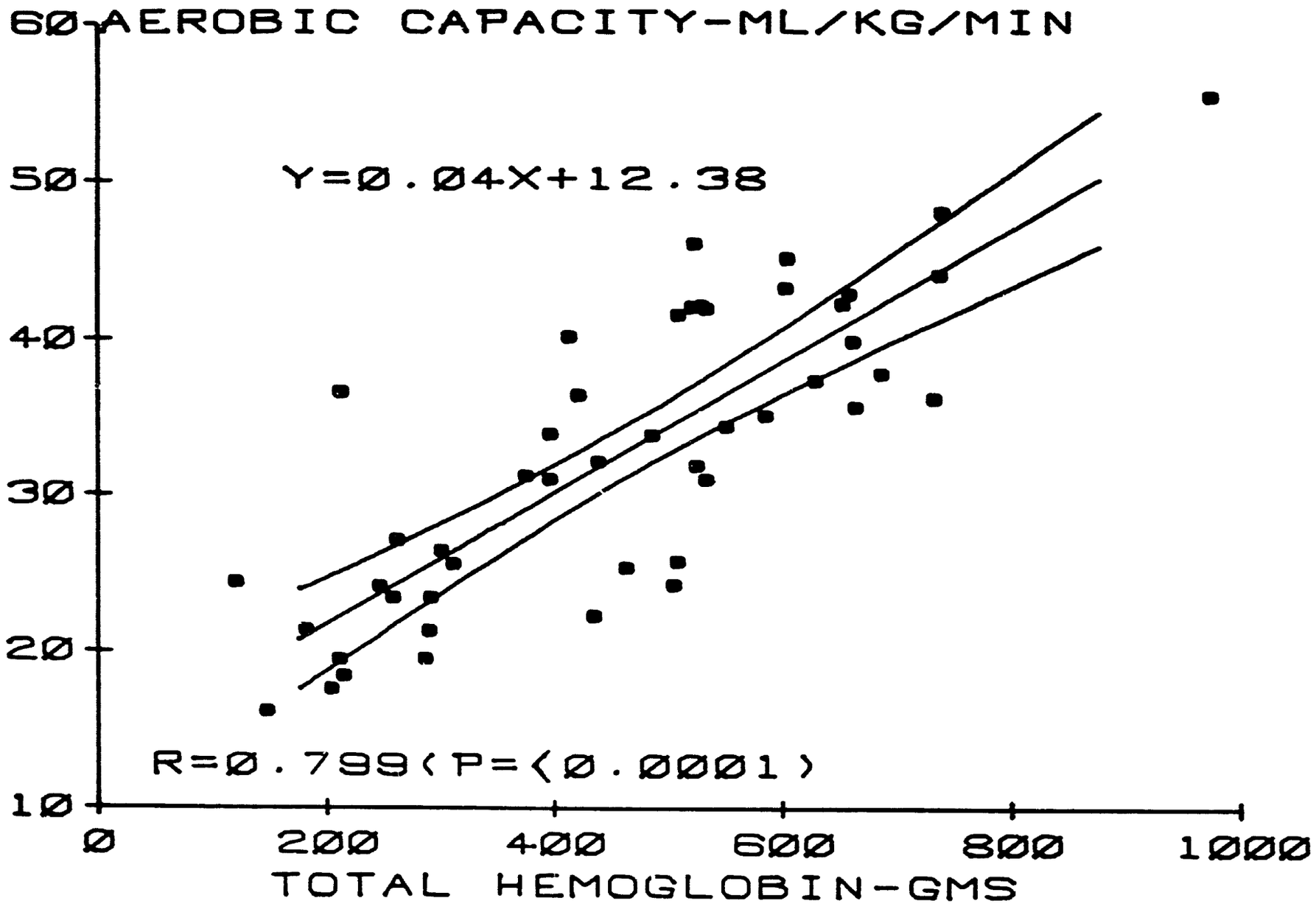

FIG. 15. Regression of aerobic capacity on total hemoglobin with 95% confidence limits.

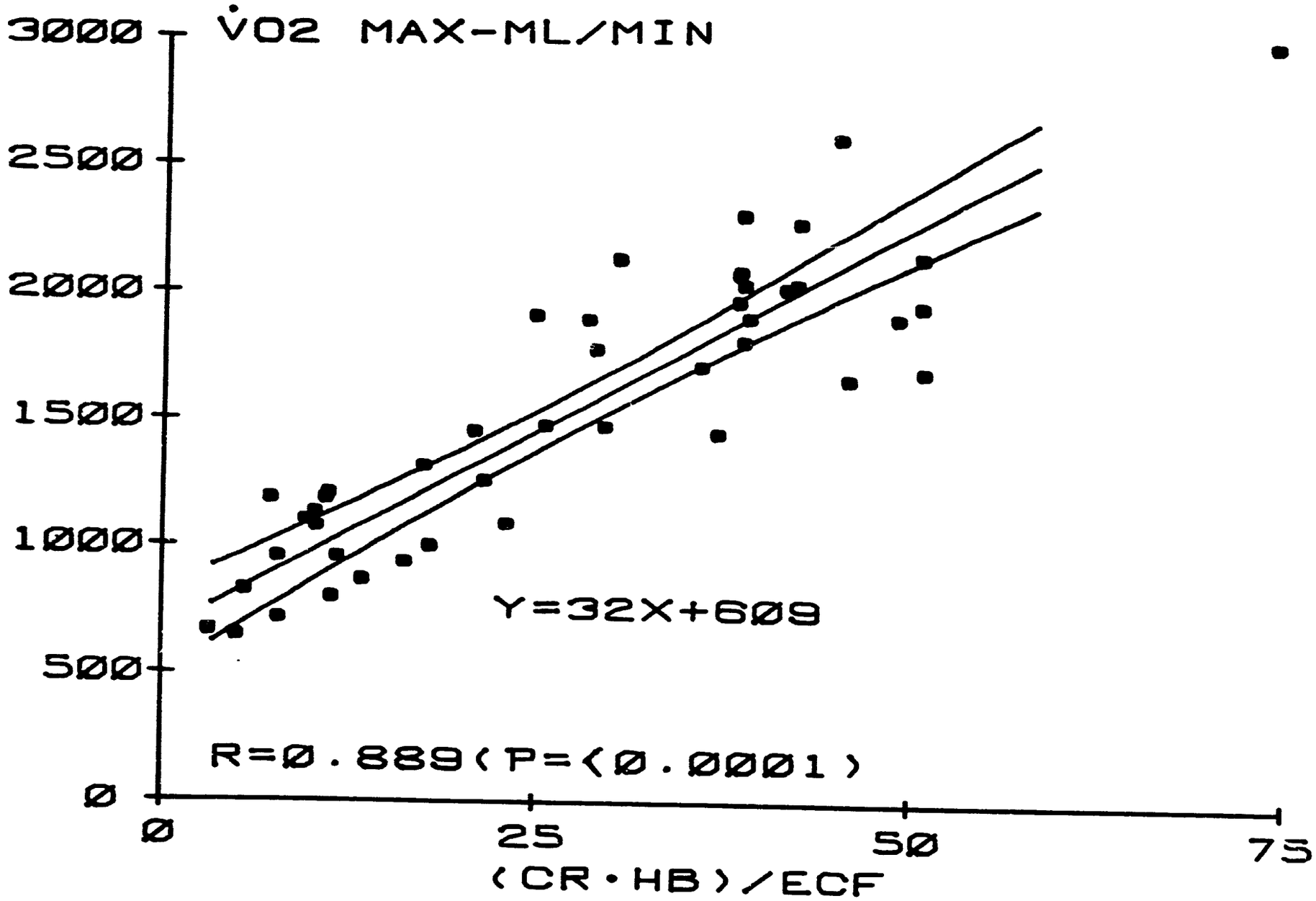

FIG. 16. Regression of $\dot{V}_{O_2}$ max on (creatinine·hemoglobin)/extracellular fluid volume with 95% confidence limits.

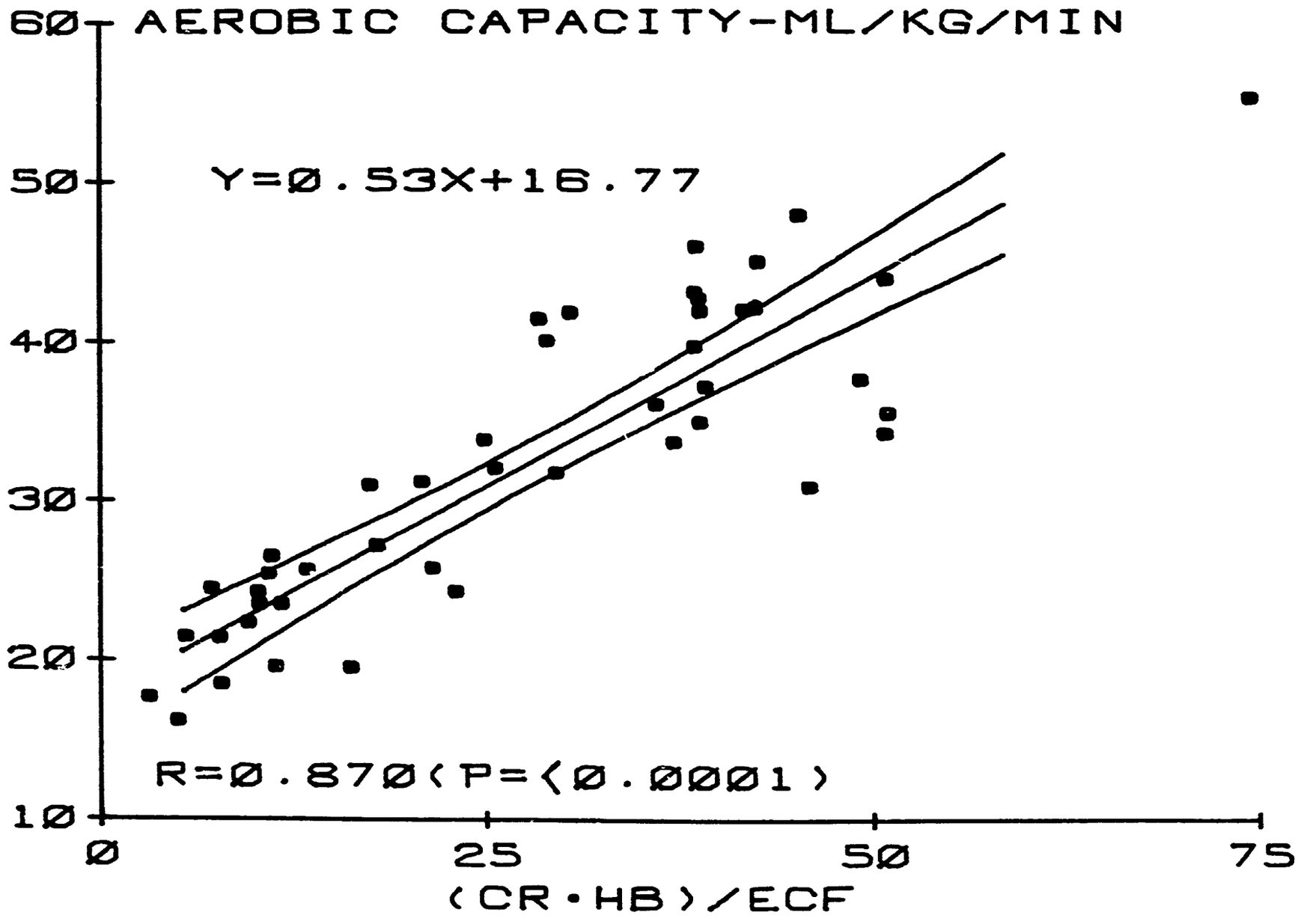

FIG. 17. Regression of aerobic capacity on (creatinine·hemoglobin)/extracellular fluid volume with 95% confidence limits.

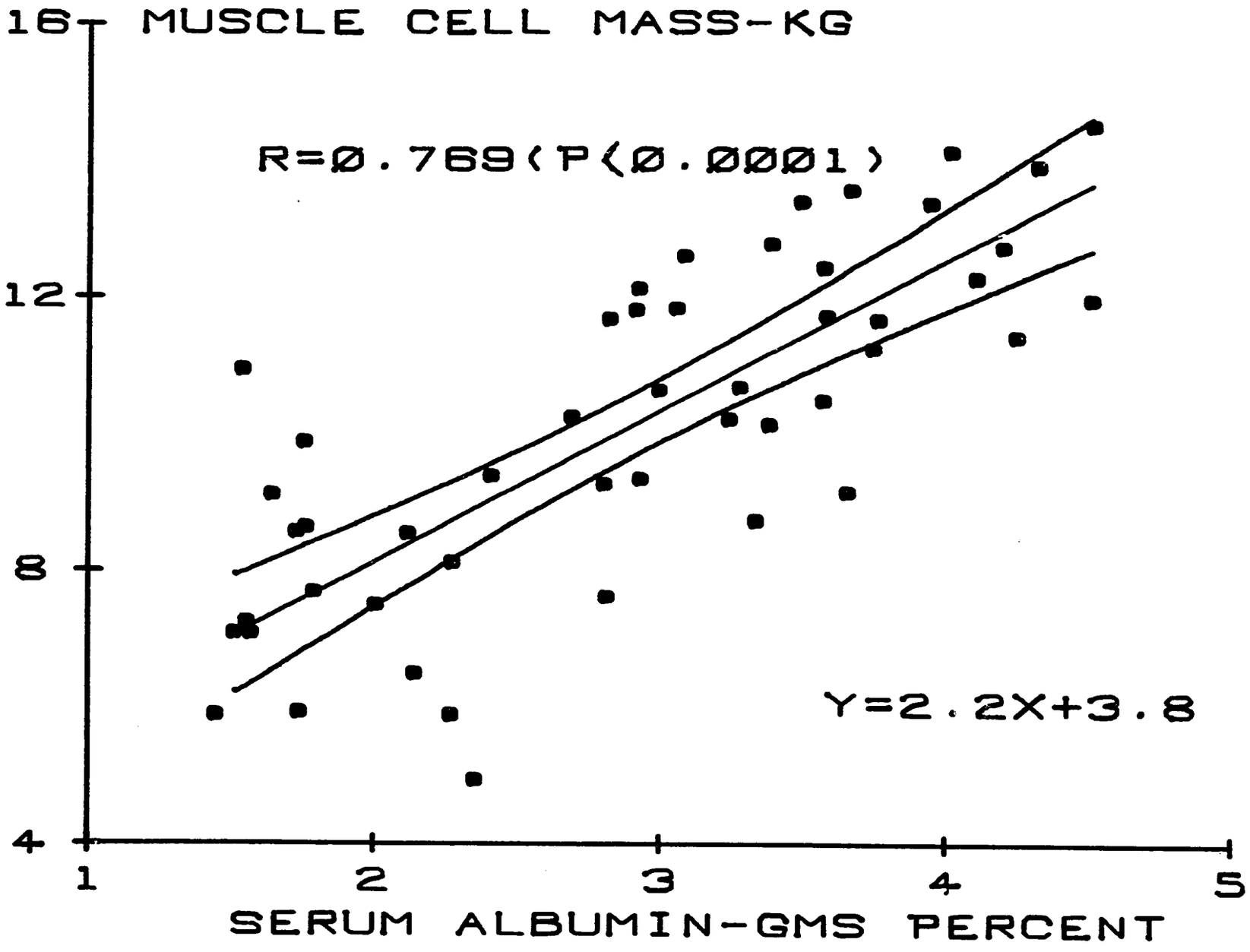

FIG. 18. Regression of muscle cell mass on serum albumin with 95% confidence limits.

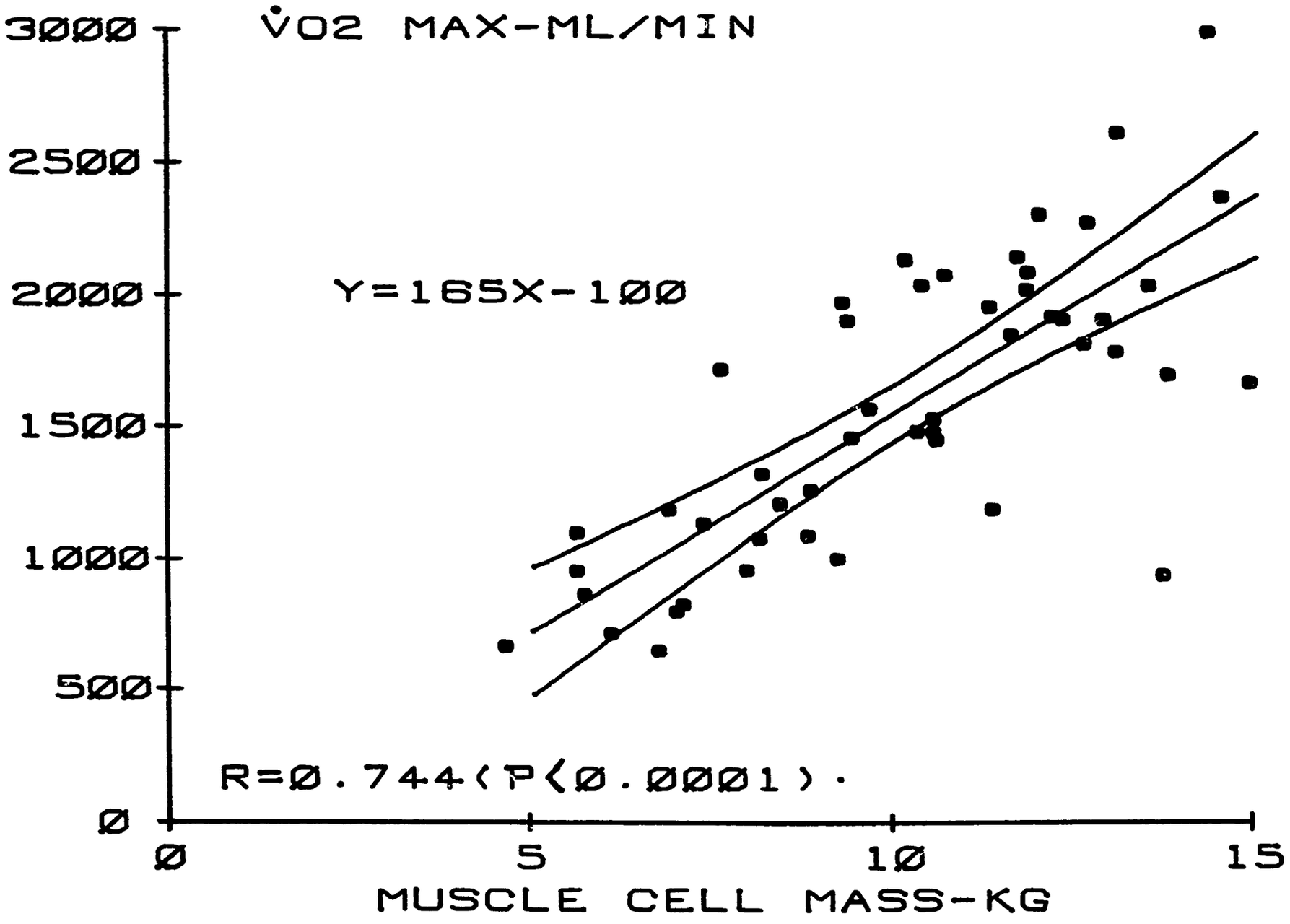

FIG. 19. Regression of $\dot{V}_{O_2}$ max on muscle cell mass with 95% confidence limits.

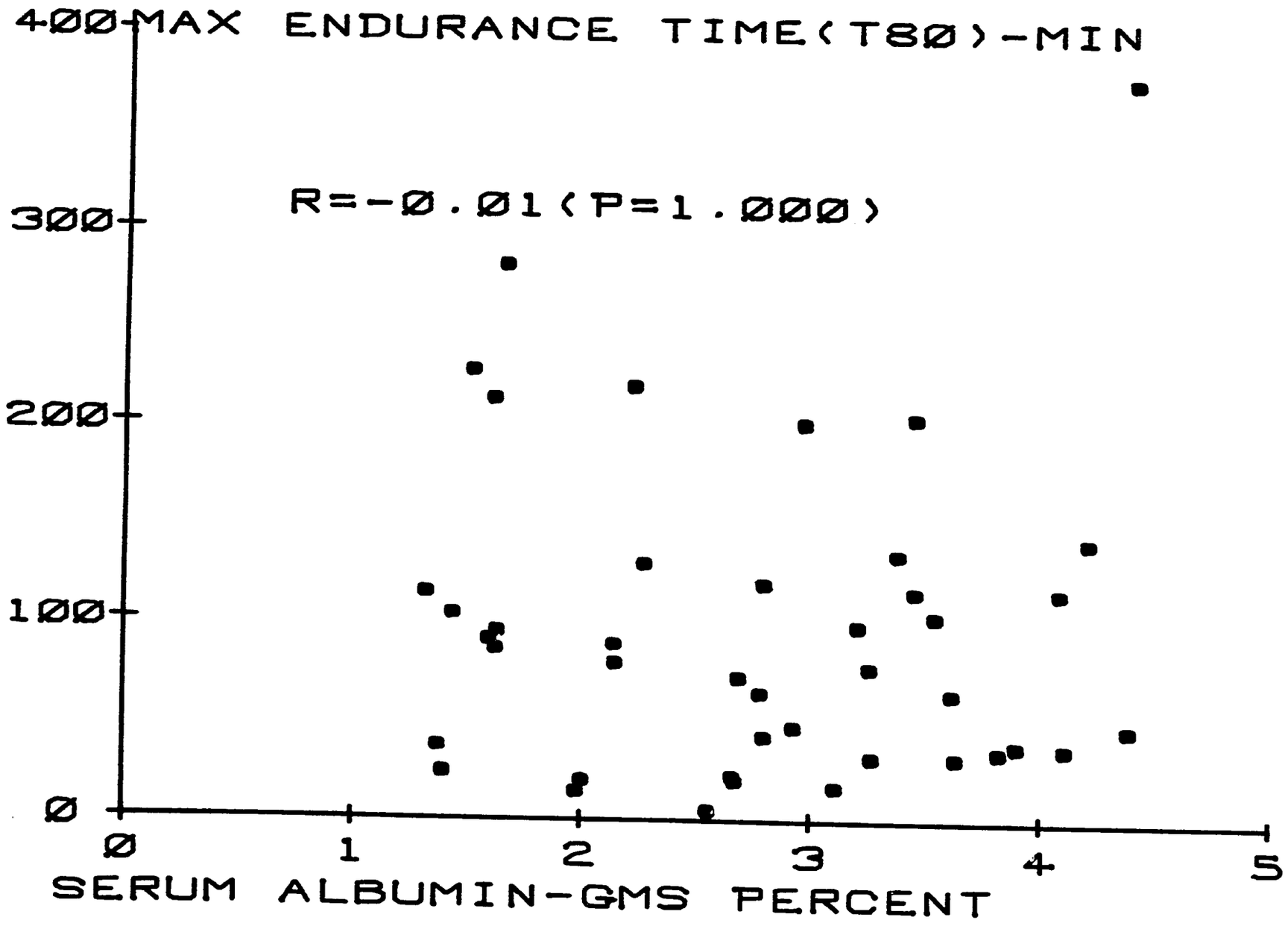

FIG. 20. Regression of maximum endurance time on serum albumin with 95% confidence limits.

