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(100) Spurr,G.B.; Barac-Nieto,M.; Maksud,M.G.
(101) Medical College of Wis.and Research Service,Milwaukee

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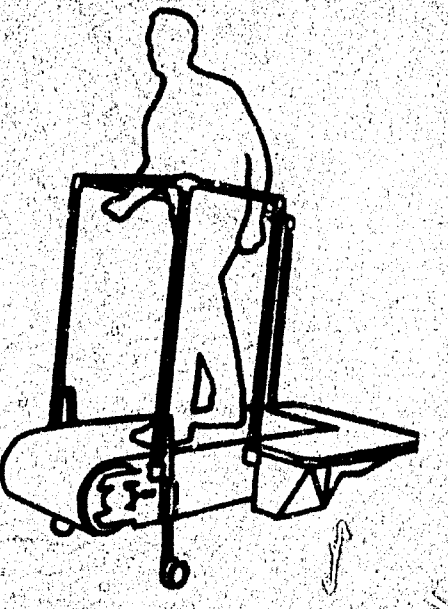
Agency for International Development
Project No. AID/CSD 2943
For the period: Jan. 1, 1971 – Dec. 31, 1972

G. B. Spurr, Ph.D.
Principal Investigator
Professor of Physiology
Medical College of Wisconsin
and Research Service
Wood VA Center
Milwaukee, Wisconsin



M. Barac N., M.D., Ph.D.
Co-Investigator
Associate
Professor
of Physiology
Universidad del Valle
Cali, Colombia

M. G. Maksud, Ph.D.
Co-Investigator
Associate Professor of
Physical Education
University of Wisconsin-
Milwaukee
and Research Service
Wood VA Center
Milwaukee, Wisconsin

MARCH, 1973

CLINICAL AND SUBCLINICAL MALNUTRITION
Their Influence on the Capacity to do Work

ANNUAL PROGRESS REPORT

to

AGENCY FOR INTERNATIONAL DEVELOPMENT

Contract No. AID/CSD 2943

for the period

January 1, 1972 to December 31, 1972

from

G. B. Spurr, Ph.D.
Principal Investigator
Medical College of Wisconsin and
Research Service, Wood VA Center
Milwaukee, Wisconsin

M. Barac N., M.D., Ph.D.
Co-Investigator
Universidad del Valle
Cali, Colombia

M. G. Maksud, Ph.D.
Co-Investigator
University of Wisconsin-
Milwaukee and
Research Service, Wood VA Ctr.
Milwaukee, Wisconsin

REPORT SUMMARY

A. 1. Project Title:

Clinical and Subclinical Malnutrition:
Their Influence on the Capacity to do Work.
Contract No. AID/CSD2943

2. Principal Investigator

G. B. Spurr, Ph.D.
Professor of Physiology
Medical College of Wisconsin
Milwaukee, Wisconsin 53233

Contractor

Medical College of Wisconsin
561 North 15th Street
Milwaukee, Wisconsin 53233

3. Contract Period

June 30, 1971 to March 31, 1973

4. Period Covered by Report

January 1, 1972 to December 31, 1972

5. Total AID Funding to March 31, 1973

$70,304

6. Not Applicable

7. Total Expenditures and Obligations to March 31, 1973

Estimated - $65,250

8. Estimated Expenditures for Next Contract Year

$61,915

B. Narrative Summary of Accomplishments and Utilization

During the period from June 30, 1971 to December 31, 1972, we have

1) procured equipment and supplies necessary to set up an Exercise Physiology Laboratory.

2) shipped the equipment and supplies to Cali, Colombia and set up the laboratory in the University Hospital of the Universidad del Valle.

3) trained a technical staff and developed the laboratory techniques required in the testing procedures.

4) set-up procedures for finding malnourished subjects in the rural Colombian population.

5) instituted studies on 11 malnourished patients in the Metabolic Ward and Exercise Laboratory of the University Hospital.

6) completed studies on 28 sugar cane cutters both in the field and in the Exercise Laboratory.

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 November of 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 subject 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.