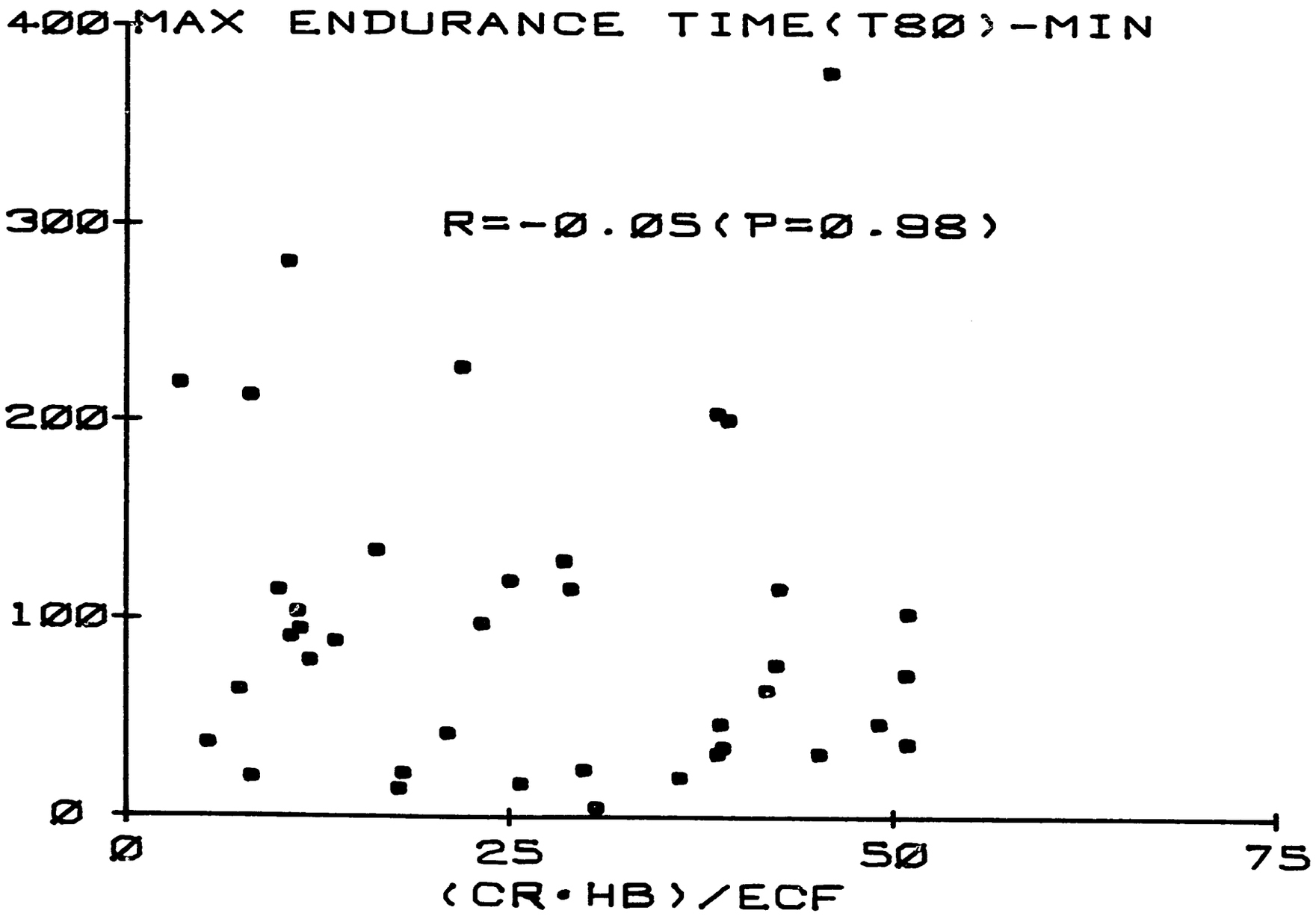

FIG. 21. Regression of maximum endurance time on (creatinine·hemoglobin)/extracellular fluid volume with 95% confidence limits.

(B) Nutritional Repletion (Longitudinal) Study

Due to various unforeseen circumstances the two measurements of the basal period were separated by an average of 45 days (S. E. = ± 5). The measurements of the repletion period were made on an average of 90 (S. E. = ± 6) days and 124 (S. E. = ± 7) days after commencement of the program (Table 22). Consequently the two measurements of the basal period were separated by 1.5 months and those made during the dietary repletion, 1.5 and 2.5 months after beginning the repletion period.

Table 22 and Fig. 22 show that during the basal period nutritional status was essentially unchanged but that dietary repletion resulted in statistically significant increase in body weight, weight/height ratio, % body fat, total plasma proteins, serum albumin and daily creatinine excretion.

The hematological and blood volume responses to nutritional repletion are present in Fig. 23 and Table 23. The hematocrit, hemoglobin concentration and total body hemoglobin did not change significantly during the basal period or the first 1.5 months of nutritional repletion. However, all three variables exhibited statistically significant increases following 2.5 months of increased protein intake in the diet. During the same periods plasma volume exhibited a tendency to fall while blood volume did not change markedly, due to the increased quantities of red blood cells.

Table 24 and Fig. 24 summarize the results of the measurements of physical condition expressed in terms of the maximal responses obtained on the treadmill. It can be seen that the total hemoglobin did not change until after 2.5 months of protein repletion. However, aerobic capacity, which showed no change during the basal period, exhibited a progressive increase during the nutritional replenishment. Maximum heart rate was unchanged throughout, indicating an absence of a training effect during the course of these studies. The important observation is that physical fitness as measured by aerobic capacity changed independently of changes in hemoglobin early in the repletion period.

TABLE 22

NUTRITIONAL STATUS BEFORE AND DURING DIETARY REPLETION (100 GM PROTEIN/DAY) IN 19 SEVERELY UNDERNOURISHED MALE PATIENTS

	Basal Period		Nutritional Repletion	
Time in program (days)	0	45 ± 5	90 ± 6	124 ± 7
Weight (kg)	43.3 ± 1.1	45.2 ± 1.3*	50.5 ± 1.3*†	53.1 ± 1.2*†‡
Weight/height ratio (kg/m)	27.7 ± 0.6	28.9 ± 0.7*	32.4 ± 0.8*†	34.1 ± 0.7*†‡
Serum albumin (gm %)	1.9 ± 0.1	2.0 ± 0.1	3.3 ± 0.1*†	3.8 ± 0.1*†‡
Total protein (gm %)	5.5 ± 0.2	5.7 ± 0.2	7.0 ± 0.2*†	7.4 ± 0.2*†‡
Cholesterol (mg %)	114 ± 22	152 ± 49*	190 ± 44*†	185 ± 24*†
Creatinine excretion (mg/24 hrs)	608 ± 30	578 ± 29	819 ± 43*†	926 ± 39*†‡

*$P < 0.05$ vs. basal period 0

†$P < 0.05$ vs. basal period 45 days

‡$P < 0.05$ vs. nutritional repletion 90 days

TABLE 23

HEMATOLOGY IN 19 SEVERELY UNDERNOURISHED MALE PATIENTS BEFORE AND DURING DIETARY REPLETION (100 GM PROTEIN/DAY)

	Basal Period		Nutritional Repletion	
Time in program (days)	0	45 ± 5	90 ± 6	124 ± 7
Hematocrit (%)	32 ± 1	32 ± 1	33 ± 1	36 ± 1*†‡
Hemoglobin (gm %)	10.2 ± 0.4	10.3 ± 0.6	10.4 ± 0.5	12.2 ± 0.5*†‡
Total hemoglobin (gm)	362 ± 29	362 ± 30	423 ± 28	501 ± 31*†‡
Total hemoglobin (gm/kg)	8.3 ± 0.5	7.9 ± 0.5	8.4 ± 0.5	9.4 ± 0.5*†‡
Plasma volume (ml/kg)	58.0 ± 2.1	53.5 ± 1.9*	56.0 ± 1.7	51.2 ± 1.7*‡
Blood volume (ml/kg)	82.3 ± 3.0	76.5 ± 2.4*	80.6 ± 2.5	77.0 ± 2.6

*$P < 0.05$ vs. basal period 0

†$P < 0.05$ vs. basal period 45 days

‡$P < 0.05$ vs. nutritional repletion 90 days

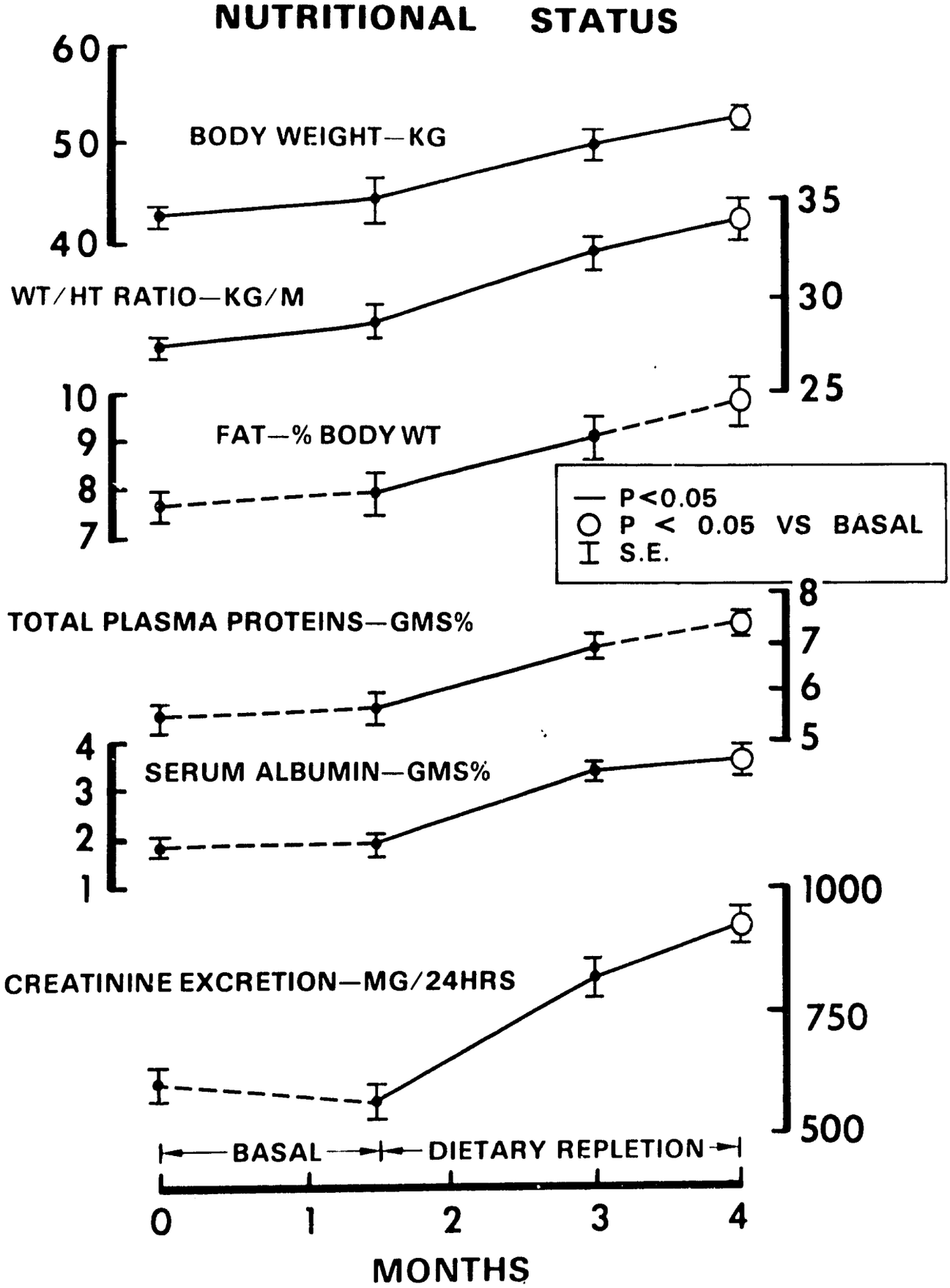

FIG. 22. Nutritional status of 19 severely malnourished subjects during a 6 week basal period and during 2-1/2 months of protein repletion (100 gms/day).

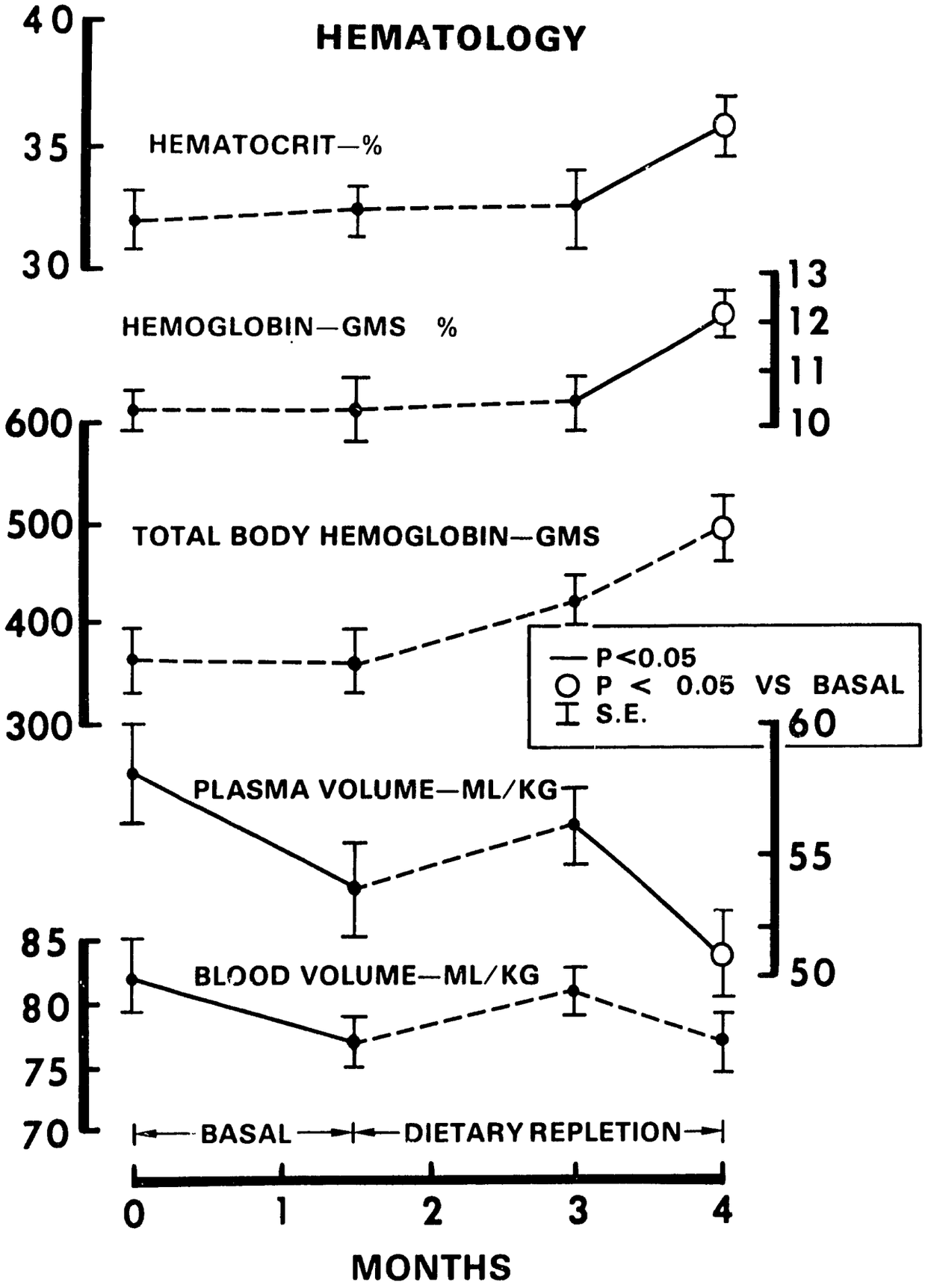

FIG. 23. Hematology of 19 severely malnourished subjects during a 6 week basal period and during 2-1/2 months of protein repletion (100 gms/day).

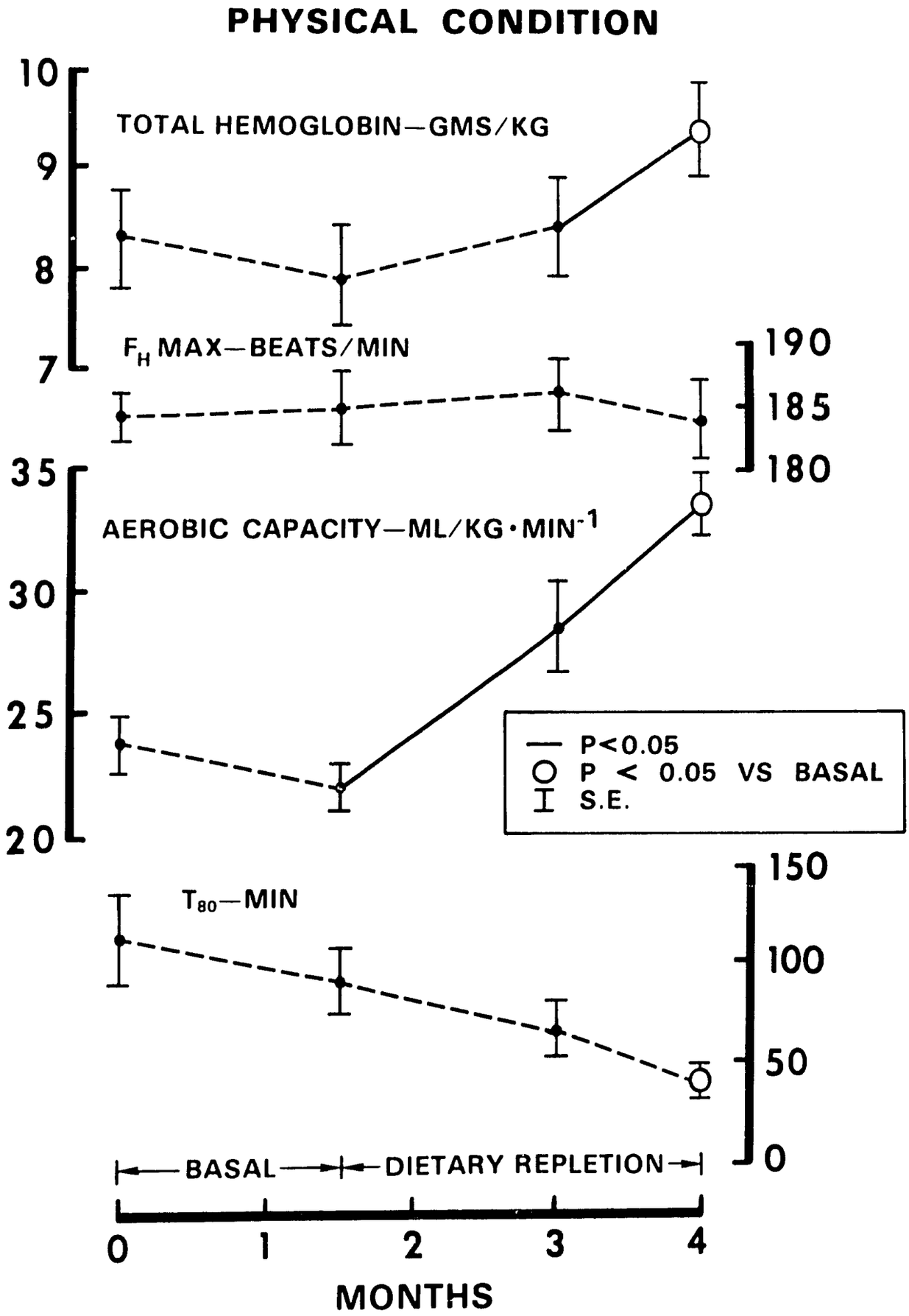

FIG. 24. Physical condition of 19 severely malnourished subjects during a 6 week basal period and during 2-1/2 months of protein repletion (100 gms/day).

TABLE 24

PHYSICAL CONDITION OF 19 SEVERELY UNDERNOURISHED MALE PATIENTS BEFORE AND DURING DIETARY REPLETION (100 GM PROTEIN/DAY)

	Basal Period		Nutritional Repletion	
Time in program (days)	0	45 ± 5	90 ± 6	124 ± 7
$\dot{V}_E$ max (L/min) (BTPS)[§]	73.19 ± 4.30	68.88 ± 3.88	91.89 ± 5.40*†	97.68 ± 4.51*†‡
$\dot{V}O_2$ max (L/min) (STPD)[§§]	1.04 ± 0.07	1.01 ± 0.05	1.45 ± 0.10*†	1.79 ± 0.08*†‡
Aerobic capacity (ml/kg·min^{-1})	23.9 ± 1.1	22.2 ± 0.8	28.7 ± 1.8*†	33.6 ± 1.3*†‡
Max heart rate (beats/min)	184 ± 2	185 ± 3	186 ± 3	184 ± 3
T_{80} (min)	113 ± 22	91 ± 21	68 ± 15	42 ± 8*†

*$P < 0.05$ vs. basal period 0

†$P < 0.05$ vs. basal period 45 days

‡$P < 0.05$ vs. nutritional repletion 90 days

§Body temperature, pressure, saturated

§§Standard temperature, pressure, dry

TABLE 25

BODY COMPOSITION OF 19 SEVERELY UNDERNOURSHED MALE PATIENTS BEFORE AND DURING DIETARY REPLETION (100 GM PROTEIN/DAY)

	Basal Period		Nutritional Repletion	
Time in program (days)	0	45 ± 5	90 ± 6	124 ± 7
Fat free weight (% body wt.)	80.2 ± 1.9	71.4 ± 2.0*	77.8 ± 1.7†	77.8 ± 2.0
Fat weight (% body wt.)	19.8 ± 1.9	28.5 ± 2.0*	22.2 ± 1.7†	22.2 ± 2.0
Fat free solids (% body wt.)	19.2 ± 0.5	16.9 ± 0.5*	20.1 ± 0.6†	20.6 ± 0.6
Body cell mass (% body wt.)	34.4 ± 1.5	27.4 ± 1.6*	37.0 ± 1.8†	38.5 ± 1.7
Cell solids (% body wt.)	7.8 ± 0.3	6.4 ± 0.3*	8.2 ± 0.4†	8.5 ± 0.3
Support tissue solids (% body wt.)	11.4 ± 0.2	10.5 ± 0.2*	11.9 ± 0.2†	12.2 ± 0.2
Muscle cell mass (% body wt.)	17.6 ± 0.7	15.9 ± 0.6*	20.3 ± 1.1*†	21.8 ± 0.9*†‡
Visceral cell mass (% body wt.)	16.9 ± 1.5	11.3 ± 1.8*	16.6 ± 1.8†	16.7 ± 2.0
Body fat (% body wt.)§	7.8 ± 0.3	8.1 ± 0.5	9.2 ± 0.5*†	9.9 ± 0.5*†
Lean body mass (% body wt.)§	92.2 ± 0.3	91.9 ± 0.5	90.8 ± 0.5*†	90.1 ± 0.5*†

*$P < 0.05$ vs. basal period 0

†$P < 0.05$ vs. basal period 45 days

‡$P < 0.05$ vs. nutritional repletion 90 days

§Derived from skinfold measurements

An interesting observation was the progressive decrease in maximum endurance times which achieved statistical significance after 2.5 months of repletion (Table 24, Fig. 24). Hansen (39) has reported reduced endurance times in rats receiving high protein diets and speculated that increased protein intake may substitude for carbohydrate and therefore compromise muscle structure and metabolism. This observation deserves more detailed study. Something similar may be occurring in our subjects receiving high protein (100 gms/day) in their diet.

Fig. 25 summarizes the results of the findings on body fluid compartments and shows a decrease in total body water which is largely due to a decreased extracellular fluid volume with little change in intracellular water.

Table 25 presents the calculations of body composition obtainable from information on body fluid compartments (27). The most marked changes observed were those in muscle cell mass. The results shown in Table 25 will have to be subjected to a more detailed analysis than is possible in this report before drawing firm conclusions. The discrepancies observed in body fat composition and lean body mass when calculated using body fluid compartments and the values obtained by the skinfold method will have to be specially scrutinized.

Table 26 presents the vitamins and transferrin responses to nutritional repletion in 13 of the subjects.

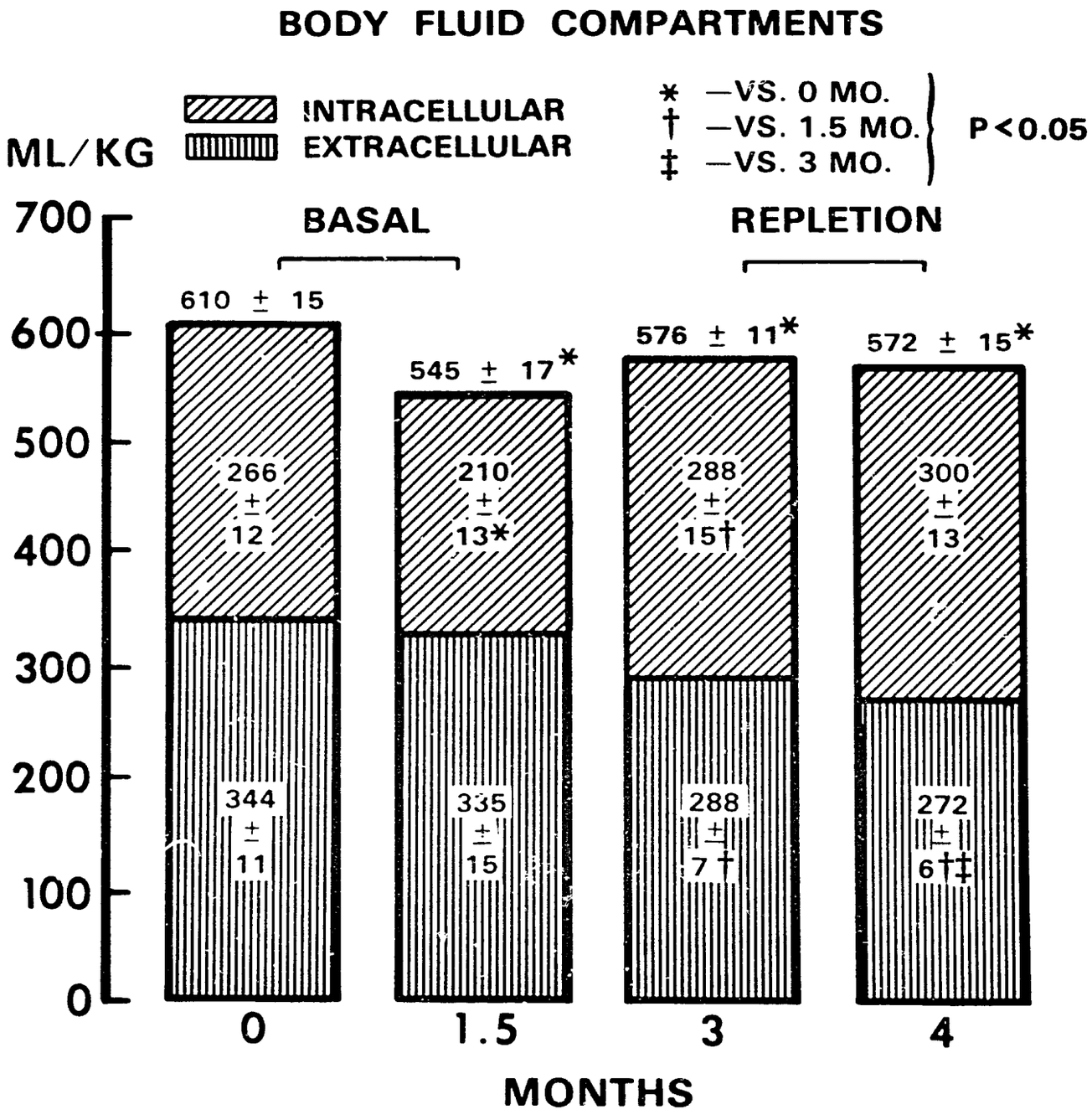

FIG. 25. Body fluid compartments of 19 severely malnourished subjects during a 6 week basal period and during 2-1/2 months of protein repletion (100 gms/day).

TABLE 26

VITAMIN AND TRANSFERRIN RESPONSES TO NUTRITIONAL REPLETION

Subject	Blood Folic Acid (ng/ml)				Per Cent Transferrin				Vitamin B_{12} (pcg/ml)			
	Basal Period		Nutritional Repletion		Basal Period		Nutritional Repletion		Basal Period		Nutritional Repletion	
	Begin	End*	1.5 mos	2.5 mos	Begin	End*	1.5 mos	2.5 mos	Begin	End*	1.5 mos	2.5 mos
V.N.	---	1.2	2.4	2.3	---	16.35	8.5	2.46	---	600	625	625
R.U.	3.0	15.5	7.3	4.5	27.95	51.13	18.1	12.85	260	175	350	265
R.C.	5.1	7.2	---	4.8	44.66	49.32	19.6	9.34	610	590	---	444
I.M.	5.9	---	1.3	2.2	11.1	---	42.88	23.60	625	815	700	501
M.Ch.	5.8	---	9.8	10.1	33.33	---	17.81	9.98	135	121	200	185
D.M.	4.0	3.8	2.5	6.0	33.33	32.42	13.19	45.39	305	375	760	200
H.R.	1.8	7.0	>1.0	5.0	11.6	36.92	32.88	---	>900	>900	455	339
L.O.	9.3	15.0	7.4	10.2	16.59	46.61	---	28.94	376	290	900	250
G.C.	---	6.4	---	---	---	---	23.21	---	---	704	---	---
A.U.	7.6	4.0	6.0	3.2	---	---	14.03	19.16	408	>1000	745	659
F.M.	10.4	6.3	1.7	11.6	---	54.16	33.33	19.15	365	---	>1000	860
F.T.	3.9	1.2	4.3	4.7	9.21	---	17.81	30.98	432	167	>1000	515
J.V.C.	4.0	8.1	---	3.8	35.68	23.83	---	---	237	>1000	---	688

*1.5 mos after beginning basal period

II. PRODUCTIVITY STUDIES (SUGAR CANE WORKERS)

(A) Sugar Cane Cutters

(1) Nutritional Status

Table 27 presents the results of the analyses for serum albumin, total proteins, hematocrit and hemoglobin in 33 of the cutters. The means, standard deviations and ranges of estimated daily dietary intakes of 27 sugar cane cutters are presented in Table 28.

(2) Productivity

The productivity of each cutter was obtained from the company records. The values are daily averages for July, August and September of 1972 or 1973, the months during which the subjects were measured. The productivity data of three of the cutters were equivocal and are not included in the results of the remaining 58, illustrated in Fig. 26.

Daily productivity varied from 2.12 to 5.22 tons/day with an average of 3.52 ± 0.72 tons/day. The sugar processing company, as well as the men themselves, classify cutters as good, average or poor--based on their productivity. The men were therefore divided into three groups. Group I consisted of 13 top producers cutting in excess of 4 tons/day with a daily average of 4.48 ± 0.37 tons/day. Group II was composed of 28 men cutting 3-4 tons/day with an average of 3.62 ± 0.24 tons/day, while Group III was made up of the 17 lowest producers (2-3 tons/day), having a daily output of 2.63 ± 0.29 tons/day. In some of the data to be presented, the results obtained on the three men who did not have reliable productivity data were placed in Group II, on the basis that the field boss judged them to be "average" producers. The productivity and energy cost data are based on the cutting of green, unburned cane.

(3) Anthropometric Data

The physical characteristics of the subjects are presented in Table 29. There were no statistically significant differences among groups

TABLE 27

MEANS AND STANDARD DEVIATIONS OF BLOOD AND SERUM VALUES IN 33 SUGAR CANE CUTTERS 4-5 HOURS POSTABSORPTIVELY

	Mean ± S.D.	Range
Total proteins (gm %)	7.55 ± 0.28	7.00 - 8.20
Serum albumin (gm %)	4.21 ± 0.27	3.70 - 4.70
Blood hemoglobin (gm %)	14.1 ± 1.3	12.0 - 16.5
Hematocrit (%)	44.9 ± 3.8	38.0 - 53.0

TABLE 28

ESTIMATED DAILY DIETARY INTAKE OF 27 SUGAR CANE CUTTERS

	Mean ± S.D.	Range
Protein		
gm	73 ± 11	50 - 83
gm/kg*	1.22 ± 0.21	0.84 - 1.61
Total kcal (%)	10.2 ± 1.5	6.9 - 14.1
Animal (%)	36 ± 8	14 - 58
Vegetable (%)	64 ± 8	42 - 86
Fat		
gm	45 ± 12	25 - 75
gm/kg*	0.76 ± 0.22	0.44 - 1.36
Total kcal (%)	14.4 ± 4.3	8.7 - 27.4
Carbohydrate		
gm	546 ± 129	313 - 948
gm/kg*	9.19 ± 2.19	5.36 - 11.16
Total kcal (%)	75.3 ± 5.5	59.8 - 83.2
Calories		
kcal	2970 ± 564	1855 - 4676

*Per kilogram body weight

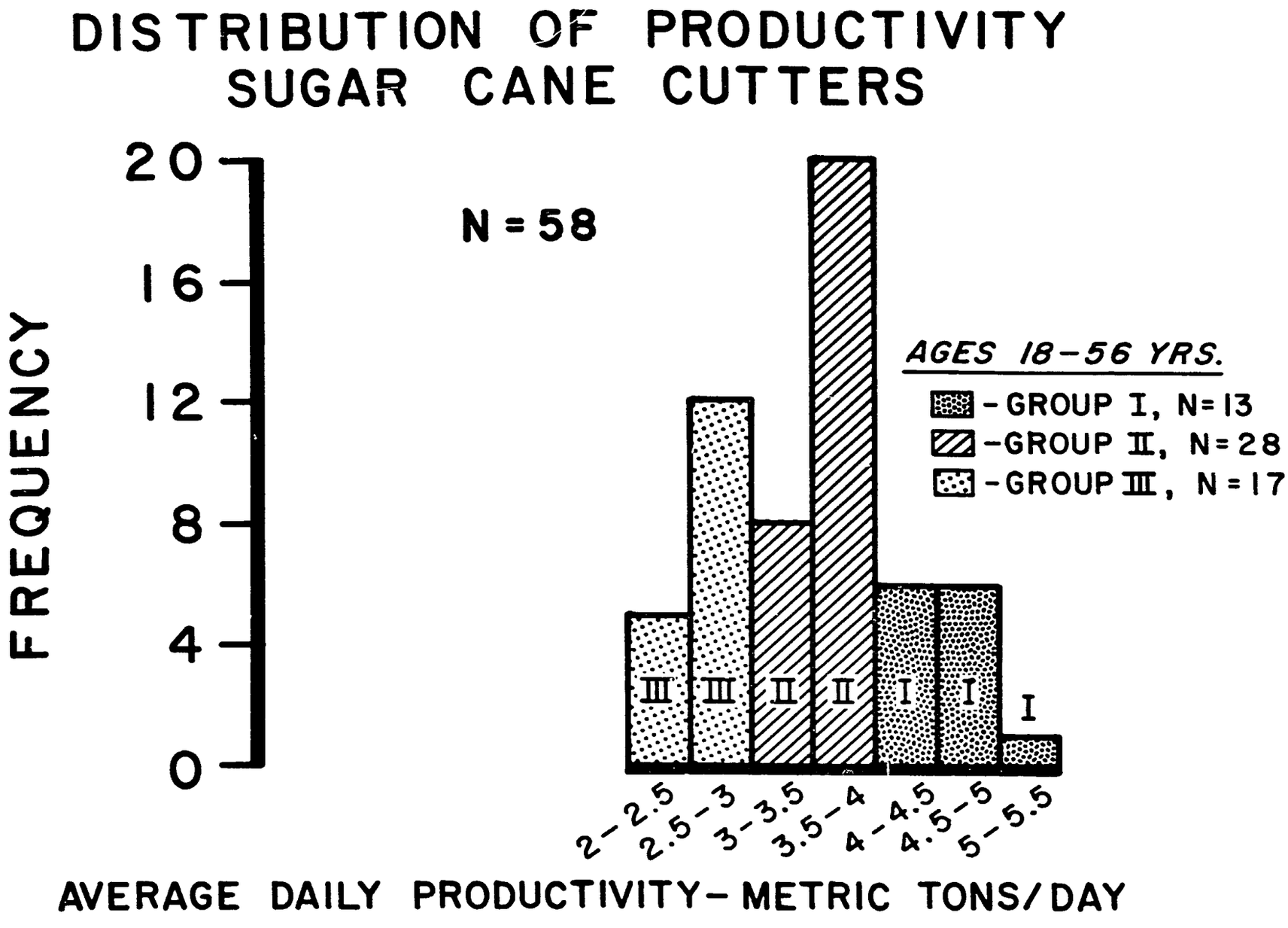

FIG. 26. Productivity of sugar cane cutters at Central Castilla, Ltda., Colombia, in July, August and September of 1972 and 1973.

TABLE 29

PHYSICAL CHARACTERISTICS OF SUGAR CANE CUTTERS

	Age	Height	Weight	Weight/Height	Body Fat		Lean Body Mass	
	Years	cm	kg	kg/m*	%	kg/m*	kg	kg/m*
				Group I (n = 13)				
Mean	32.5	168.8	62.5	36.6	10.2	3.8	55.9	32.6
S.D.	8.2	6.5	6.9	3.5	1.6	0.9	5.9	2.8
				Group II (n = 29)				
Mean	29.3	162.9†	58.0†	35.5	9.9	3.5	52.3	32.0
S.D.	6.4	5.5	5.3	2.6	1.1	0.6	4.5	2.2
				Group III (n = 17)				
Mean	28.6	159.8†	56.7†	35.4	11.2‡	4.0	50.3†	31.4
S.D.	6.1	6.4	7.4	3.6	2.1	1.2	5.7	2.6
				Total (n = 59)				
Mean	29.8	163.3	58.6	35.7	10.3	3.7	52.5	32.0
S.D.	6.7	6.7	6.5	3.1	1.6	0.9	5.4	2.4

*Height in meters

†$P \leq 0.05$ compared to Group I

‡$P < 0.05$ compared to Group II

in age, weight/height ratios, or lean body mass expressed in terms of height. However, the better producers tended to be larger men. The men in Group I were significantly taller ($P < 0.01$) than those in Groups II and III, although the latter were not different from each other. The same tendency is seen in body weight and lean body mass expressed in kg (Table 29). The percent body fat was significantly higher ($P < 0.02$) in Group III than in Group II. This statistically significant difference disappeared when fat weight was expressed in terms of height.

(4) Ventilation, Oxygen Consumption and Heart Rates

The results of the measurements of $\dot{V}_E$, $\dot{V}_{O_2}$ and cardiac frequency (f_H) are illustrated in Fig. 27 for the three groups of subjects. There were no statistically significant differences among the groups and, with the exception of resting heart rates ($P < 0.05$), there were no differences between AM and PM measurements. Table 30 presents a statistical summary of these data, together with the oxygen pulse and ventilation equivalent. Heart rates averaged about 135 beats/min, $\dot{V}_{O_2}$ approximately 1.5 L/min (STPD), and $\dot{V}_E$ about 48 L/min (BTPS) while cutting sugar cane. The oxygen pulse was elevated to about 11 ml/min/beat and the ventilation equivalent fell significantly during work, indicating a relative hyperventilation at rest.

Utilizing the resting and the 5- and 20-min values for heart rate (f_H) and $\dot{V}_{O_2}$, a least squares regression line was calculated for each subject in the AM and in the PM. A heart rate at $\dot{V}_{O_2}$ = 1.5 L/min (the approximate average level of work) was calculated using the equations obtained. The results of this analysis are presented in Fig. 28. The slopes were significantly less in the PM than in the AM in Group I ($P < 0.05$) and in Groups II and III ($P < 0.004$). In addition, there was a progressive increase in slope, both in the AM ($P < 0.05$) and in the PM ($P < 0.01$), as the average productivity decreased from Group I to Group III (right insert, Fig. 28). The intercepts were significantly elevated ($P < 0.003$) in all

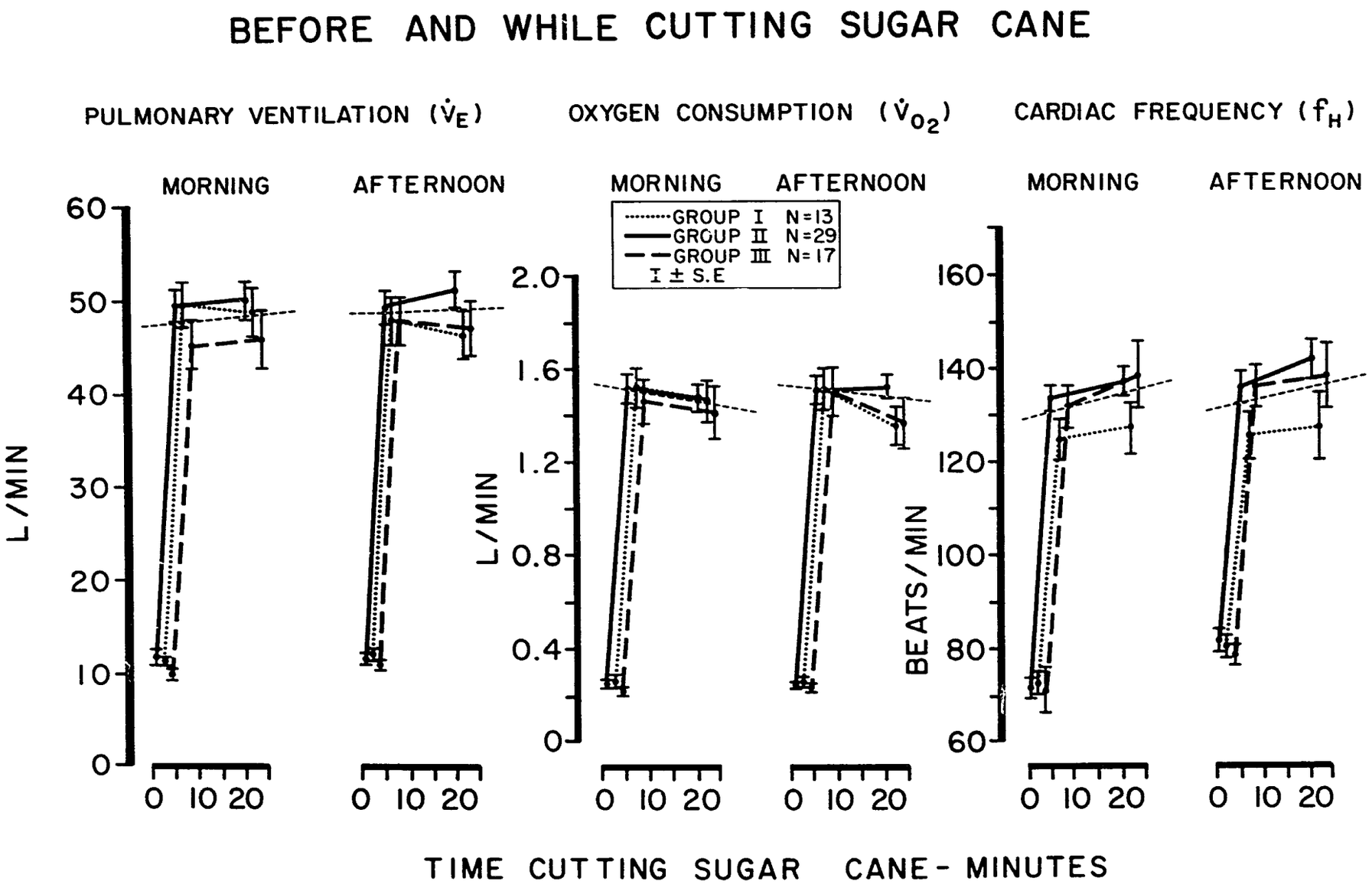

FIG. 27. Physiological responses during sugar cane cutting in the morning and afternoon in three groups of cutters classified as good (Group I), average (Group II) and poor (Group III) producers. The dashed lines are through the averages of the 5- and 20-min meaurements.

TABLE 30 (continued)

		Morning ($\overline{T}_a$ = 24.6°C)			Afternoon ($\overline{T}_a$ = 30.2°C)		
		Cutting Cane*			Cutting Cane*		
		Rest	5 min	20 min	Rest	5 min	20 min
Pulmonary	n	59	58	54	57	57	50
Ventilation	Mean	11.12	48.35	48.66	11.31	48.42	48.77
($\dot{V}_E$)	S.D.	3.58	9.70	10.28	2.36	9.12	10.02
L/min BTPS§	Range	7.02-32.33	27.33-70.23	28.03-70.40	6.33-18.66	30.53-68.66	27.89-70.73
Ventilation	n	58	57	51	54	54	48
Equivalent	Mean	4.60	3.28	3.41	4.71	3.27	3.50
($\dot{V}_E$/100 cc $\dot{V}_{O_2}$)	S.D.	0.84	0.39	0.45	1.04	0.35	0.43
	Range	2.46-6.22	2.23-4.02	2.27-4.14	2.66-7.30	2.17-4.02	2.71-5.03

*All values while cutting cane are significantly different from values at rest; $P < 0.05$

†Significantly different from comparable value in morning; $P < 0.001$

‡Standard temperature and pressure, dry

§Body temperature, ambient pressure, saturated

$\overline{T}_a$ = mean air temperature

TABLE 30

PHYSIOLOGICAL RESPONSES WHILE CUTTING SUGAR CANE

		Morning ($\bar{T}_a$ = 24.6°C)			Afternoon ($\bar{T}_a$ = 30.2°C)		
		Cutting Cane*			Cutting Cane*		
		Rest	5 min	20 min	Rest	5 min	20 min
Cardiac	n	59	57	48	56	52	40
Frequency	Mean	72	131	135	80†	133	137
(f_H)	S.D.	10	16	20	10	17	20
Beats/min	Range	55-97	103-165	101-172	59-110	96-172	96-179
Oxygen	n	58	57	52	55	55	49
Consumption	Mean	0.25	1.50	1.46	0.25	1.51	1.44
($\dot{V}O_2$)	S.D.	0.09	0.34	0.34	0.07	0.34	0.31
L/min STPD‡	Range	0.15-0.61	0.85-2.74	0.85-2.52	0.11-0.46	0.93-2.68	0.94-2.42
Oxygen	n	58	55	46	54	50	38
Pulse	Mean	3.53	11.45	10.70	3.11	11.27	10.59
($\dot{V}O_2/f_H$)	S.D.	1.27	2.26	2.34	0.81	2.07	1.79
ml/min/beat	Range	1.85-8.73	8.11-17.70	7.08-19.21	1.50-5.81	7.75-16.42	6.98-14.54

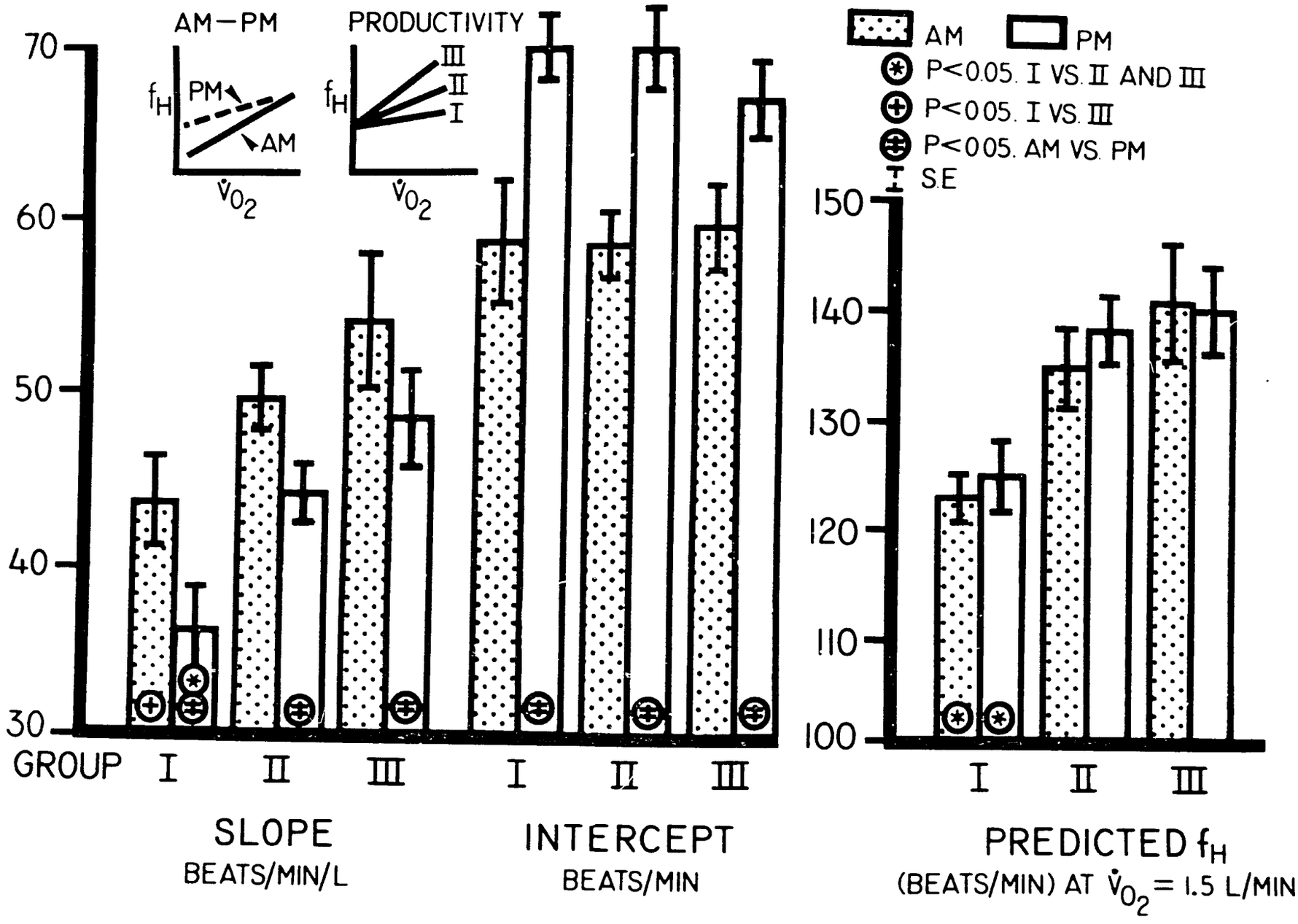

FIG. 28. Slopes and intercepts of the regression of heart rate (f_H) on $\dot{V}_{O_2}$ during sugar cane cutting in good, average and poor producers (Groups I, II and III, respectively). Predicted f_H at $\dot{V}_{O_2}$ = 1.5 L/min calculated from the regression lines.

three groups of cutters in the PM, but exhibited no statistically significant differences among the subject groups in the AM or PM (left insert, Fig. 28 The predicted heart rates at a $\dot{V}_{O_2}$ of 1.5 L/min are also shown in Fig. 28. It can be seen that there were no statistically significant differences between AM and PM values, but that heart rates were significantly lower ($P < 0.03$) in the good cutters at this work level and became progressively higher as the group productivity decreased. The average estimated heart rates were 123 ± 9, 133 ± 17, and 141 ± 20 per min in the AM and 125 ± 11, 137 ± 16, and 140 ± 14 in the PM for Groups I, II and III, respectively.