C. Continued Relevance of Objectives

The overall objectives of the research are the same i.e. to quantitate the presumed impairment in physical work capacity in 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. Our results to date (Appendix I) show clearly that we are on the right track but that more work is needed.

D. Accomplishments to Date:

1. Findings:

The results to date are presented in detail in Appendix I (Section H). Briefly, we have studied 11 patients, who had varying degrees of malnutrition, in the University Hospital of the Universidad del Valle. The findings show clearly that the depression in work capacity is indeed related to the severity of malnutrition and that it can be quantitated. Instead of developing a simple work test to reveal sub-clinical malnutrition it may be possible to relate the impairment in physical work capacity to some simpler measurement such as serum albumin or height-weight ratios. Our results show statistically significant correlations of physical work capacities with these and other indicies of nutritional state. However, our data are too prliminary as yet to make firm conclusions.

In addition to the studies in patients we have measured the energy cost of cutting sugar cane in 28 subjects and related it to their productivity (since they are paid by the metric ton of sugar cane cut) and their maximum capacity to do work as determined under laboratory conditions. Again, the results are preliminary and do not permit final conclusions. However, they are encouraging.

Consequently, in general the anticipated results are being obtained and we are confident that the work objectives will be attained. There do not seem to be any foreseeable difficulties in applying the results.

2. Interpretation of Data and Supporting Evidence:

The reader is referred to the Results and Discussion Section of Appendix I for a complete interpretive discussion. Briefly we have determined that cutting of sugar cane is heavy work which can be readily measured from the standpoint of energy expenditure. Furthermore, it appears that productivity is related to various physiologically definable parameters. Also, as anticipated, the capacity to do work is related to the nutritional state of the subject, being markedly depressed in clinically malnourished patients and showing an increase as the nutritional state is improved.

3. Research Design:

The only significant modification in the research design was the dropping of the techniques for measuring cardiac output and pulmonary diffusing capacity. These were found to impede the subject's willingness to cooperate with the investigators in the performance of the work tasks. It is hoped that these can be completed in selected subjects.

Also we have found that the endurance time at 40% of the maximum work capacity is not a useful parameter and are planning an increase to a higher level.

Otherwise, the approach and techniques have proven to be worthwhile and will continue.

E. Dissemination and Utilization of Research Results:

1. No attempt has been made as yet to disseminate the information obtained. Publication of parts of the data are planned for the future. The rest will have to await the accumulation of additional data.
2. There is no evidence of use of the findings by LDC's or the United States. The findings are too preliminary.
3. No.

4. The major portion of this work is being done at the Universidad del Valle in Cali, Colombia. There are 3 professional people and 3 technicians currently involved in the work who are Colombians working at the University. One of them, Dr. Mario Barac, is a co-investigator and so has been involved in all aspects of the project from the beginning.

5. No publications have resulted as yet.

F. Statement of Expenditures and Obligations:

	Initial Amount 6/30/71	Estimated Expenditure to 3/31/73	Estimated Balances 3/31/73
Salaries & Wages	23,084	19,818	3,266
Fringe Benefits	2,308	2,800	- 492
Overhead	6,200	4,750	1,450
Travel, Transportation and Allowances	6,950	4,451	2,499
Other Direct Costs	9,577	9,045	532
Equipment, Vehicles, Materials & Supplies	22,186	24,386	-2,200
TOTALS	$ 70,305	$ 65,250	$ 5,055

G. Work Plan and Budget Forecast for Coming Year

1. Anticipated Accomplishments

We plan to carry 8 clinically malnourished patients through the 16 week replenishment regime as described in the proposal. We also hope to considerably increase the number of borderline (subclinical) patients but cannot give a specific number. This will depend on the availability of subjects as well as the work load on the laboratory.

This summer two U. S. personnel (Drs. Spurr and Maksud) will spend 6-8 weeks in Cali doing field studies on sugar cane cutters and those who load the cane. It is anticipated that we may be able to do 40-50 subjects and perhaps finish this aspect of the study.

2. Procedures

These are described in Appendix I.