The average oxygen debts for the five men in whom they were measured were 1.09 ± 0.34 liters in the AM and 0.70 ± 0.35 liters in the PM ($P < 0.20$). For the 25-min work periods these values amounted, on the average, to only 44 and 28 ml/min, respectively, or less than 3% of the aerobic $\dot{V}_{O_2}$ determinations.

(5) Energy Expenditure

The energy expenditure of 61 men cutting cane was calculated from the $\dot{V}_{O_2}$, utilizing 5.047 kcal/L as the caloric equivalent and expressed as kcal/min. There were no signficant differences between the 5- and 20-min measurements, between AM and PM values, nor among the three groups of subjects (Fig. 29). The four values for each man were then averaged. The mean and standard deviations for all 61 men were 7.4 ± 1.5 kcal/min (range 4.5-12.4 kcal/min).

The weight of the cane collected during each measurement in the field was expressed as kilograms of cane cut per hr (Fig. 30). It can be seen that the rate of cane cutting tended to be higher in the PM, and this was statistically significant in Group II ($P < 0.001$). Since there were no statistically significant differences among the three groups, the data were averaged and showed that the rate of cane cutting increased significantly from 686 ± 181 kg/hr in the AM to 762 ± 191 kg/hr in the PM ($P < 0.001$).

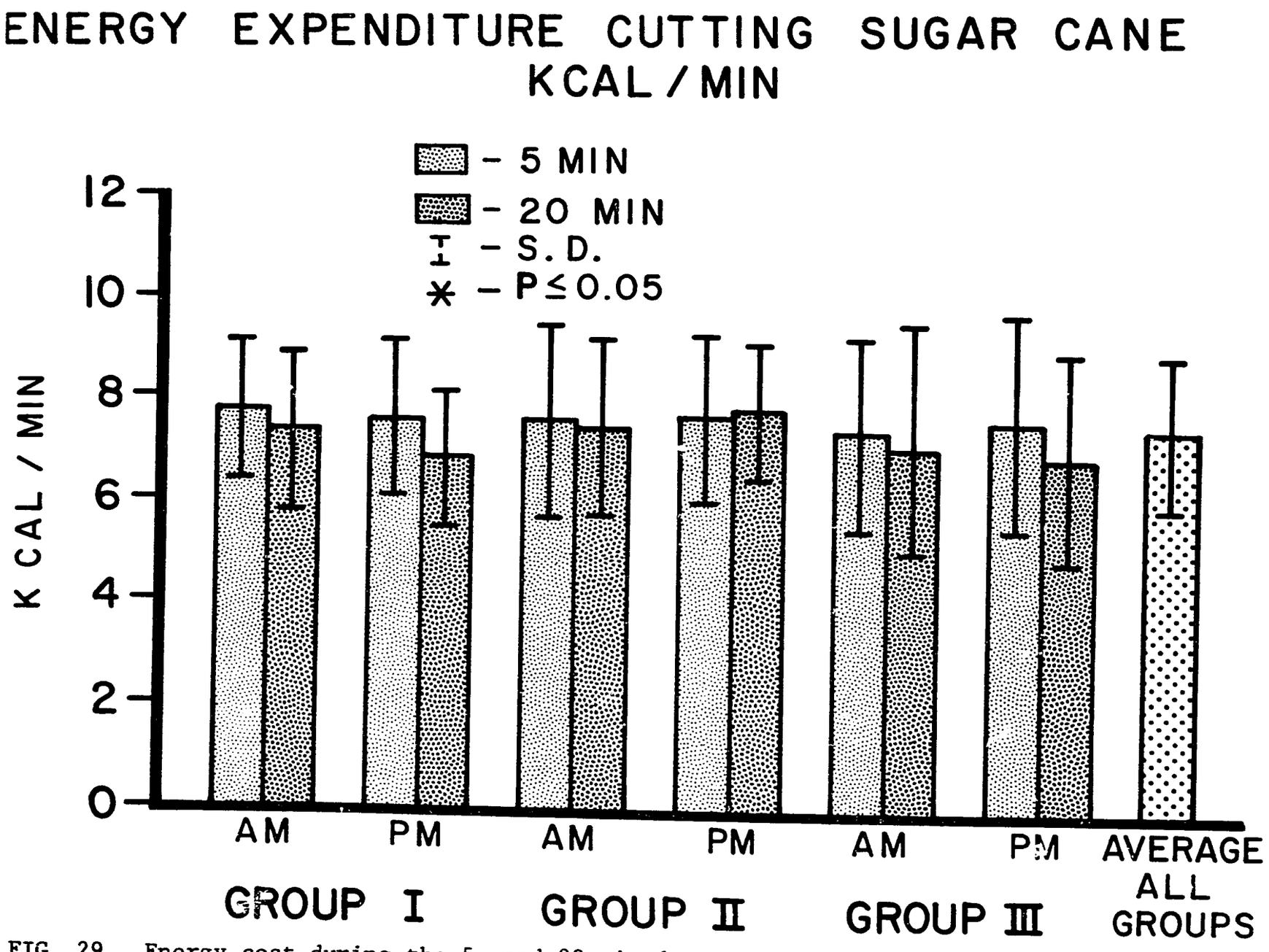

FIG. 29. Energy cost during the 5- and 20-min determinations while cutting sugar cane in the morning and afternoon; N = 61.

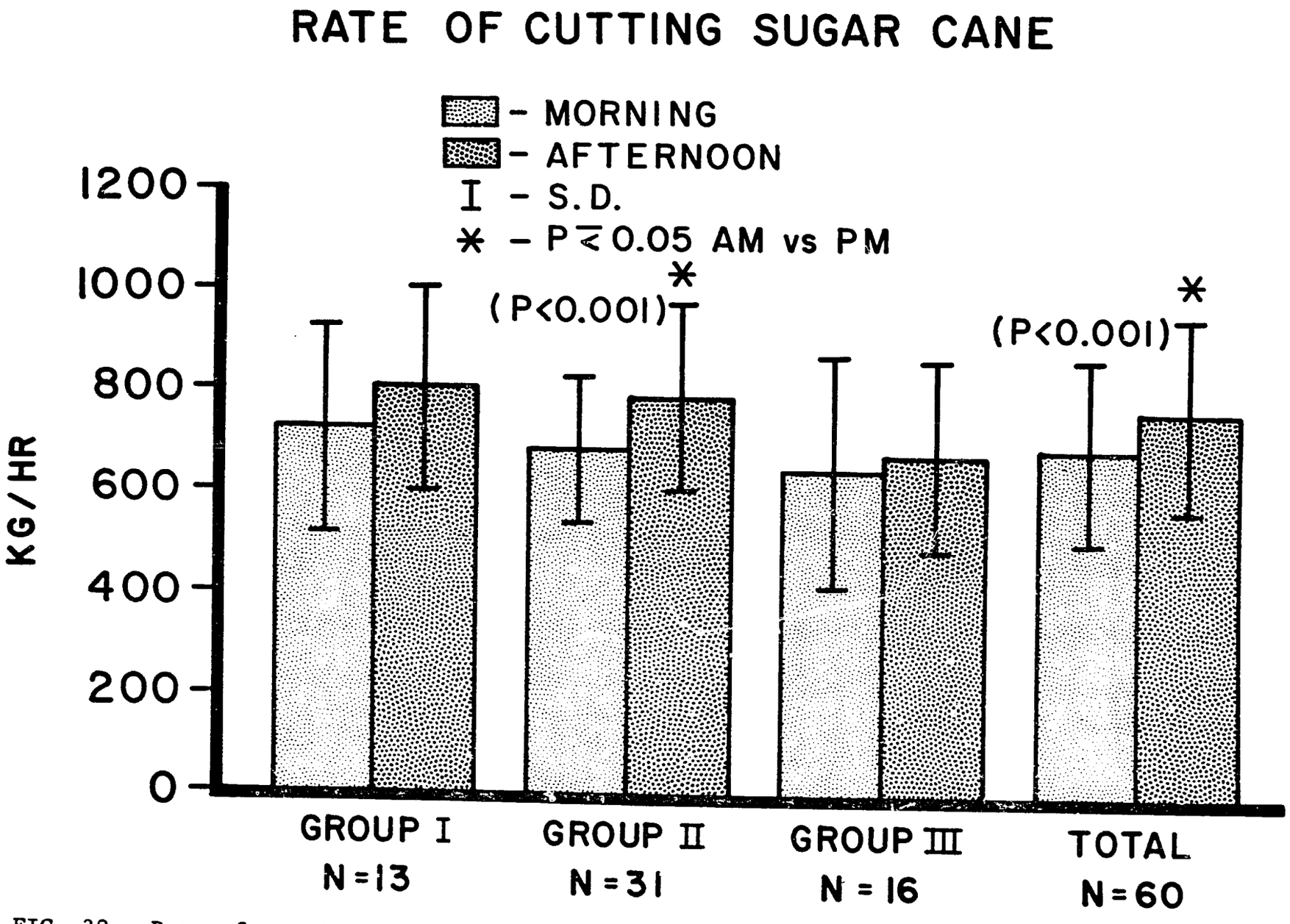

FIG. 30. Rate of cutting sugar cane in the morning and afternoon of good, average and poor producers (Groups I, II and III, respectively). No statistically significant differences exist among groups.

The energy expenditure (kcal) per kilogram of sugar cane cut was calculated from the $\dot{V}_{O_2}$ and the cane weight as an expression of efficiency and is presented in Fig. 31. The mean values in the PM were less in all three groups, and this was statistically significant in Group II ($P < 0.001$). Since there were no statistically significant differences among the groups, the data were averaged and demonstrated a statistically significant decrease in caloric expenditure per kilogram of cane from 0.676 ± 0.159 kcal/kg in the AM to 0.616 ± 0.147 kcal/kg in the PM ($P < 0.001$), an increase in efficiency of about 9%. Using the daily productivity for each man and the average of his AM and PM values for efficiency (kcal/kg of cane cut), it is possible to estimate the daily caloric expenditure for each man cutting sugar cane. For the working day this averaged 2254 ± 562 kcal/8 hr.

The percent $\dot{V}_{O_2}$ max which the men were utilizing during the four measurement periods was calculated from the $\dot{V}_{O_2}$ determined in the field and the $\dot{V}_{O_2}$ max measured in the laboratory (2.63 ± 0.37 L/min, 45.2 ± 5.2 ml/kg min^{-1}). The results in 55 cutters are shown on the left in Fig. 32. The values were 57.4 ± 13.6% and 56.3 ± 13.4% during the 5- and 20-min measurements in the AM and 57.7 ± 12.9 and 56.2 ± 11.2 during the same periods in the PM. There were no significant differences between AM and PM. These values are considered higher than can be sustained for an 8-hr workday (7, 40). Furthermore, it can be calculated from the rates of cane cutting (Fig. 30) that, if the men had sustained these rates for 8 hr, their daily productivities would be much higher than they were. Knowing the average daily productivity and the $\dot{V}_{O_2}$ per kilogram of cane cut, the oxygen cost of the daily productivity of each worker can be calculated and expressed as estimated percent $\dot{V}_{O_2}$ max that would have to be sustained during an 8-hr workday. These results are presented on the right in Fig. 32. Using the $\dot{V}_{O_2}$ values observed during the four measurement periods, the values obtained were 37.4 ± 11.0% and 36.4 ± 10.1% during the 5- and 20-min determinations, respectively, in the AM and 34.5 ± 9.4% and 32.3 ± 8.9% during the same measurements in the PM. The differences

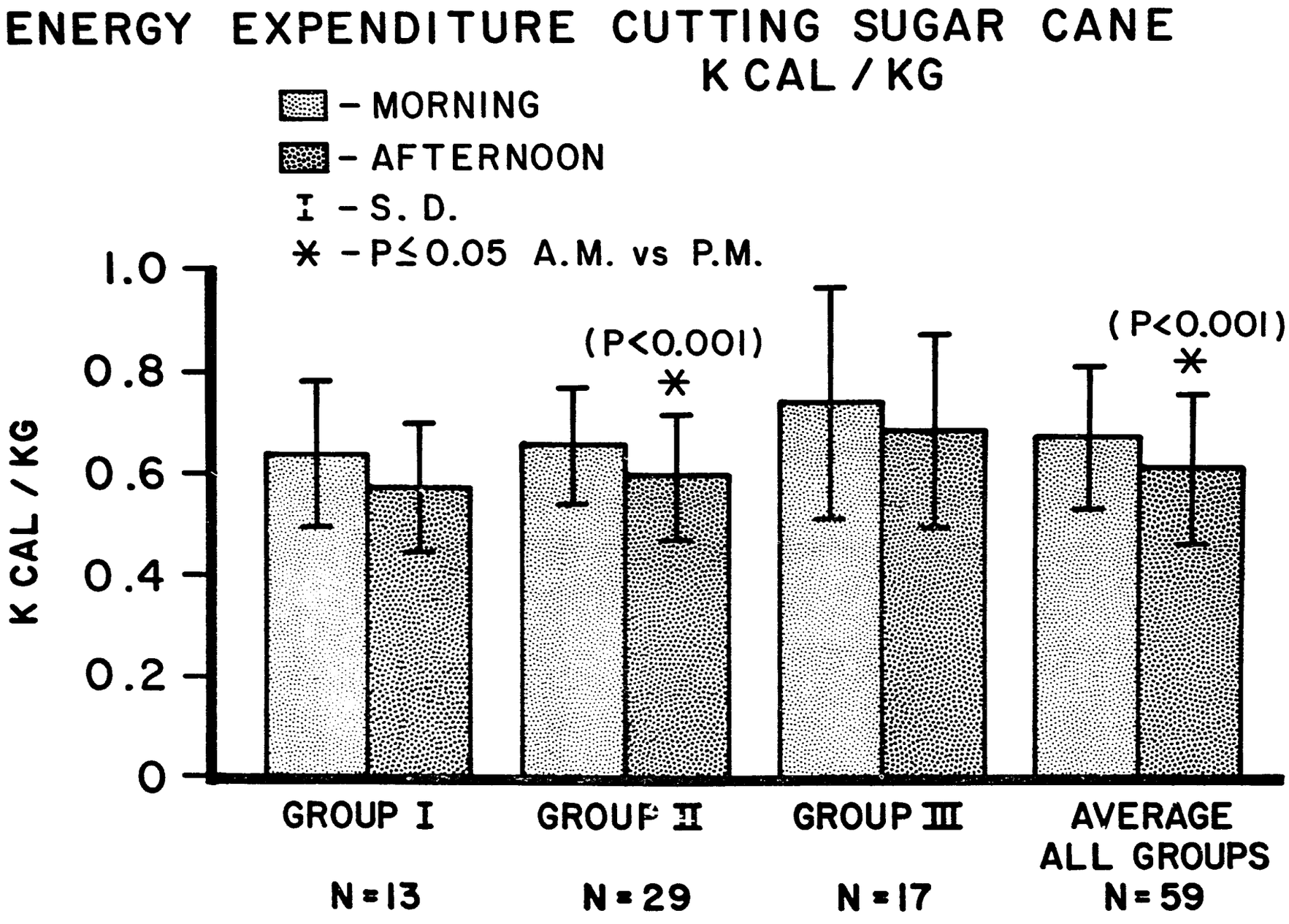

FIG. 31. Efficiency expressed in terms of kcal/kg of cane cut in the morning and afternoon by good, average and poor producers (Groups I, II and III, respectively). No statistically significant differences exist among groups.

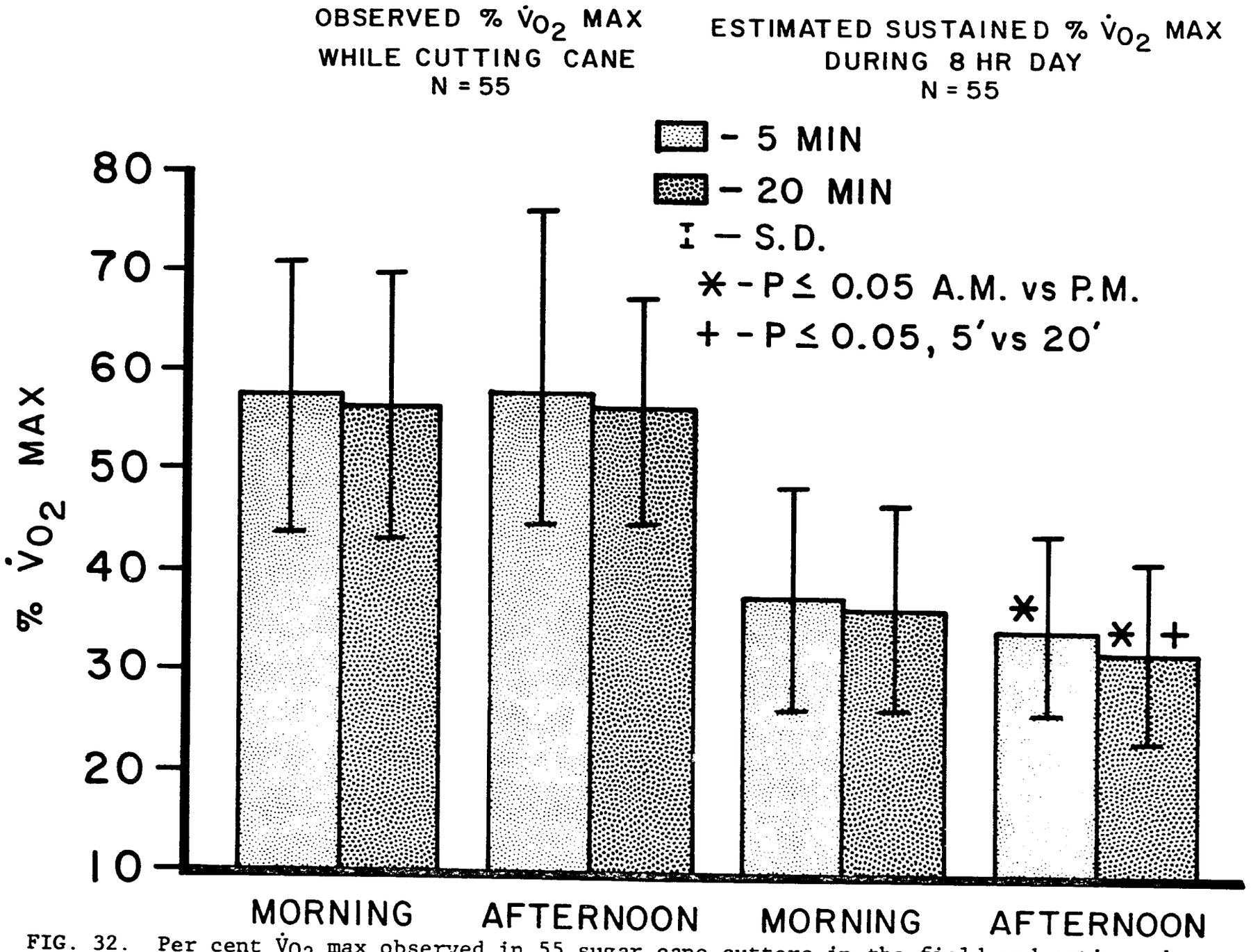

FIG. 32. Per cent $\dot{V}O_2$ max observed in 55 sugar cane cutters in the field and estimated per cent $\dot{V}O_2$ max which can be sustained for 8 hr, calculated from the energy cost/kg of cane cut (Fig. 31) and productivity of each subject for the 5- and 20-min measurements in the morning and afternoon.

between AM and PM were statistically significant ($P < 0.05$), indicating a slightly decreased effort as the day progressed.

(6) Sweat Rates

The sweat rates for the 20 individuals in whom they were measured averaged 0.80 ± 0.34 kg/hr (15.18 ± 6.24 gm/kg/hr) in the AM and 1.26 ± 0.50 kg/hr (22.25 ± 8.20 gm/kg/hr) in the PM. Ambient air temperatures for each group and each determination are shown in Table 31. The difference between AM and PM was statistically significant ($P < 0.01$). Ambient air temperatures averaged 24.6 ± 3.4°C in the AM and 30.2 ± 2.9°C in the PM ($P < 0.001$). Relative humidity was 76 ± 14% in the AM and 47 ± 14% in the PM ($P < 0.001$).

The above figures for sweat rates were obtained during the approximate 25 min allowed for each test. Since it is evident from the rate of cane cutting (Fig. 30) that the men worked at a higher rate during the measurement periods than they sustained all day, it follows that the sweat rates were higher. Utilizing the ratio of the estimated sustained percent $\dot{V}_{O_2}$ max to measured percent $\dot{V}_{O_2}$ max (35.2/56.9 = 0.62), utilized in cutting cane (Fig. 32) and the measured sweat losses, it was possible to calculate an estimated sustained rate of sweating during the AM and PM work periods and from this to estimate an 8-hr sweat loss. The AM sweat rate, corrected in this manner, was 0.57 ± 0.22 kg/hr (10.4 ± 4.2 gm/kg/hr) and 0.77 ± 0.28 kg/hr (13.8 ± 4.6 gm/kg/hr) in the PM. This amounted to about 5 kg/8-hr workday in the 18 men for whom values were available.

The men carry water jugs into the field and refill them at intervals during the day. No measurements of water intake were made. However, body weights prior to beginning the field tests were available on 25 of the men. These averaged 56.86 ± 5.82 kg in the AM and 56.74 ± 5.79 in the PM, and the difference was not statistically significant. Because seven of these subjects were measured shortly after their noon meal, only

TABLE 31

AMBIENT AIR TEMPERATURES (°C) DURING WORK TESTING IN SUGAR CANE CUTTERS

		Morning			Afternoon		
		Rest	5 min	20 min	Rest	5 min	20 min
Group I	Mean	23.7	24.6	25.3	31.5*	31.7*	31.2*
	S.D.	3.1	3.6	3.6	2.8	3.4	3.5
Group II	Mean	23.9	24.7	25.1	30.3*	30.3*	30.4*
	S.D.	2.6	3.0	3.4	2.2	2.2	2.5
Group III	Mean	24.3	24.7	24.9	28.9*	29.1*	29.5*
	S.D.	3.6	4.0	4.2	2.7	3.0	3.4

*Significantly different from comparable values in the morning ($P < 0.02$)

the 18 whose weights were obtained after 2 PM were compared. These were 57.38 ± 6.22 kg in the AM and 57.10 ± 6.15 in the PM, and the difference was just statistically significant ($P < 0.04$).

(7) Activity Levels

Using the activity level classifying system presented by Saltin and Grimby (33), the men were categorized into one of four groups. All were classified in Group IV (heavy physical labor) for the occupational activity. Forty were in Group I (almost completely inactive), 18 in Group II (some physical activity during at least 4 hr per week) and one in Group III (regular activity) for their spare time physical activity. There was no relation between leisure time activity and productivity.

(8) Productivity and $\dot{V}_{O_2}$ max

Productivity data and valid $\dot{V}_{O_2}$ max determinations (37) were obtained in 54 sugar cane cutters 18 to 56 years of age. Because of the known decrease of aerobic capacity with age (30, 41) the data on the 8 subjects older than 34 were not included in the following analyses.

There was a statistically significant negative correlation between aerobic capacity and age of the 46 subjects in this study ($r = -0.31$; $P < 0.05$). The regression line was

$$\text{Aerobic capacity } (\text{ml/kg} \cdot \text{min}^{-1}) = 56.32 - 0.379 \cdot (\text{Age})$$

There is therefore a predicted decrease in aerobic capacity of 0.38 $\text{ml/kg} \cdot \text{min}^{-1}$ per year in subjects 18 to 34 years of age.

The productivity of the subjects varied between 2.15 and 4.79 metric tons/day and averaged 3.45 ± 0.69 tons/day. The subjects were divided into three groups based on their productivity. Group I consisted of 8 producers cutting in excess of 4 tons/day (4.45 ± 0.28 tons/day). Group II was made up of 23 subjects cutting 3 to 4 tons/day (3.64 ± 0.25 tons/day), while Group III was composed of 15 subjects who cut less than 3 tons/day (2.63 ± 0.29 tons/day).

Utilizing the energy cost of cutting sugar cane, the average daily productivity and the $\dot{V}_{O_2}$ max, it was possible to calculate an estimated percent of $\dot{V}_{O_2}$ max which had to be sustained during the 8-hr workday to cut the amount of cane reported for each individual. It was shown that the subjects maintained an average of about 35% of the $\dot{V}_{O_2}$ max during the workday (42). Productivity was not significantly correlated with age (Fig. 33), but there was a statistically significant correlation between age and the estimated sustained percent $\dot{V}_{O_2}$ max ($r = 0.43$; $P < 0.01$).

The data on the physical characteristics of 59 subjects by productivity groups have been presented previously (42). Fig. 33 summarizes these data for the subjects 18 to 34 years of age and, in addition, presents the correlation analyses of these variables with daily productivity. It shows that productivity is positively related to height, weight and lean body mass, negatively to body fat, and that age does not appear to be a factor in the producitivity of sugar cane cutters.

Figure 34 presents the $\dot{V}_{O_2}$ max (liters/min) and aerobic capacity (ml/kg · min^{-1}) data for the three productivity groups and shows the correlation analyses with daily productivity. The correlation of productivity with $\dot{V}_{O_2}$ max and aerobic capacity is statistically significant. The correlations of productivity with $\dot{V}_{O_2}$ max after normalization for height, lean body mass and body surface area were 0.446 ($P < 0.002$), 0.353 ($P < 0.02$), and 0.419 ($P < 0.005$), respectively. Figs. 35 and 36 show the regression-correlation analyses of productivity and $\dot{V}_{O_2}$ max.

A stepwise multiple regression analysis was done of productivity with body weight, height, surface area and percent fat, fat weight (kg), lean body mass (kg), $\dot{V}_{O_2}$ max (liter/min and per kg body weight and lean body mass), maximum heart rate and estimated sustained $\dot{V}_{O_2}$ max. The results (Table 32) showed that only $\dot{V}_{O_2}$ max (liters/min), height (cm), and percent body fat contributed significantly to explain the variations of productivity in the following relationship;

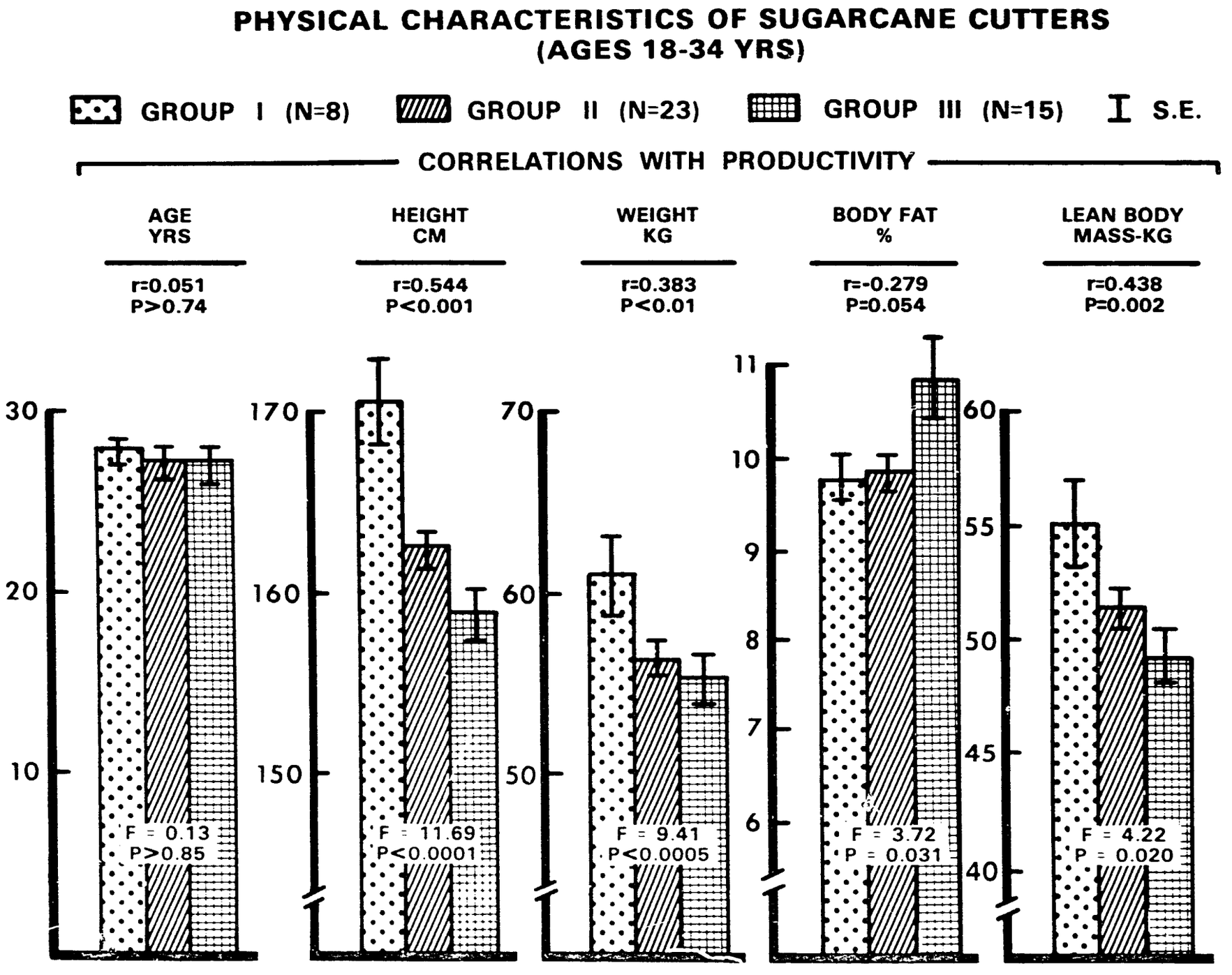

FIG. 33. Physical characteristics of good (Group I), average (Group II) and poor (Group III) sugar cane cutters and their relationships to productivity. F-ratio values are from a one-way analysis of variance.

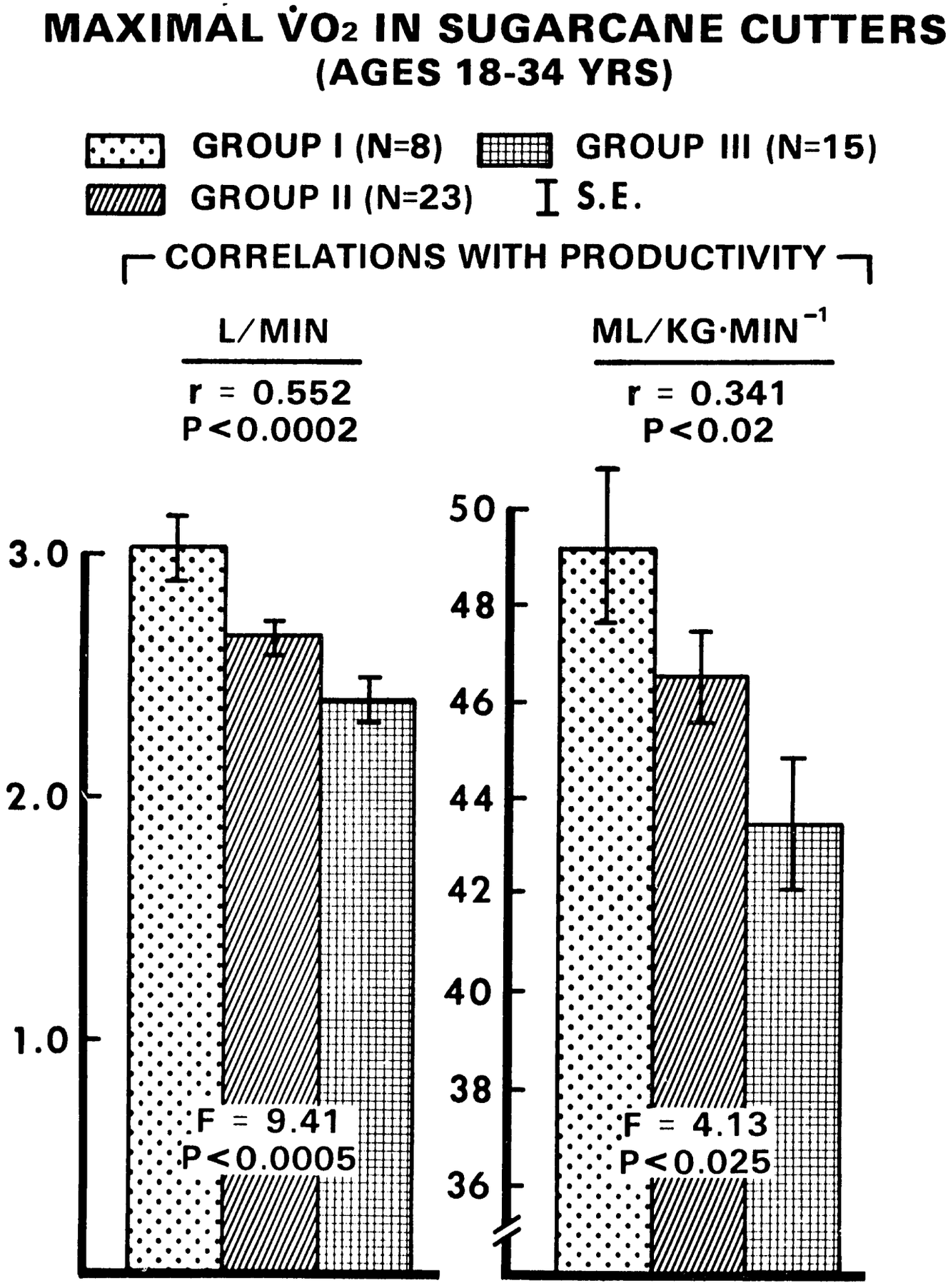

FIG. 34. $\dot{V}O_2$ max (L/min) and aerobic capacity (ml/kg·min^{-1}) of good (Group I), average (Group II) and poor (Group III) sugar cane cutters. F-ratio values are from a one-way analysis of variance.

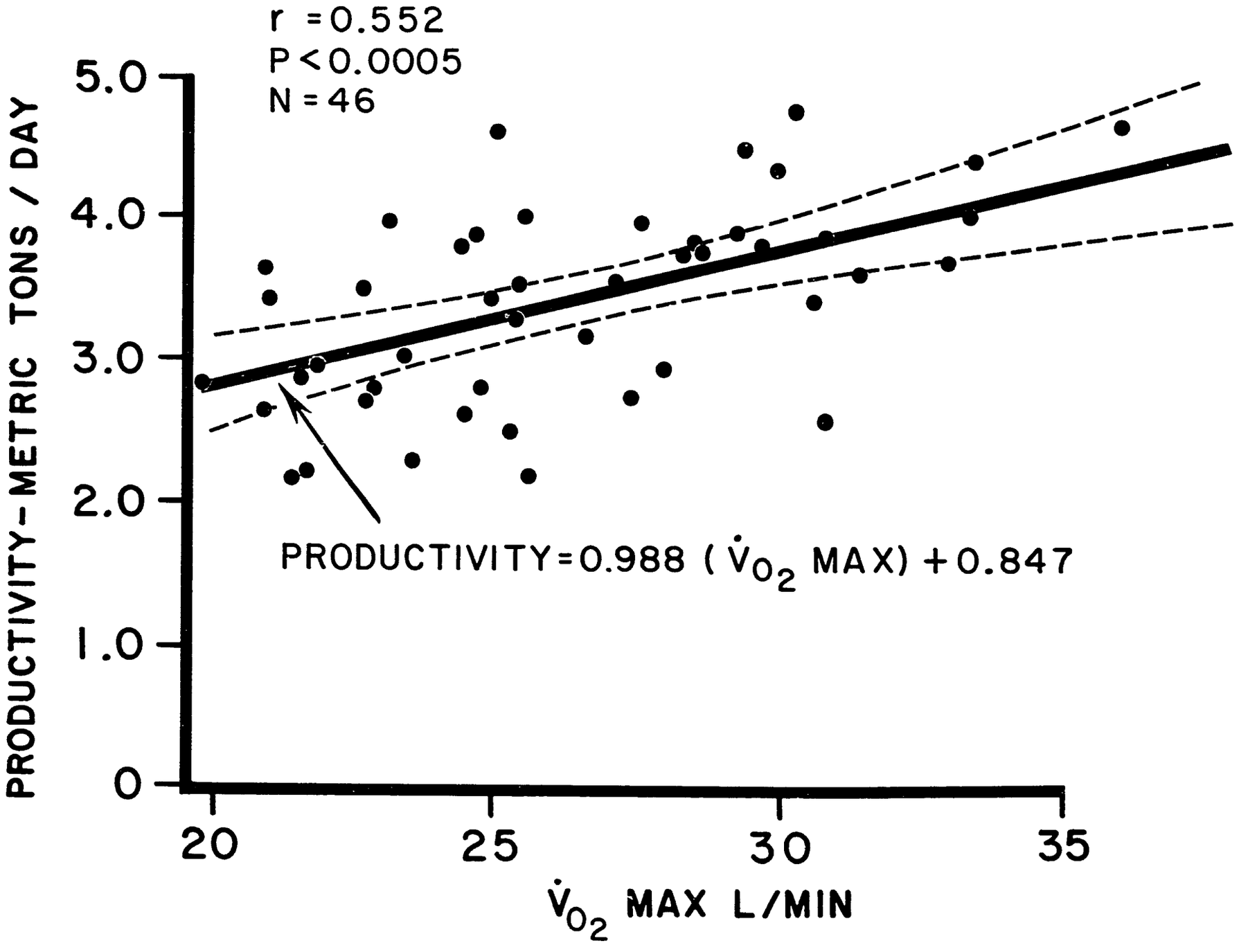

FIG. 35. Regression of productivity on $\dot{V}_{O_2}$ max (with 95% confidence limits) in sugar cane cutters.

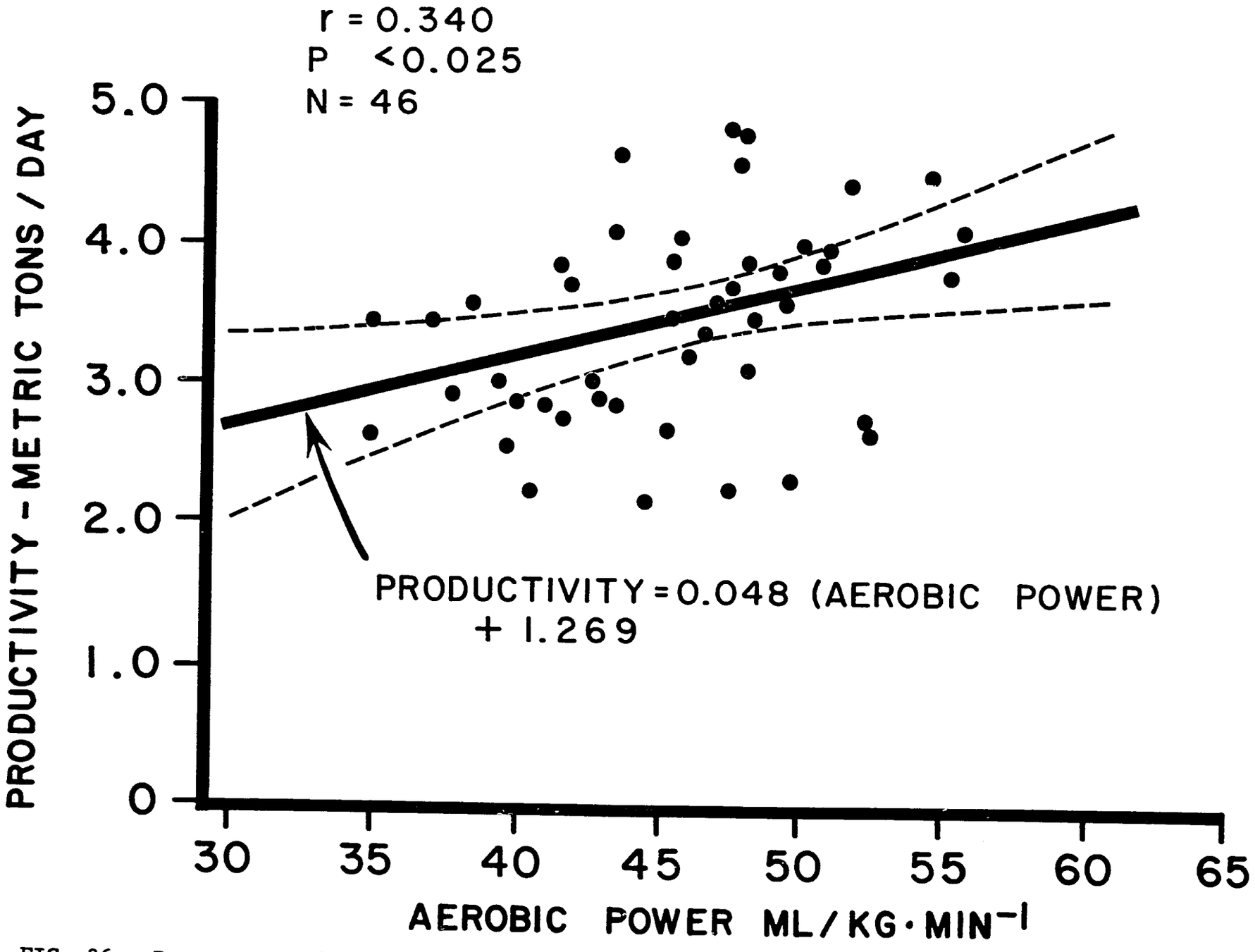

FIG. 36. Regression of productivity on aerobic power (with 95% confidence limits) in sugar cane cutters ages 18-34 years.

TABLE 32

STEPWISE MULTIPLE REGRESSION OF DAILY PRODUCTIVITY ON $\dot{V}O_2$ MAX (L/MIN), % BODY FAT AND HEIGHT (CM) IN 46 SUGAR CANE CUTTERS 18 TO 34 YEARS OF AGE

	Regression Coefficients			Intercept	Multiple Correlation Coefficient
	$\dot{V}O_2$ max	% Body Fat	Height		
$\dot{V}O_2$ max	0.99	---	----	0.846	0.552*
$\dot{V}O_2$ max, % body fat	1.05	-0.18	----	2.552	0.646*
$\dot{V}O_2$ max, % body fat, height	0.81	-0.14	0.03	-1.962	0.685*

*$P < 0.001$

$$P = 0.81\ V - 0.14\ F + 0.03\ H - 1.96 \quad \text{where}$$

P = productivity (tons/day)

$V = \dot{V}_{O_2}$ max (liters/min STPD)

F = percent body fat

H = height (cm)

(9) Efficiency and Effort

Figure 37 is a graphic presentation of productivity and the estimated percent $\dot{V}_{O_2}$ max which workers have to sustain to achieve their daily productivity. When the sustained effort is less than 40% of the $\dot{V}_{O_2}$ max, the correlation ($r = 0.71$) between productivity and sustained percent $\dot{V}_{O_2}$ max is statistically significant and simply indicates that productivity is related to effort. However, above 40% the correlation coefficient is not statistically significant; the slope of the regression line is not significantly different from zero but is significantly different from the slope of the regression line for those who exerted less than 40% effort during the workday ($P < 0.005$). Consequently, there is statistical justification for treating the two groups separately.

Table 33 shows the frequency distribution and average productivity of men in each group for those subjects in each of the three productivity groups, above and below a sustained 40% of $\dot{V}_{O_2}$ max. A x^2 analysis demonstrated that there was no difference in the frequency of men in each of the three productivity groups (Table 33) nor were the average productivities different in the two effort groups.

Because of the difference in the subjects above and below a sustained effort of 40% $\dot{V}_{O_2}$ max (Fig. 37) separate groups were formed. Those below 40% were subdivided into three productivity groups (Table 33) while those above 40% were combined into one group called Group IV. A one-way analysis of variance of a number of physiological variables was then done on the four groups of subjects. The results are presented in Figs. 38-40.

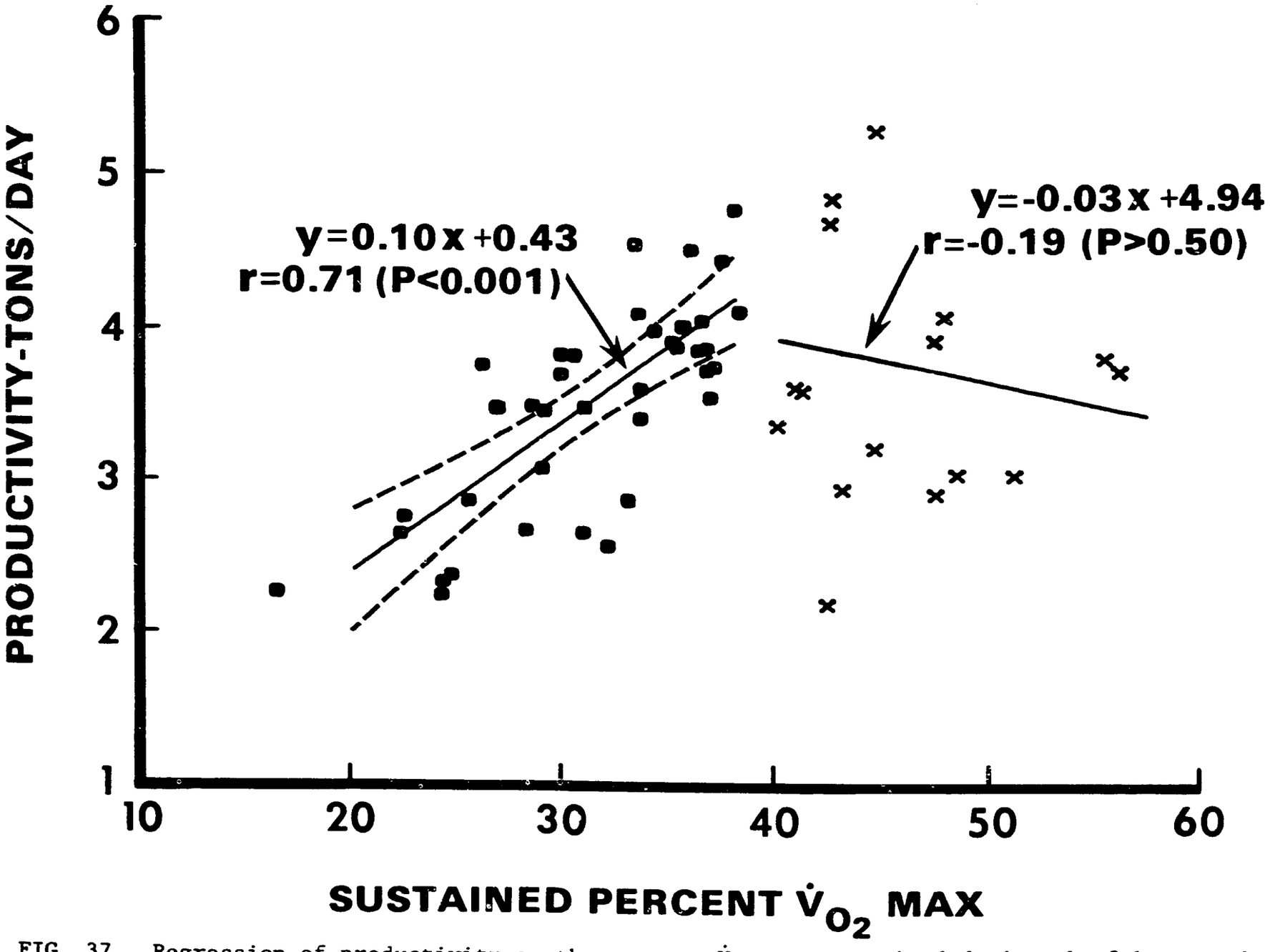

FIG. 37. Regression of productivity on the percent $\dot{V}_{O2}$ max sustained during the 8-hour work-day in 38 sugar cane cutters who exerted less than 40% and 16 who expended greater than 40% effort.

TABLE 33

PRODUCTIVITY OF GOOD, AVERAGE AND POOR SUGAR CANE CUTTERS EXERTING LESS THAN AND GREATER THAN 40% OF $\dot{V}O_2$ MAX DURING THE 8-HOUR WORKDAY

Productivity Group	Effort					
	<40% $\dot{V}O_2$ max			>40% $\dot{V}O_2$ max		
	n*	Mean	S.D.	n*	Mean	S.D.
I (>4 tons/day)	6	4.36	0.27	4	4.66	0.50
II (3-4 tons/day)	21	3.65	0.24	7	3.55	0.24
III (<3 tons/day)	11	2.54	0.23	5	2.78	0.36

*X^2 = 0.82 (P > 0.60)

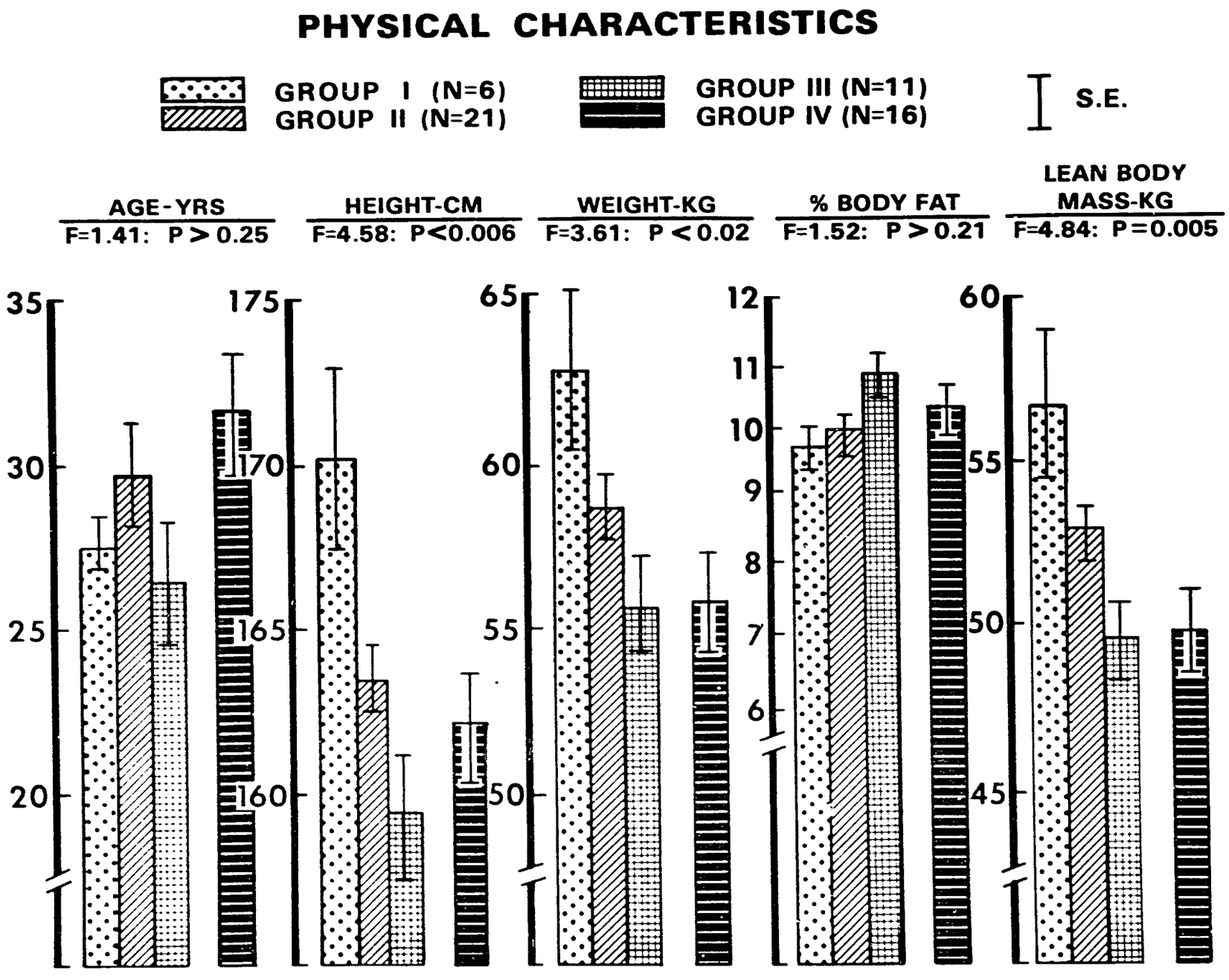

FIG. 38. Physical characteristics of sugar cane cutters who expended less than 40% $\dot{V}O_2$ max (Groups I, II and III) and greater than 40% $\dot{V}O_2$ max (Group IV) during the 8-hour workday. Groups I, II and III are good, average or poor cutters according to productivity.

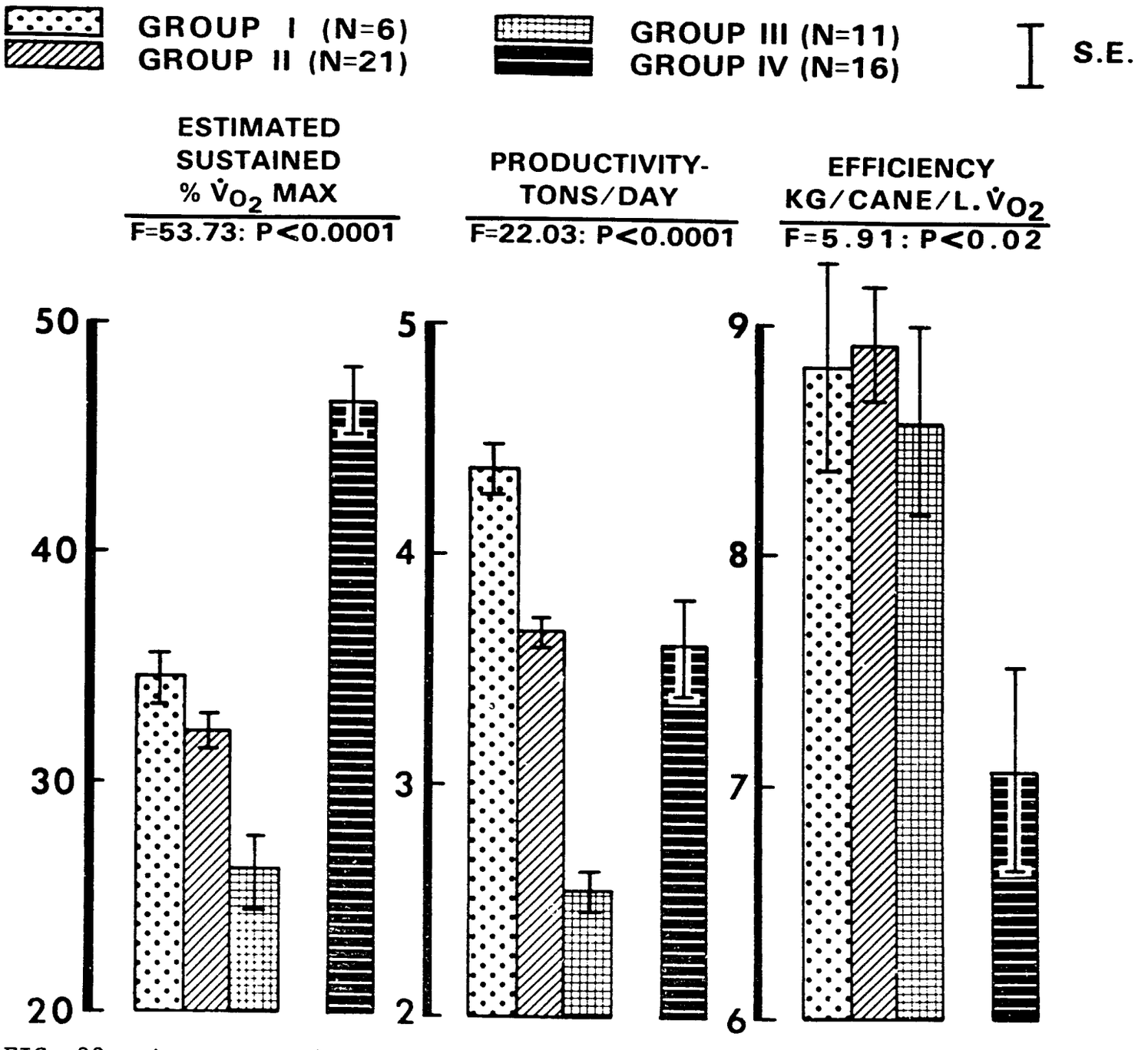

FIG. 39. Averages and standard errors of effort, productivity and efficiency of sugar cane cutters who expended less than 40% $\dot{V}_{O_2}$ max (Groups I, II and III) and greater than 40% $\dot{V}_{O_2}$ max (Group IV) during the 8-hour workday. Groups I, II and III are good, average or poor cutters according to productivity.

In general, the results obtained in Groups I, II and III are similar to those presented earlier for these subjects (42). With the exception of the average age, subjects in Group IV had mean values for height, weight, percent body fat and lean body mass which were similar to those found in Group III (i.e., the subjects with the lower productivity) or fell between the averages of Groups II and III. The average productivity of Group IV was similar to Groups I, II and III (Table 33, Fig. 39). However, Fig. 39 shows that the mean percent of $\dot{V}_{O_2}$ max which was sustained for the 8-hr workday was 46.7 ± 6.5% which was significantly higher than each of the other three groups (Fig. 39). This amounts to an 8-hr sustained work rate of 5.6 ± 0.9 kcal/min, or, since the average body weight in this group was 55.8 ± 6.0 kg, to 6.5 kcal/min/65 kg (43).

Previously, efficiency of cutting cane was shown to be higher in the PM and AM and that it was not different in the three productivity groups (33). In order to obtain an estimated daily value of efficiency for each man, the AM and PM differences were ignored and the average taken. Figure 39 shows that there was no difference in Groups I, II or III, but that Group IV had an average efficiency of 7.1 kg/liter $\dot{V}_{O_2}$ ($F = 5.91$; $P < 0.02$).

Figure 40 presents the $\dot{V}_{O_2}$ max (liters/min), aerobic capacity (ml/kg · min^{-1}) and maximum heart rates of the four groups. An analysis of variance showed a statistically significant F ratio for $\dot{V}_{O_2}$ max ($P < 0.0005$) and aerobic capacity ($P < 0.01$). Unpaired Student's "t" test comparisons revealed that, in both instances, the values for Group IV were significantly less than Groups I and II, but were not statistically different from Group III. Maximum heart rate (f_H max) did not exhibit significant differences among the four groups, although poorer producers tended to have higher f_H max than the better producers.

Utilizing the f_H and $\dot{V}_{O_2}$ values measured during work in the field, a slope and intercept of the regression of f_H on $\dot{V}_{O_2}$ was calculated

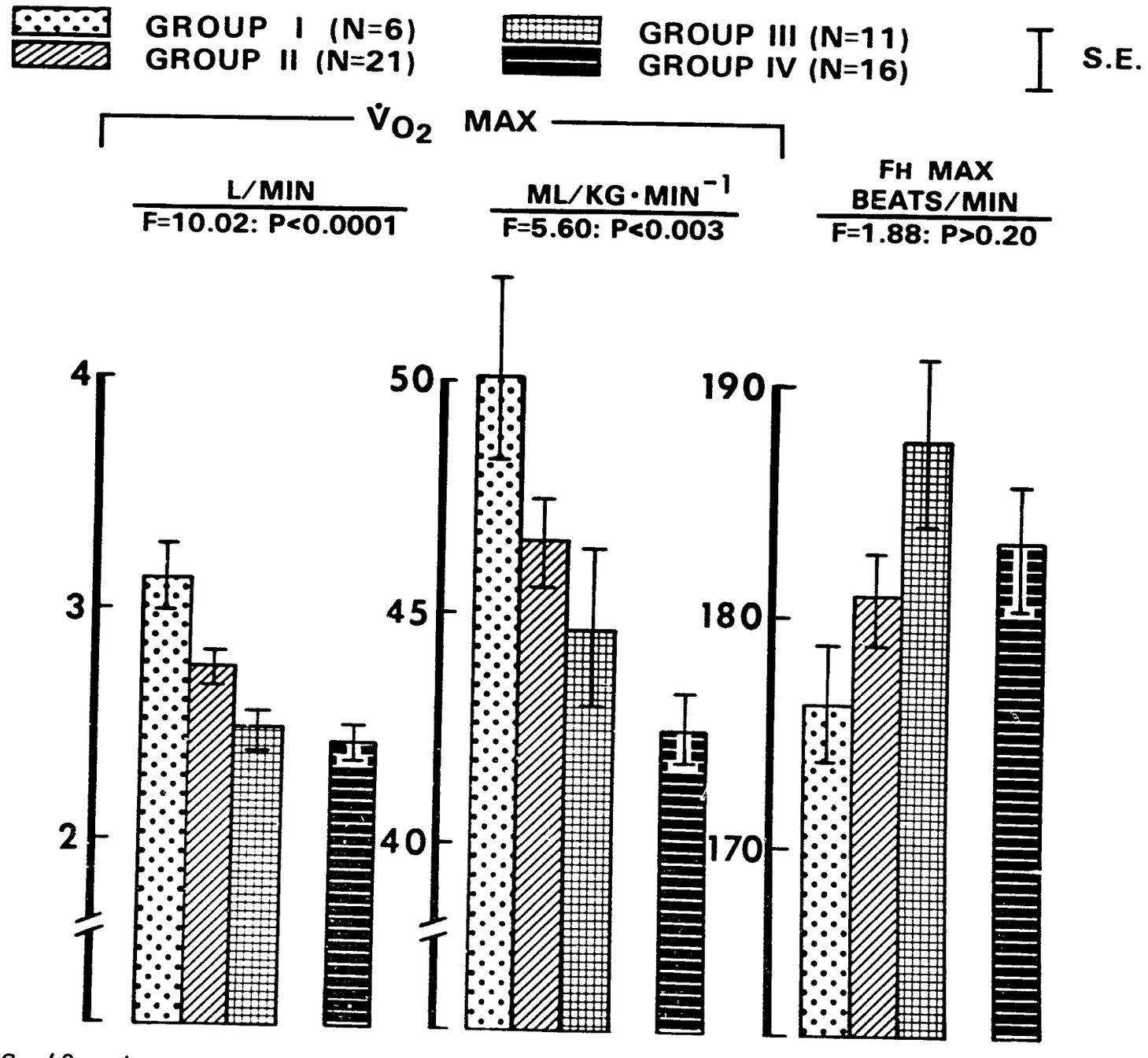

FIG. 40. Averages and standard errors of $\dot{V}O_2$ max and maximum heart rate of sugar cane cutters who expended less than 40% $\dot{V}O_2$ max (Groups I, II and III) and greater than 40% $\dot{V}O_2$ max (Group IV) during the 8-hour workday. Groups I, II and III are good, average or poor cutters according to productivity.

for each subject in the AM and PM, and an f_H at $\dot{V}_{O_2}$ = 1.5 liters/min ($f_{H_{1.5}}$) obtained from the resulting equations (42). Since statistical analyses of the AM, PM, or the average of the two gave the same conclusions, only the latter are presented for purposes of conciseness. The values for $f_{H_{1.5}}$ were 124 ± 9, 135 ± 16, 144 ± 15 and 140 ± 10 beats/min for Groups I, II, III and IV, respectively. The one-way analysis of variance gave an F ratio = 2.95 ($P < 0.05$). The $f_{H_{1.5}}$ for Group IV was significantly higher than for Group I but not significantly different from Groups II and III. Resting heart rates were not significantly different among the four groups in the AM ($F = 0.38$; $P > 0.75$) or PM ($F = 0.27$; $P > 0.80$).

(B) Sugar Cane Loaders

The data obtained on the sugar cane loaders has not yet been completely analyzed. Table 34 summarizes the data obtained in the field during work loading sugar cane. The physical characteristics and data on $\dot{V}_{O_2}$ max are presented in a subsequent section.

The energy cost of work was 6.4 ± 1.0 kcal/min. The relative costs of cutting sugar cane and loading it on a wagon are compared in Fig. 41 to other work tasks.

III. STUDIES IN COLOMBIAN AND U.S. LABORERS

The age and anthropometric measurements of the various groups are presented in Table 35. The lowest values for height were observed in the three groups of Colombian laborers and the United States migrant workers. The height differences among the Colombian laborers were not statistically significant, nor were the differences between the migrant workers, the sugar cane loaders and the general farm laborers. The United States civil service laborers were significantly taller than all of the other groups ($P < 0.05$).

TABLE 34

STATISTICAL SUMMARY OF ALL DATA ON ALZADORES

VARIABLE	N-VALUE	MEAN	STD. DEV.	STD. ERROR
AGE-YRS	28	34.1785	5.9817	1.1304
HEIGHT-CM	28	165.1464	5.6632	1.0702
WEIGHT-KG	28	60.3007	6.7674	1.2789
SURFACE AREA-M2	28	1.6610	0.1107	0.0209
W/H RATIO	28	36.4960	3.3435	0.6318
RECIP.PON.INDEX	28	12.7525	0.3988	0.0753
DENSITY	28	1.0773	0.0045	0.0008
% BODY FAT	28	9.3582	1.7574	0.3321
LBM-KG	28	54.2953	5.6274	1.0634
PROD-TONS/DAY	28	9.6999	1.0722	0.2026
VO2 MAX L/MIN	26	3.0211	0.4053	0.0794
F H MAX BEATS/MI	27	190.9629	10.4273	2.0067
AEROB. POWER	26	49.7234	6.2736	1.2303
VO2 REST L/MIN	27	0.2536	0.0419	0.0080
VO2-15 L/MIN	27	1.2708	0.2253	0.0433
VO2-30 L/MIN	27	1.2496	0.2220	0.0427
VO2-45 L/MIN	22	1.2505	0.1637	0.0349
FH-REST	28	73.4642	10.9222	2.0641
FH-15	27	117.1966	16.7287	3.2194
FH-30	27	121.1592	16.2545	3.1281
FH-45	22	123.0000	17.6610	3.7696
VE REST-L/MIN	28	11.2371	2.3283	0.4400
VE 15-L/MIN	27	38.7592	7.0476	1.3563
VE 30-L/MIN	27	39.2234	7.3490	1.4125
VE 45-L/MIN	22	38.6237	4.9846	1.0627
CANE LOAD KG/HR	28	1744.3500	324.0294	61.2375
VO2 AV L/MIN	28	1.2530	0.1995	0.0375
ENERGY-CAL/MIN	28	6.3167	0.9947	0.1879
FH AV-BEATS/MIN	28	119.8214	16.1773	3.0572
EFF-KG/L O2	26	24.0169	4.0725	0.7696
% VO2 MAX	26	41.7634	5.9356	1.1738
NO. WAGONS/DAY	26	2.9346	0.3071	0.0602
TIME LOAD HRS/DA	26	2.3530	0.2914	0.0571
SUS % VO2 MAX	26	28.5615	5.8167	1.1407

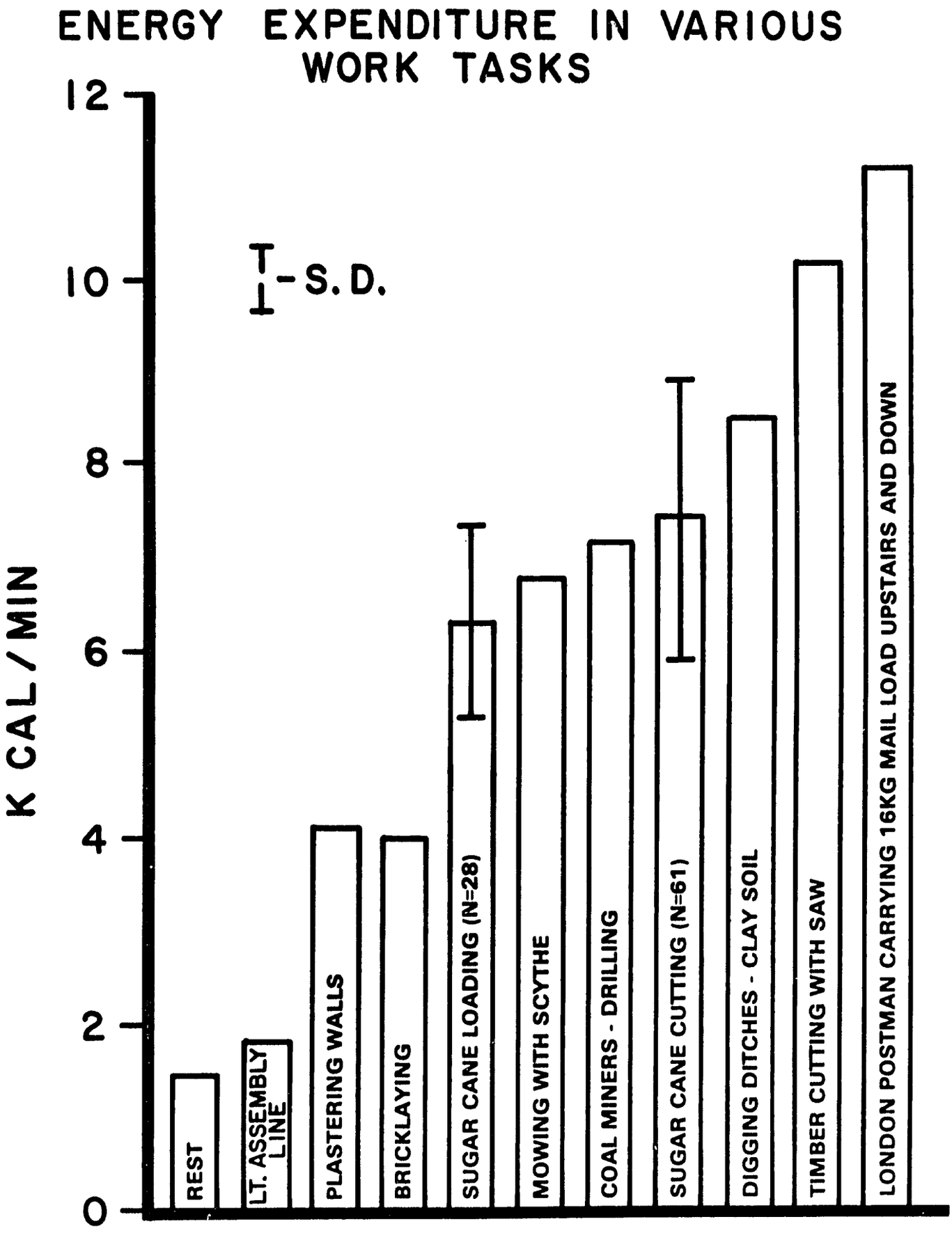
ENERGY EXPENDITURE IN VARIOUS WORK TASKS
K CAL/MIN
0
2
4
6
8
10
12
S.D.
REST
LT. ASSEMBLY LINE
PLASTERING WALLS
BRICKLAYING
SUGAR CANE LOADING (N=28)
MOWING WITH SCYTHE
COAL MINERS - DRILLING
SUGAR CANE CUTTING (N=61)
DIGGING DITCHES - CLAY SOIL
TIMBER CUTTING WITH SAW
LONDON POSTMAN CARRYING 16KG MAIL LOAD UPSTAIRS AND DOWN

FIG. 41

TABLE 35

ANTHROPOMETRIC MEASUREMENTS

		Age (yrs)	Height (cm)	Weight (kg)	Weight/Height (kg/m)	Body Fat (%)	Body Fat (kg/m)	Lean Body Mass (kg)	Lean Body Mass (kg/m)
				Colombian Groups					
Sugar cane loaders	Mean	33.1	165.1	60.3	36.5	9.9	3.6	54.3	32.8
(n = 28)	S.D.	8.4	5.7	6.8	3.3	1.8	0.9	5.6	2.7
Sugar cane cutters	Mean	29.1	163.0	57.8	35.4	10.3	3.6	52.5	31.7
(n = 55)	S.D.	7.0	6.3	5.5	2.6	1.3	0.6	5.4	2.3
General farm laborers	Mean	25.5	164.8	61.4	37.2	11.6	4.4	54.4	32.8
(n = 18)	S.D.	4.5	5.0	9.9	5.4	3.1	1.8	7.5	4.0
				United States Groups					
Civil service laborers	Mean	27.4	175.0	75.9	43.7	15.2	6.6	64.2	36.6
(n = 20)	S.D.	3.0	8.1	9.0	4.9	2.8	1.6	6.6	2.8
Migrant workers	Mean	22.1	166.7	71.0	42.6	11.7	5.4	62.3	37.0
(n = 15)	S.D.	4.3	4.8	6.8	4.2	2.6	1.6	5.3	4.1

The mean body weights for the three Colombian groups are similar, although the differences between the cutters and the farm laborers did reach statistical significance. Statistically, body weights of all of the Colombian groups were lower ($P < 0.05$) than those of the two United States groups. The United States migrant workers also had a statistically lower ($P < 0.05$) mean weight than the civil service laborers. The calculation of the weight/height ratio suggests significant differences ($P < 0.05$) between the Colombian and United States populations, while no significant differences were found between the United States groups.

The calculated fat percentages were similar for the loaders and cutters and were statistically lower than the other groups. The values for the general farm laborers and the migrant workers were also similar and were statistically lower than the civil service laborers. Body fat, normalized for height (kg/m), was lowest in the sugar cane workers, highest in the U.S. civil service laborers and intermediate in the Colombian farm laborers and migrant workers. The differences between the loaders and cutters were not significant; however, all other differences did attain statistical significance.

Analysis of the calculated mean lean body mass data, expressed both as percent or kg/m, indicates that the Colombian populations have values that are significantly lower ($P < 0.05$) than the United States groups but not different from each other. There were no statistically significant differences between the two United States groups.

The blood chemistry data is shown in Fig. 42. With the exception of total protein, no significant differences were observed among the Colombian groups on the various blood measurements. The total protein levels of the general farm laborers were significantly higher than those of the cane loaders or cutters.

The maximal physiological responses are shown in Table 36. The highest mean values for maximum heart rate were observed with the civil service laborers (198 beats/min) followed by the migrant workers (192 beats

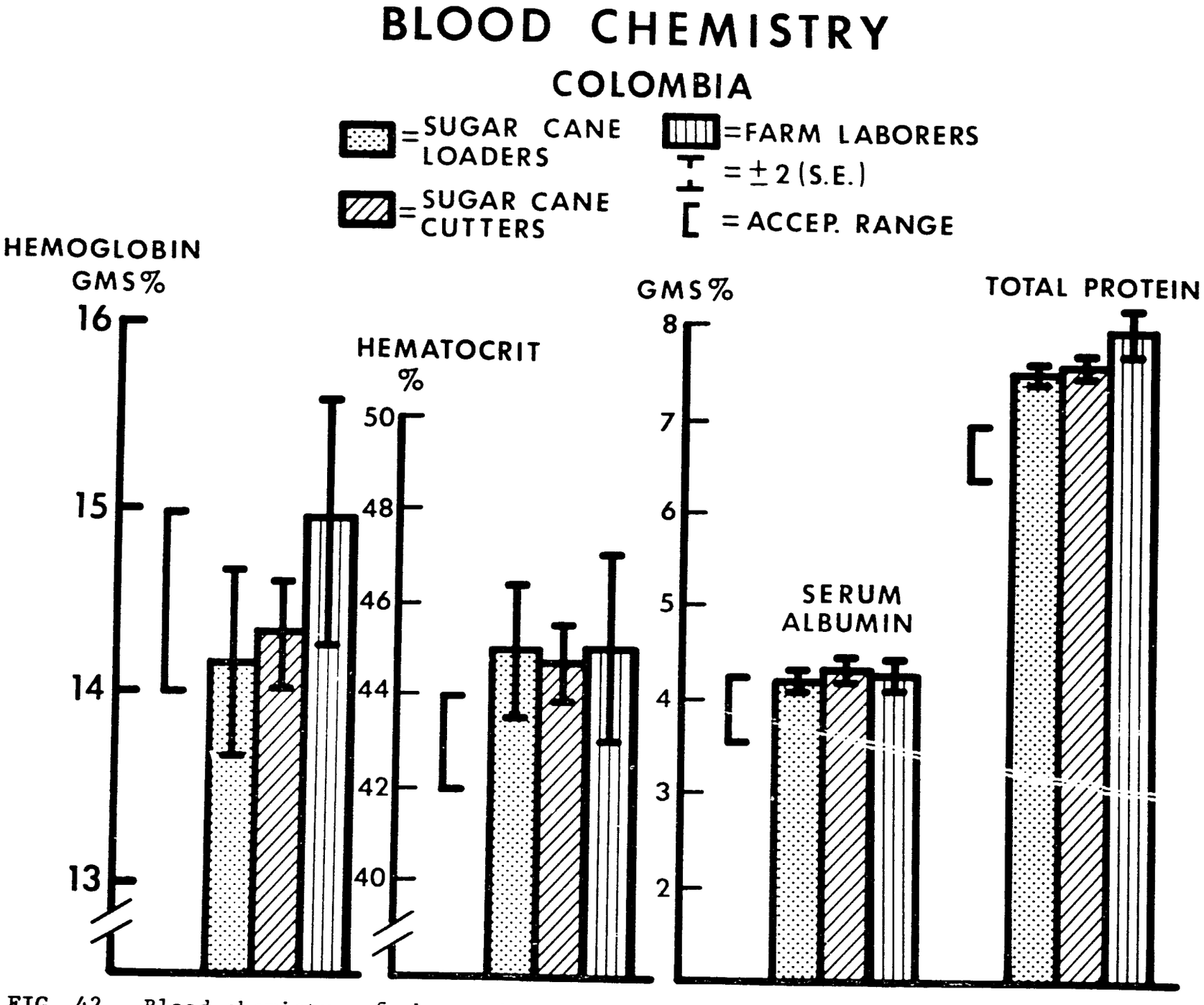

FIG. 42. Blood chemistry of the various Colombian groups.

TABLE 36

MAXIMAL PHYSIOLOGICAL RESPONSES

		Heart Rate (beats/min)	$\dot{V}_E$-BTPS (L/min)	$\dot{V}O_2$-STPD (L/min)	$\dot{V}O_2$-STPD (ml/kg·min^{-1})	O_2 Pulse (ml/beat)	$\dot{V}_E$ Equivalent ($\dot{V}_E$/100 cc $\dot{V}O_2$)
				Colombian Groups			
Sugar cane loaders	Mean	181.0	111.41	2.971	49.0	16.4	4.0
	S.D.	10.4	20.12	0.474	7.2	2.4	0.6
Sugar cane cutters	Mean	182.5	106.52	2.634	45.3	14.7	3.8
	S.D.	10.3	21.29	0.366	4.7	2.2	0.7
General farm laborers	Mean	190.2	105.60	2.704	44.1	14.4	3.9
	S.D.	6.6	17.99	0.479	3.9	2.8	0.6
				United States Groups			
Civil service laborers	Mean	198.0	119.67	3.018	39.8	15.0	3.9
	S.D.	8.1	20.79	0.485	5.1	2.6	0.7
Migrant workers	Mean	191.9	106.30	2.858	40.9	14.7	3.7
	S.D.	10.2	21.83	0.480	7.0	2.5	0.4

per min) and the general farm laborers (190 beats/min). The lowest mean values were observed with the sugar cane loaders and cutters with the mean values of 181 and 182.5 beats/min, respectively. These latter values were statistically lower ($P < 0.05$) than all of the other groups but were not statistically different from each other. The values for the general farm laborers and the migrant workers were statistically lower than those of the civil service laborers but not different from each other.

The mean ventilations during maximal exercise, shown in Table 36 range between 106-120 liters/min (BTPS). The only statistically significant differences were between the civil service laborers and the other groups. Larger ventilations are generally associated with the anthropometric characteristics of height and weight. When ventilation was normalized for height ($\dot{V}_E/m$) there were no significant differences among any of the groups.

The mean aerobic power appears to separate into three "strata". The mean value observed with the sugar cane loaders was significantly higher ($P < 0.05$) than all of the other groups. The cutters and Colombian farm laborers had slightly lower values but were not statistically different from each other. The lowest values were observed in the migrant workers and civil service laborers. The mean values for the latter two groups were not statistically different from each other.

The highest mean oxygen pulse was observed with the sugar cane loaders. This value was significantly higher ($P < 0.05$) than all of the other groups. The oxygen pulse for the remaining four groups ranged betwen 14.4 - 15.0 ml/beat and no significant differences were observed between these groups. The values for ventilation equivalent at $\dot{V}O_2$ max were generally similar for the various groups with only the difference between the migrant workers and the sugar cane loaders attaining statistical significance.

The total accumulated work for the various groups is shown in Fig. 43 The sugar cane loaders achieved the largest total work (13491 kgm). This value was significantly larger ($P < 0.05$) than all of the other groups

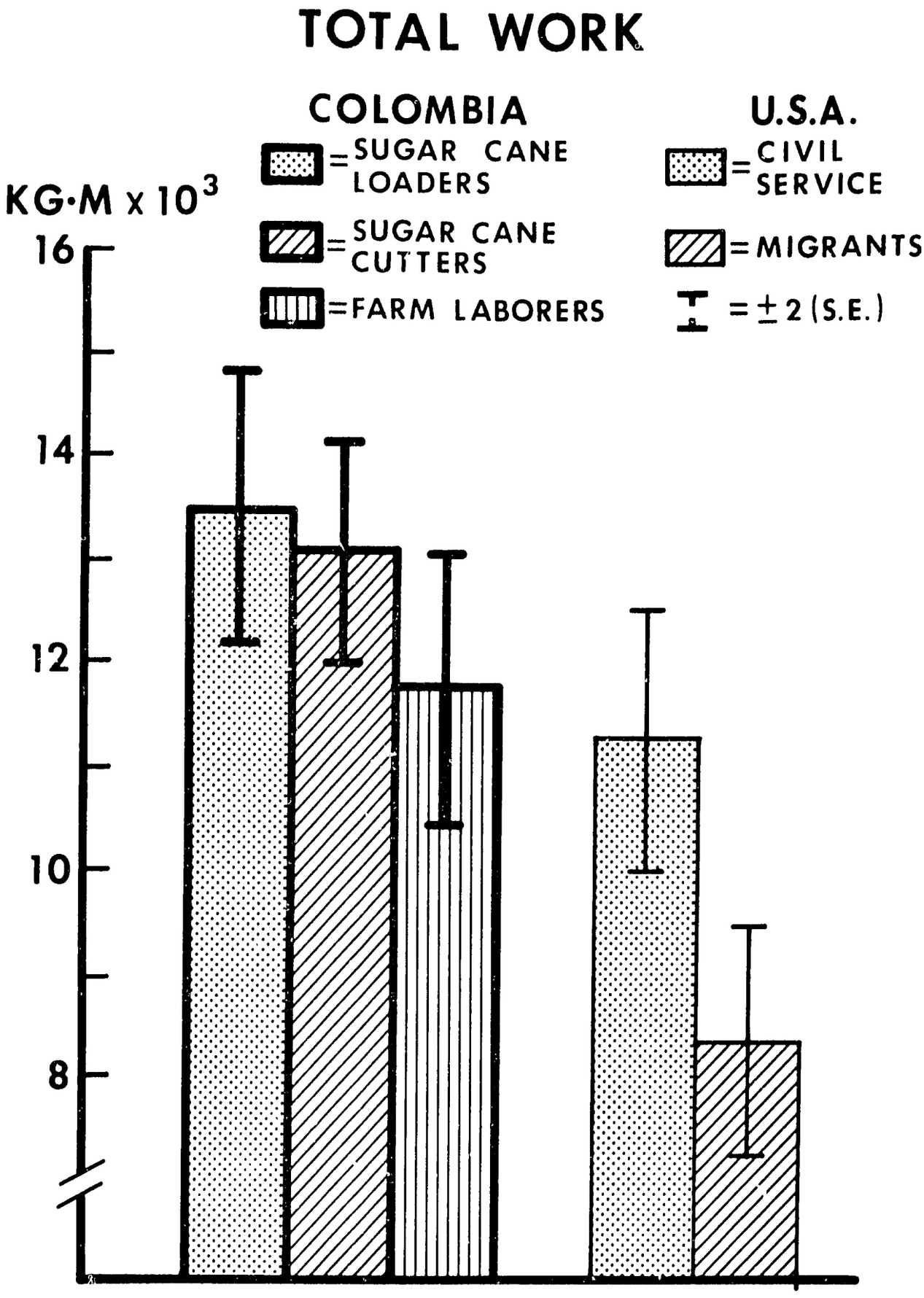

FIG. 43. Total work performed during treadmill exercise test.

with the exception of the sugar cane cutters. The work output of the cutters was significantly larger than the remaining groups. The values for the farm laborers and civil service laborers were not significantly different. All groups had statistically higher ($P < 0.05$) values than the migrant workers.

IV. STUDIES IN CHILDREN (RESULTS AND DISCUSSION)

The data on the growth of the children in the Human Ecology Research Station program (34) during the period between 3 and 6 yrs of age (Table 37 shows clearly that the advantaged children were taller and heavier than the disadvantaged ones of Groups 1, 4 and 6, and that nutritional supplementation either at school or in the home-based program was effective in improving the body size deficit but did not correct it completely. The children in Groups 1 and 6 were still smaller than the advantaged children of Group 5 at age 6, though larger than those of Group 4 who did not receive the nutritional supplementation.

Table 38 presents the data obtained during the exercise testing on all five groups of children. The $\dot{V}_{O_2}$ max in Group 4, expressed in L/min, is significantly lower than that in Groups 1 and 6, which is probably related to their smaller body size since, when normalized for body weight, the differences among the three groups disappear. However, all three of the disadvantaged groups exhibit a lower aerobic capacity ($ml/kg \cdot min^{-1}$) than Groups 5 and 7, which is statistically significant. These results indicate that early undernutrition up to 3 yrs of age reduces the physical work capacity and that 3 yrs of nutritional supplementation does not improve the earlier impairment. The maximal heart rates presented in Table 38 are essentially identical in all four groups of children. This does not indicate that they are in the same physical condition, but rather that all groups were stressed to the same extent and were working at maximal or near maximal capacity, and is indicative of the similarity of the relative work loads among the five groups. These maximal heart rates in 6 yr old children compare well with

TABLE 37

MEANS AND STANDARD DEVIATIONS OF WEIGHT AND HEIGHT OF CHILDREN FROM DEPRIVED (GROUPS 1, 4, 6) AND ADVANTAGED (GROUP 5) URBAN ENVIRONMENTS AT SELECTED AGES (34)

Age (mos)	Body Wt. (kg)	% Normal	Height (cm)	% Normal	Weight/Height
			Group 1 (n = 10)		
37	10.4 ± 0.8	71.0 ± 5.8	81.8 ± 4.2	85.1 ± 4.6	12.7 ± 0.8
58	14.6 ± 1.4	81.4 ± 8.7	96.2 ± 3.3	88.3 ± 2.8	15.2 ± 1.4
78	17.4 ± 1.7	81.9 ± 8.0	106.8 ± 3.3	90.9 ± 2.7	16.3 ± 1.4
			Group 4 (n = 10)		
37	10.4 ± 1.0	71.2 ± 1.4	83.9 ± 3.2	86.8 ± 3.6	12.4 ± 0.9
58	13.1 ± 1.5	71.9 ± 8.8	96.0 ± 5.6	87.1 ± 5.2	13.7 ± 1.1
78	14.9 ± 1.5	69.0 ± 7.7	103.4 ± 4.9	89.3 ± 7.1	14.4 ± 1.0
			Group 6 (n = 10)		
39	11.0 ± 1.5	74.0 ± 8.2	84.4 ± 4.1	86.6 ± 4.8	13.0 ± 1.0
59	14.6 ± 4.5	78.3 ± 8.0	96.0 ± 3.7	87.3 ± 1.5	15.2 ± 1.5
79	17.1 ± 4.5	79.0 ± 7.5	107.0 ± 3.2	91.8 ± 6.8	16.0 ± 1.2
			Group 5 (n = 6)		
41	16.7 ± 2.6	110.1 ± 18.0	101.5 ± 3.9	102.9 ± 5.5	16.5 ± 2.1
64	21.2 ± 4.2	115.6 ± 19.4	114.6 ± 5.4	102.9 ± 4.6	18.4 ± 2.9
80	23.8 ± 4.8	110.0 ± 22.7	121.5 ± 5.9	102.6 ± 5.2	19.6 ± 3.3

TABLE 38

MAXIMAL OXYGEN CONSUMPTION, HEART RATES AND BODY WEIGHTS OF 6 YEAR OLD CHILDREN FROM DEPRIVED URBAN ENVIRONMENTS

	Height (cm)	Weight (kg)	$\dot{V}O_2$ max* (ml/min)	$\dot{V}O_2$ max* ($ml/kg \cdot min^{-1}$)	$\dot{V}_E$ max** (L/min)	Heart Rate Max (beats/min)
			Group 1 (n = 10)			
Mean	105.6	17.49	602	34.1	29.64	197
S.D.	3.1	1.59	75	3.9	5.14	12
			Group 4 (n = 10)			
Mean	101.8†	14.95†	500‡	33.1	27.10	196
S.D.	4.5	1.33	102	5.5	6.98	10
			Group 6 (n = 10)			
Mean	105.7	16.91	564	32.8	27.49	195
S.D.	3.4	1.27	111	5.2	4.93	9

MAXIMAL OXYGEN CONSUMPTION, HEART RATES AND BODY WEIGHTS OF 6 YEAR OLD CHILDREN FROM ADVANTAGED URBAN ENVIRONMENTS

			Group 5 (n = 6)			
Mean	120.5§	23.82§	900§	38.1§	44.12§	197
S.D.	2.6	4.56	123	2.6	6.60	6
			Group 7 (n = 6)			
Mean	120.0§	21.66§	912§	41.6§	29.52	191
S.D.	6.6	3.44	227	4.7	5.36	7

*STPD

**BTPS

†Significantly different from Groups 1 and 6; $P < 0.05$

‡Significantly different from Group 1; $P < 0.02$

§Significantly different from Groups 1, 4 and 6; $P < 0.05$

those reported in the literature (5,41) with the exception of those reported for Swedish children 7 to 9 yrs old (205/min, female; 212/min, male). However, the most remarkable feature of the aerobic capacity measurements in all the children tested was the much lower average values observed when compared with figures reported in the literature for "normal" children of approximately the same age (5,41,44,45). Åstrand reports values of aerobic capacity of 55 ml/kg · min for children 7 to 9 yrs old (5). Bruce and Dehn (41) obtained values of 52.3 ml/kg · min for a group of 26 children with an average age of 6.7 yrs. This implies a lower aerobic capacity (35-40%) of all the children tested in this pilot study.

It is apparent that the lower values of aerobic capacity observed in this population of children were not affected by the treatments employed. Either treatments were ineffective in this respect or they were instituted too late when irreversible changes in parameters determining aerobic capacity had already occurred. A third possibility is that a "catch-up" may occur during a later period.

The two populations of advantaged Colombian and American children did not exhibit a significant different in $\dot{V}_{O_2}$ max. The low values for both groups when compared to other children may be reflective of "habitual activity." Children from advantaged families in Cali are not allowed to play freely outside of the home without adult supervision as they are in other societies. However, with such small numbers of subjects it is impossible to speculate about causes.

DISCUSSION

I. MALNOURISHED ADULTS

A detailed interpretive analysis of the data on the two studies of malnutrition in adults will be presented as a part of the manuscripts to be published.

II. SUGAR CANE CUTTERS

(A) Nutritional Status and Energy Balance

The results of the blood analyses in 33 of the subjects showed that total proteins, serum albumin, hematocrit and hemoglobin values were comparable to those reported for the Colombian civilian population (46) None of the subjects were in the "deficient" range; 15 were in the "low" range for hemoglobin (12.0 - 13.9 gm %), and 5 were low for hematocrit (36 - 41%). All were in the "high" range for total proteins (46). The relatively high protein intake (1.2 gm/kg/day, Table 28), as compared to that recommended (0.8 gm/kg/day) for the United States population (28), may account for the latter.

Viteri (6) reported anthropometric data on several groups of adult male Guatamalan subjects who were classified according to their socioeconomic status, nutritional background and intake, and by work activity. The value of 32.0 ± 2.4 kg/m for lean body mass measured in the cane cutters (Table 29) is very close to those reported by Viteri (6) for the subjects he considered as having a good nutritional intake during his studies and higher than those he classified as having only an adequate or poor intake (6). On the other hand, the body fat content of the cutters (Table 29) is significantly lower than the values for all of Viteri's (6) groups, except those having "poor" nutritional intake. Our values were significantly higher than the latter. The differences in fat content may reflect differences in work activity levels, as well as nutritional differences (6). More active populations tend to have lower fat contents (47).

The average total caloric intake of 2970 kcal/day (Table 28) may be a low estimate. If one assumes that each worker obtained 8 hours of sleep at 1 kcal/hr/kg and that 8 hours were spent at a very low level of activity at approximately 1.5 kcal/hr/kg and using the mean body weight of 58.6 kg (Table 29), the estimated caloric expenditure for the nonworking hours would be 1172 kcal. The calculated energy cost of 8 hours of work was 2254 kcal for a total of 3426 kcal/24 hrs. Part of the discrepancy between daily caloric intake and expenditure may be explained by two unmeasured sources of calories. Company policy discourages consumption of cane during work, although it is common to see workers chewing on cane in the field. Its consumption may not have been reported accurately to the nutritionist. Secondly, the workers bring small plastic jugs of sugar water from home for consumption during working hours. Subsequent fillings are made from a water tank in the field, which does not contain sugar.

The body weights of five subjects were measured 1 yr apart under the same laboratory conditions. In 1972, the mean weight was 62.87 ± 5.27 kg; in 1973 it was 63.84 ± 5.61 kg. The difference was not statistically significant. In general, it would seem that the subjects studied were in adequate nutritional condition and that their caloric intake approximated the energy expended in 24 hours.

(B) Productivity

The average productivity of 3.52 ± 0.72 tons/day of our Colombian cutters is comparable, though slightly higher than that reported by Morrison and Blake (48) for 200 Rhodesian cane cutters (3 tons/day) and by Davies (49) for 78 cutters (3 tons/day) in Tanzania, East Africa, all of whom were cutting unburned cane. In the latter case, the author also divided his subjects into high, medium and low producers with daily averages of 3.51, 3.04 and 2.60 tons/day, respectively.

The physical characteristics of the subjects presented in Table 29 indicate that the lower producers weighed less and were shorter than the

good cutters in Group I. A similar tendency is seen in the data reported by Davies (49).

(C) Heart Rates

The resting heart rates of the subjects in the three groups were significantly higher ($P < 0.001$) in the PM than in the AM, probably as a result of previous work and the noon meal (50). Other than this, there were no statistically significant differences in $\dot{V}_E$, $\dot{V}_{O_2}$ or heart rates among the three groups, nor between AM and PM values (Fig. 27). Although there appeared to be a tendency for the heart rates of the cutters in Group I to be lower than the other two groups, the differences were not statistically significant. However, when one removes the simultaneous variation of $\dot{V}_{O_2}$ and f_H, a relationship between heart rate at a given workload (1.5 L/min $\dot{V}_{O_2}$) and productivity group can be seen (right insert, Fig. 28). The lower heart rates, at a given workload, indicate that the high producers are in better physical condition than the poorer producers (5).

The lack of difference in heart rates during work in the AM and PM may be due to the average ambient temperatures encountered. Nielson (51) has shown that, while body temperature was regulated to a higher level during work and was dependent on the workload, it was independent of the environmental temperature in the range 5-30°C.

Oxygen pulse, an indicator of stroke volume (5), was no different in the AM or PM (Table 30) while cutting cane, suggesting no difference in cardiac output. A lack of difference in cardiac output during work, in comfortable and hot environments, was found by Williams et al. (52).

(D) Energy Expenditure and Efficiency

When the average energy expenditure of 7.4 kcal/min is expressed in terms of a standard 65 kg man (53), utilizing the mean body weight of 58.6 kg (Table 29), one obtains a value of 8.2 kcal/min/65 kg for the energy expenditure. This is within the range of energy expenditures described as

"heavy" by Durnin and Passmore (43). Because of the obvious stimulating effect of observations on the work level (Fig. 32), this value is higher than is sustained during the day. Using the ratio of estimated sustained percent $\dot{V}_{O_2}$ max to observed percent $\dot{V}_{O_2}$ max, it is possible to estimate that this value would be about 5.1 kcal/min/65 kg, which would place it in the "moderate" category of industrial work presented by Durnin and Passmore (43) This is in very close agreement with the value of 5 kcal/min suggested by Passmore and Durnin (53) as the probable upper limit which can be sustained during an 8-hr day in heavy industry. This raises a question about classification systems, based on relatively short-term measurements which are influenced by subject stimulation so familiar in the psychological literature (54). For example, if the value of 7.4 kcal/min obtained in the present study had been used to estimate daily caloric expenditure in cutting sugar cane, we would have obtained about 3570 kcal/8-hr day instead of 2254 ± 562 kcal/8 hr. Some other measure(s) of energy expenditure, like productivity and energy expenditure/unit of product, is needed to improve accuracy of estimates.

The 57% of $\dot{V}_{O_2}$ max utilized in cutting sugar cane is considered to be higher than can be sustained for 8 hours (7,40). The revised estimated percent $\dot{V}_{O_2}$ max that can be sustained for 8 hours, about 35%, is in close agreement with that reported by Michael, Hutton and Horvath (7) for laboratory subjects and lower than the 50% reported by Åstrand (40).

Morrison and Blake (48) reported a value of 1.42 ± 0.15 L/min for $\dot{V}_{O_2}$ in 200 Rhodesian cane cutters while harvesting unburned cane at a rate of 9.0 ± 1.6 kg/min (540 kg/hr). This amounts to 7.2 kcal/min, which is comparable to the energy expenditure found in the present study. These authors state that their Rhodesian cutters were also working at a higher rate than usual during the tests (48). However, when related to the rate of cutting, the efficiency of the Rhodesians is lower than that of the Colombians. It can be calculated that the former were expending 0.8 kcal/kg of cane cut as compared to values of 0.676 and 0.616 kcal/kg found in the latter. The

Rhodesians utilized a somewhat different cutting technique than that employed by the Colombian cutters (48).

The improved efficiencies observed in the PM (Fig. 31) were the result of an increased rate of cutting sugar cane (Fig. 30) and an unchanged $\dot{V}_{O_2}$ (Fig. 27). Williams et al. (52) and Brouha and collaborators (55) reported a similar finding in that the $\dot{V}_{O_2}$ of their subjects was lower in the heat at the same workloads. Rowell et al. (56) found no thermally-induced change in $\dot{V}_{O_2}$ in their experiments, while Robinson (47) and Consolazio et al. (58) reported higher $\dot{V}_{O_2}$ during submaximal work in the heat. These differences are no doubt due to a variety of variables such as degree of heat acclimatization, physical condition of the subjects, as well as laboratory and field conditions under which the experiments were done. Another factor which might contribute is that the second time the subjects performed the test (always in the PM) may have been easier for them than the first (AM) test. In the present study, the lack of statistically significant differences in the results of the O_2 debt measurements on five sugar cane cutters in the AM and PM indicates that the increased efficiency was not the result of increased utilization of anaerobic sources of energy in the PM.

Exercise results in an increase in muscle temperature above changes produced in the rectal or esophageal temperatures (59). If this muscle temperature rise is higher in the PM than in the AM, it could explain the increased efficiency (Fig. 31) observed in the present experiments through a direct effect of temperature on cellular enzyme systems (52).

(E) Sweat Rates

The sweat rates measured as weight loss during the working hours demonstrated a statistically significant increase from AM to PM when the ambient temperatutes were higher and relative humidities lower. The values obtained in the 25-min measurement periods of this study were higher than those of 9.9 gm/kg/hr reported by Leithead et al. (60), measured over 1-2 hr periods of time while cutting sugar cane in British Guiana. When

estimates were made of the "sustained" sweating rates (10.4 and 13.8 gm/kg/hr in the AM and PM, respectively), the results of the two studies were more comparable, though direct comparisons are difficult because of differences in ambient temperatures and humidities in the two studies (60). There was a slight, though statistically significant, decrease in the prework body weights between AM and PM. This amounted to only 280 gm (0.5% of body weight) and therefore water replacement would appear to have been adequate. No observations were made on salt intake and there were no reported incidences of muscle cramps in our subjects during the period of this study. The incidence of muscle cramps amounted to less than 1% of the population studied by Leithead et al. (60).

Therefore, the cutting of sugar cane by these subjects is hard physical work involving a sustained effort which uses about 35% of the maximum effort during an 8-hr workday. The productivity is related to body size and the physical condition of the subjects, as evidenced by the calculated heart rates at a given workload.

(F) Maximum $\dot{V}_{O_2}$ and Productivity

The regression line of the relationship between aerobic capacity and age was almost identical with that derived by Dehn and Bruce (41) from 700 observations in healthy men and boys from about 6 to in excess of 80 years of age, published in the literature (Aerobic Capacity = 56.59 -0.398 · (Age)). Consequently, the regression equations developed for cross-sectional studies are reproducible even though derived from quite disparate populations of subjects. However, the predicted rates of decrease in aerobic capacity appear to be lower than those which can be derived from longitudinal studies (41).

Age is also significantly correlated with the estimated sustained percent $\dot{V}_{O_2}$ max, although the magnitude of the coefficient was not high (r = 0.43). Since there is a decrease in $\dot{V}_{O_2}$ max with age (41) and the oxygen cost of a task (muscular movement) is age-independent (43), it follows that, if productivity does not change with age (Fig. 33), a larger fraction of the $\dot{V}_{O_2}$ max would have to be utilized to maintain productivity as the worker grows older.

A similar finding has been observed in the tire manufacturing industry (W. G. Reddan, personal communication).

The data of the present study show clearly that productivity in sugar cane cutters is related to body size, leanness, and to the physical condition of the subject as measured by $\dot{V}_{O_2}$ max. When the $\dot{V}_{O_2}$ max is normalized for various parameters of body size (weight, height, lean body mass and surface area), statistically significant relationships still exist between productivity and these expressions of physical fitness (5). However, the relatively low magnitudes of the correlation coefficients are such that the relationships would not be useful for predictive purposes.

Hansson (8) found that lumberjacks with high $\dot{V}_{O_2}$ max had a greater output than those with lower $\dot{V}_{O_2}$ max values. Davies (49) reported a significant correlation of 0.46 between daily productivity and $\dot{V}_{O_2}$ max (liter/min) in East African sugar cane cutters, and Morrison and Blake (48) observed that six Australian cutters, whose productivity was much higher than their Rhodesian counterparts, also had a higher $\dot{V}_{O_2}$ max (liter/min), although the difference disappeared when the data were normalized for body weight. Neither Hansson (8) nor Davies (49) expressed their $\dot{V}_{O_2}$ max data in terms of body weight. Davies also found significant correlations between productivity and body weight, lean body mass, and leg volume, though not with height or skinfolds (49). Hansson (8) was unable to detect any differences between his top and average producers in height, weight and circumferences of lower and upper arms and chest. The Australian subjects of Morrison and Blake (48) were significantly heavier than the Rhodesian cutters, but they also had more body fat as evidenced by skinfold measurements. Heights were not reported. The data of these investigators are somewhat difficult to interpret because the comparisons are between two heterogenous groups rather than within a homogenous group, as in the present study and those of Hansson (8) and Davies (49).

The stepwise multiple regression analysis of the present data revealed a highly significant relationship between daily productivity and $\dot{V}_{O_2}$ max, height and body fat. The importance of this relationship is not in its possible utilization in predicting productivity (since less than one-half of the variability of the latter is explained in the relationship (Table 32) but rather in the fact that productivity is simultaneously related to three parameters which, in turn, are reflections of previous and/or present nutritional status, as well as the present state of physical fitness of the individual. The height of an individual is depressed by undernutrition during the years of growth (61), and the fat content and $\dot{V}_{O_2}$ max can be markedly decreased by both acute (4) and chronic undernutrition (62, 63). The $\dot{V}_{O_2}$ max (5) and body fat (64, 65) are also related to physical fitness. Since the nutritional status of the men was judged to be normal at the time of this study (Tables 28, 29), variations in productivity were probably related to physical fitness (Fig. 34) and perhaps to early nutritional history. In any event, the factors which tend to result in a lower $\dot{V}_{O_2}$ max (nutritional deprivation, poor physical condition) also depress productivity. Undernutrition in the adult would bring about its effect on productivity primarily through its effect on $\dot{V}_{O_2}$ max (Table 32).

(G) Efficiency and Effort

In speaking of the percent of $\dot{V}_{O_2}$ max which can be sustained for 8 hours of work, Åstrand and Rodahl (5) state that "a 50% load is too high for a steady state if the physical activity is continuous for a whole working day." Michael, Hutton and Horvath (7) presented evidence from experiments in three young men working in the laboratory that work loads below 35% of maximum could be sustained without undue fatigue for 8 hours. The estimates of the percent $\dot{V}_{O_2}$ max utilized by Colombian sugar cane cutters during an 8-hour workday were made on the basis of several short periods of measurement in the field which were projected to 8 hours (Fig. 32). The 16 men who exhibited a change in the relationship between productivity and sustained percent $\dot{V}_{O_2}$ max above 40% $\dot{V}_{O_2}$ max were found to have an

average productivity very close to the average of Groups I, II and III or to Group II alone (Fig. 39). The mean height, percent body fat and $f_{H_{1.5}}$ of Group IV were between those found for the average and low producers, and the weight and lean body mass were almost equal to that found for the poorer producers (Fig. 38). The latter was also true for the total $\dot{V}_{O_2}$ max (liter/min) and after normalization for body weight (Fig. 40). It would seem therefore that, in terms of anthropometry (Fig. 38) and physical fitness (Fig. 40), the men would be more closely classified with the poorer producers. However, the very low efficiency and therefore high percent of $\dot{V}_{O_2}$ max expended during the 8-hour workday clearly set Group IV apart from the others (Fig. 37). It is interesting to note that Morrison and Blake (48) utilized the same measure of efficiency and that their Rhodesian cutters, who were also harvesting green cane, had an average efficiency of 6.3 kg cane/liter $\dot{V}_{O_2}$, which is comparable to the "inefficient" Colombian cutters in Group IV (Fig.

The causes of the inefficiency of Group IV are unknown. The lack of differences in the resting heart rates obtained while the subjects were wearing the equipment utilized for the field measurements indicate that the subjects in Group IV were not under special emotional stress as a result of the tests. The experience of these men in cutting cane was not different from the other three groups nor were different machetes used. A number of studies have shown that the tools employed in a particular task may influence the efficiency with which the task is accomplished (5). We do not have a measure of the "sharpness" nor the condition of the machetes employed, but presume that one of the first things a cutter learns is the care of his instrument. All of the cutters were in a good nutritional state at the study (42). The fact that the men in Group IV had a lower mean $\dot{V}_{O_2}$ max and aerobic capacity than the others indicates that they are in poorer physical condition (5). This is also indicated from the calculated $f_{H_{1.5}}$ during work. In spite of this, they were able to maintain a work rate of 6.4 kcal/min/65 kg which amounted to about 47% of their $\dot{V}_{O_2}$ max during the 8-hour

workday. Both of these figures are higher than the values of about 5 kcal/min/65 kg (53), and 35% $\dot{V}_{O_2}$ max (7) which are the upper limits that men can expend during a regular workday. This raises the question of motivation of these workers. It is known that motivation plays an important role in man's ability to perform physical work and in his capacity to endure under conditions of heavy physical labor (5). The present investigation was not designed to study motivation. However, the results show that about 30% of the sugar cane cutters in this study had a normal distribution of productivity (Table 33) in spite of low efficiency and physical fitness and anthropometric measurements which would classify them among the poor producers. The motivational factors involved in their markedly increased effort to maintain this productivity would make an interesting psychological study.

An additional factor which may deserve future consideration is related to habitual use of alcoholic beverages. Pirola and Lieber (66) have recently postulated an energy wastage in alcoholism and abuse of some other drugs as a result of the stimulation of hepatic microsomal enzymes and by providing ethanol as a major source of calories. We have no information about the drinking habits of our subjects. However, alcoholism is a common problem and cheap alcohol drink is readily available from home fermented mixtures.

III. COLOMBIAN AND U. S. LABORERS

Growth and body size may be determined or modified by a variety of factors including ethnic background and nutritional state (67, 68). The height measurements in our groups appear to be related to ethnic background. The tallest group consisted of civil service laborers. These subjects were Caucasians with a European ancestry. The height data for the migrant workers and the Colombian population were similar. In addition, the heights are very similar to data reported by Viteri (6) for Guatemalan males considered to be in good nutritional state.

The body weight measurements separate into three divisions. The values for the three Colombian groups are similar to each other and to values reported by Viteri (6) for well nourished Guatemalan males. When the height/weight ratio is calculated, the Colombian groups again have very similar values. The mean values are almost identical to those reported by Viteri (6) for well nourished military service cadets and supplemented farm workers. The height/weight ratio for the two United States groups are similar to each other.

The calculated percent fat of different populations varies over a wide range and is influenced primarily by dietary patterns (69) and activity levels (64,65). Physically active populations tend to have less body fat, with athletes engaging in strenuous endurance exercise having very low fat levels (70). The lower fat values observed with the sugar cane workers reflect in part the strenuous demands of their occupational tasks (42). The groups work at about 35 percent of their maximal oxygen uptake approximately 8 hours/day year round. The lower fat values may also reflect dietary intake, since the caloric intake for the sugar cane cutters was estimated to be similar to their daily caloric expenditure (42). The percentage fat observed with the general farm laborers and migrant workers are similar to values reported for farm laborers (71). The value observed with the civil service laborers is similar to data generally reported for the American male (72). These data suggest that the occupational demands of this group are not sufficient to induce a significant reduction in adiposity.

A review of the results on lean body mass suggests a separation between the Colombian groups and the United States groups. Both in terms of total LBM and LBM/m, the Colombian groups have lower values than the United States groups. The differences are probably due more to body size than the nutritional state. This is supported by the observation that the ratio of LBM to height is very similar to the data of Viteri (6) on well nourished Guatemalan subjects.

The maximal heart rates (Table 36) show the sugar cane workers to have lower values than the other groups. Several explanations for the significantly lower values of these two groups may be proposed; one possibility is age. The sugar cane workers were older than the other populations (Table 35) and a reduction in maximal heart rate with age has been reported (5). However, on the basis of predicted maximal heart rate, the values would be approximately 187 beats/min for the loaders and 191 beats/min for the cutters. Another explanation may be differences in physical fitness levels. In athletes, maximal heart rates tend to be lower after training (47, 73) although the difference is generally small. One could also speculate that they did not push themselves to maximal effort. This appears unlikely in light of several observations. First, the $\dot{V}_{O_2}$ max attained by these groups was higher than the other groups and the criteria for attaining $\dot{V}_{O_2}$ max were satisfied (37). Secondly, it is apparent from Fig. 43 that the total work attained by these two groups was generally significantly greater than the other groups. A further possible explanation may be previous nutritional status. Studies on the effect of acute malnutrition have reported a relative bradycardia (4). Whether this phenomena is exhibited at maximal levels of work has not been established. While there was no evidence of clinical malnutrition in these populations at the time of the study, the problem of chronic malnutrition does exist in this rural population of Colombia and the observations may reflect a manifestation of malnutrition earlier in life.

The difference in maximal ventilations observed between the various groups in this study appeared to be related to differences in body size. When the ratio of maximal exercise ventilation to body height is calculated, the values are quite similar, varying between 64-68 liters/meter.

The maximal aerobic power is influenced by a variety of factors including genetic endowment (74), nutritional state(4), environmental factors (75, 76), physical fitness levels (35, 72) and age (5, 41). The highest values are generally observed in endurance athletes and a decrease is observed

with age (5). The values observed with the sugar cane loaders are similar to data reported for other groups of physically-active populations, as reported by Wyndham (77). The aerobic power of the loaders is significantly higher than the other groups in this study. If one applies an age correction, the difference would be increased further, since the loaders are also the oldest group studied. The values observed for the sugar cane cutters and the Colombian farm laborers, while lower than those seen with the loaders, are also generally typical of workers in physically demanding occupations (77). The mean values are slightly higher than values reported by Viteri (6) for nutritionally supplemented farm laborers in Guatemala.

The aerobic power of the other groups averages about 40 $ml/kg \cdot min^{-1}$. Since these groups are generally younger, the lower aerobic power is probably related to poorer physical fitness levels. This may reflect the level of occupational effort and/or the activity profiles during their leisure. We would speculate that the occupational demands of laborers engaged in civil service occupations in the United States are not physically demanding.

The relatively low aerobic power of the migrant workers is puzzling. This may reflect in part the seasonal nature of the occupations and, perhaps, a higher degree of mechanization than that available to the Colombian workers. All sugar cane cutting and loading is done by hand in Colombia. The sugar cane cutters average 3.52 tons of sugar cane per day (42), while the loaders attain 9.7 tons per day (Table 34). We have no information on the "productivity" of the United States laborers, but doubt that the tasks are as demanding as those of the Colombian sugar cane workers.

The oxygen pulse, which provides an index of stroke volume (5), followed the pattern observed for aerobic power. The highest value was observed with the loaders reflecting their higher aerobic power and lower maximal heart rate. This is consistent with the observation that stroke volume is higher in the trained state (35).

The total work performed generally followed the expected pattern with the highest levels attained by the group with the largest aerobic power. The major exception is the population of migrant workers. While their aerobic power was similar to that of the United States laborers, the total workload achieved was significantly lower. One may speculate that the type of work performed by migrant workers, namely, picking various crops, may not enhance peripheral adaptation of the leg musculature; therefore this group would tend to experience leg muscle fatigue earlier. The specificity of training on aerobic power (78, 79) and on cellular adaptation has previously been documented (80, 81).

SUMMARY

In order to determine the relationship(s) between nutritional status and economic productivity, two sets of studies have been performed. In the first, laboratory studies of body composition, nutritional status and physical condition (work capacity) have been done on 49 undernourished and normal adult males in Colombia, South America. Nineteen of the most severely malnourished of this group were also studied during a 2.5 month dietary repletion period in which the daily protein intake was increased from 28 gms/day to 100 gms/day.

The second set of studies was performed on 61 well nourished male sugar cane cutters and 28 sugar cane loaders in whom nutritional status, body composition, physical work capacity, energy expenditure during work and work productivity were determined under laboratory and field conditions. Sugar cane workers were chosen because of the relative ease in measuring productivity. These workers were compared with 18 other agricultural workers in Colombia not engaged in the harvesting of sugar cane, with a group of 20 civil service laborers in Milwaukee and with 15 Mexican-American migrant workers at the end of a harvest season in Wisconsin.

Finally, some measurements of maximum oxygen consumption were also done on 42 - 6 yr old children of differing nutritional and ethnic backgrounds to give some preliminary results of the effects of early malnutrition on some of the work parameters studied in the adults.

The studies in the Colombian adults were carried out:

(a) to establish a relationship between physical work capacity, as measured by the maximal oxygen consumption, and nutritional status in the undernourished subjects; and

(b) to establish a relationship between physical work capacity and productivity in the nutritionally normal sugar cane workers.

The establishment of (a) and (b) above would allow for the indirect establishment of a relationship between nutritional status and productivity.

The results have been grouped into studies of the physical work capacity as related to:

(A) Nutritional Status

(B) Nutritional Repletion

(C) Productivity

and can be summarized as follows.

(A) Nutritional Status

Of the 49 subjects in this group, 79% exhibited some form of intestinal parasitism and 69% some level of vitamin deficiency. The severity of malnutrition was associated with progressively more severe anemia (decreased hematocrit and blood hemoglobin), and a slight increase in plasma volume, which in the face of a decreased red cell volume resulted in no difference in blood volume expressed in terms of body weight. Total body water (ml/kg) was increased due to an elevated extracellular fluid volume. No significant difference in intracellular volume (ml/kg) was detected as a result of differences in nutritional status. Body composition (fat weight, fat free weight, fat free solids, body cell mass, cell solids, support tissue solids, muscle cell mass and visceral cell mass) was markedly influenced by nutritional status when expressed in absolute terms (kg) but only muscle cell mass was significantly related to nutritional status when body composition was expressed in terms of % body weight. Differences in body fat derived from body fluid compartment calculations and those based on skinfold measurements raise the question of the accuracy of both methods when applied to malnourished subjects.

The maximum oxygen consumption, expressed as L/min or after normalization for various parameters of body composition and nutritional status, exhibited a marked dependency on nutritional status. It was severely depressed in the malnourished subjects. There were highly significant statistical correlations between $\dot{V}_{O_2}$ max and numerous measures of nutritional status, with the highest being with creatinine excretion, total body

hemoglobin and extracellular fluid volume. These were sufficiently high to permit the development of predictive equations for $\dot{V}_{O_2}$ max and aerobic capacity. On the other hand, maximum heart rate was not correlated with nutritional status.

The maximal endurance time at 80% of $\dot{V}_{O_2}$ max (T_{80}) was not related to the nutritional status.

(B) Nutritional Repletion

The studies of the influence of dietary protein repletion consisted initially of a basal period which endured an average of 45 days and during which the protein intake was the same as that taken prior to entering the hospital, i.e., 28 gms/day. Following the basal period there ensued a 2-1/2 month dietary repletion period in which the protein intake was 100 gms/day. Measurements of body composition, nutritional status and physical work capacity (maximal oxygen consumption) were made at the beginning and end of the basal period and at 1.5 and 2.5 months after beginning the protein repletion.

The increased protein intake resulted in statistically significant increases in body weight, serum albumin, plasma proteins, plasma cholesterol and creatinine excretion. There was a slight decrease in plasma volume as part of an overall decrease in extracellular volume. Blood hematocrit and hemoglobin were initially unchanged by protein repletion but exhibited a significant increase at the end of the high protein diet.

The maximum oxygen consumption did not change in the basal period but showed a progressive and statistically significant increase during protein repletion. This increase was not only the result of the change in body weight since it was present after normalization of $\dot{V}_{O_2}$ max for weight. An important observation was the significant improvement in this parameter before significant changes in blood hemoglobin concentration or total body hemoglobin content were observed. There was no significant alteration in

maximum heart rate throughout the entire experiment in these subjects, indicating the lack of a training effect as a result of the several exercise tests performed.

An interesting observation in these subjects was the significant decrease in maximum endurance time on the treadmill when the subjects were working at 80% of their $\dot{V}_{O_2}$ max. This may be related to the substitution of carbohydrate calories by protein calories in the daily diet. This observation has also been made by others in animal experiments (39).

Body compositional changes were also statistically significant and in general showed an increase in most components with changes in muscle cell mass being the most outstanding.

(C) Productivity

The studies on the sugar cane cutters showed clearly that in heavy physical work the productivity is related to body size (height and weight) as well as to physical condition as determined by the $\dot{V}_{O_2}$ max measured in the laboratory and heart rates measured during work in the field. These findings are those intuition would predict. Multiple regression analysis resulted in the following equation which contains those factors which contribute significantly to productivity:

$$P = 0.81\ V - 0.14\ F + 0.03\ H - 1.96$$

wherein;

P = productivity (tons of sugar cane cut/day)

V = $\dot{V}_{O_2}$ max (L/min STPD)

F = % body fat

H = height (cm)

However, since the equation accounts for only about 50% of the variability in productivity, it cannot be used as a predictor of productivity. The data indicate that productivity is affected indirectly by nutritional status through the influence of the latter on height, fat content and $\dot{V}_{O_2}$ max.

Evidence is also presented that as the worker ages a higher percent of the $\dot{V}_{O_2}$ max has to be utilized in order to maintain productivity.

Among the cane cutters there was a group of men who were inefficient in the work performed and therefore had to utilize an inordinately high fraction of their $\dot{V}_{O_2}$ max to maintain normal productivity. This raises questions about the effects of motivation and habitual alcohol consumption (since the latter has been shown to affect efficiency) on daily productivity in these subjects. Answers are not available since these variables were not measured in the present studies.

It would seem, then, that productivity is the result of many factors such as body size and composition, physical condition, nutritional status, motivation, habitual alcohol consumption and, perhaps, even weather conditions. We have measured daily productivity over a 3-month period and taken an average for purposes of these studies. However, the daily values for productivity show a marked variability which the 3-month average was designed to minimize. It may be that one of the newer approaches of mathematics described by Zeeman (82) will find application in quantitating the complex relationships between productivity and the multitude of variables which can affect it.

In comparing the Colombian sugar cane workers (cutters and loaders) with other agricultural workers in Colombia and with laborers and migrant workers in the United States, it was found that the Colombian workers had values for $\dot{V}_{O_2}$ max significantly larger than the U. S. subjects. These findings were probably related to greater physical fitness associated with the physical demands of their occupations.

Finally, the preliminary studies on 6 year old children indicate that malnutrition early in life (up to 3 yrs of age) results in depressed $\dot{V}_{O_2}$ max values and that subsequent nutritional supplementation for 3 years improves physical condition but does not return the children to normal

levels. These results are preliminary and suggest the need for a larger study on the influence of malnutrition on the growth and development of work capacity in children.

CONCLUSIONS

The specific conclusions to be drawn are stated simply and largely restricted, in this section, to the specific questions asked of the experiments performed as stated in the Introduction to this progress report. A broader statement of the findings and conclusions is found in the Summary.

1) Does the nutritional state influence the maximal aerobic power of the subject?

The results show clearly that $\dot{V}_{O_2}$ max is significantly related to various measures of nutritional status and that some of these have high enough correlations to be utilizable in predicting $\dot{V}_{O_2}$ max, particularly when several are combined.

2) Does the nutritional state influence the fatigability (maximal endurance time at the same <u>relative</u> work load)?

The results obtained on this point are ambivalent. When maximal endurance times at a work load of 80% of $\dot{V}_{O_2}$ max (T_{80}) was related to nutritional status of the 49 subjects in the nutritional status (vertical) study, there was no statistically significant correlation with any of the parameters which measure nutritional status (e.g., serum albumin or (creatinine excretion x total hemoglobin)/extracellular fluid volume). However, the 19 subjects studied during nutritional repletion with dietary protein exhibited a significant decrease in endurance time at the end of the 2.5 month repletion period. This may be related to the substitution of protein for carbohydrate in the isocaloric diet consumed by the subjects.

3) Is productivity related to the work capacity as measured by the maximum ability of the subject to consume oxygen (aerobic power)?

The answer to this question is "yes." While the degree of statistical correlation of productivity with aerobic power was not high ($r = 0.34$), it was statistically significant.

4) Since these studies were performed in Colombian agricultural workers, what were the normal values for maximal oxygen consumption in Colombian workers as compared to laborers in other ethnic groups?

Normal values of $\dot{V}_{O_2}$ max for Colombian sugar cane cutters and loaders and general farm workers have been established and found to be higher than Milwaukee County civil service laborers and Mexican-American migrant farm workers. The difference is probably related to the severity of daily work tasks.

5) Does malnutrition early in life affect the maximal oxygen consumption?

Undernutrition in 6-yr old children results in severe depression of $\dot{V}_{O_2}$ max. Children who were undernourished at age 3 and received dietary supplementation for the 3 years prior to being studied at 6 years showed some recuperation of physical condition but were still in poorer physical condition than children from upper socioeconomic groups who had never been exposed to undernutrition.

In general, it has been found that physical work capacity ($\dot{V}_{O_2}$ max) is directly related to nutritional status. It has also been established that productivity is directly related to $\dot{V}_{O_2}$ max as well as to other nutritionally related parameters. By inference, then, the productivity of workers engaged in physically taxing occupations is directly related to the nutritional status of the individual.

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