3. Factors which will promote or impede

We do not anticipate any difficulties. The presence of the 3 principal investigators together in Cali for 6-8 weeks should considerably enhance the planning of the work and data analysis for publication.

4. Plan for Dissemination

Publication of the data is planned in the open physiological literature when the data warrants it.

5. Budget Statement for Coming Year

Summary

Salaries & Wages	$ 29,578
Fringe Benefits	4,250
Overhead	8,269
Travel	6,900
Other Direct Costs	8,000
Equipment, Materials and Supplies	5,500
Consultants	1,050
TOTAL	$ 63,547

H. APPENDIX I

DETAILED RESEARCH REPORT

ACKNOWLEDGEMENT

The authors wish to express their deep appreciation for the cooperation granted them by the management of Central Castilla, Ltd. and La Quinta during the summer of 1972. The willing participation of the corteros in these studies as well as that of the hospital patients, is acknowledged with gratitude. The authors also express their appreciation for their competent technical assistance, in various phases of the work, to the following: Srtas. Maria Cristina Narvaez and Julia Maria Tascon, Snra. Serbula de Rivera, Sr. Santiago Rivas, Mrs. Judith Hoernke and Mrs. Judith Broaddrick.

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TABLE OF CONTENTS

	Page
List of Tables	iv
List of Figures	vii
Symbols	x
Introduction	1
Materials and Methods	6
I. Studies in Sugar Cane Cutters	6
A. Type of work	6
B. Subject Selection	7
C. Measurements in the Field	8
D. Analysis of Gas Samples	11
E. Testing in the Laboratory	12
II. Studies in Malnourished Patients	13
A. Type of Patients	13
B. Patient Selection Procedure	13
C. Longitudinal Study	15
D. Vertical Study	19
E. Summary of Criteria for Patient Selection	22
F. Exercise Testing	23
1. Reproducibility of Exercise Tests	23
2. Exercise Protocol	25
3. Criteria for Maximal	26

Page

G. Statistical Analysis 27

Results and Discussion 28

I. Studies on Sugar Cane Cutters 28

A. Productivity 28

B. Anthropometric Data 35

C. Heart Rates 35

D. Oxygen Consumption and Pulmonary Ventilation . . 43

E. Energy Expenditure and Rate of Cutting Sugar Cane. 43

F. Maximum Oxygen Consumption (Aerobic Power) 51

G. Percent $\dot{V}_{O_2}$ max 57

H. Productivity and Aerobic Power ($\dot{V}_{O_2}$ max) 59

I. Activity Levels 61

J. Dietary Histories 66

II. Studies in Malnourished Subjects 69

A. Basal Data 69

B. Effects of Training 74

C. Effects of Protein Repletion on Physical Work Capacity, Body Composition and Blood Composition . 77

D. Vertical Group 82

E. Relationship Between Nutritional State and Endurance at Identical Relative Work Loads. . . . 87

Page

F. Relationship of Maximal Aerobic Power to Nutritional State 89

G. Relationship of Total Body Water to Maximal Aerobic Power 92

Summary and Preliminary Conclusions 103

I. Studies in Sugar Cane Cutters 103

II. Studies in Malnourished Subjects 104

Future Studies 105

References 108

LIST OF TABLES

		Page
I	N_2 Balance Before, During (Exercise Test on Day 4) and After a $\dot{V}O_2$ Max Test.	17
II	N_2 Balances in Subjects in Vertical Study.	20
III	N_2 Balances Before and After Exercise.	21
IV	Productivity Data from Sugar Cane Cutters at La Quinta	29
V	Productivity Data from Sugar Cane Cutters at Central Castilla	30
VI-A	Physical Characteristics of Sugar Cane Cutters	33
VI-B	Physical Characteristics of Sugar Cane Cutters	34
VII	Heart Rates at Rest and During Cutting of Sugar Cane .	38
VIII	Physiological Responses Cutting Sugar Cane	40
IX	"t" Values for Comparison of Slopes and Intercepts of the Regression Lines of Heart Rate on Oxygen-Consumption in Groups I, II and III of Sugar Cane Cutters Presented in Fig. 4	41
X	Ambient Air Temperatures During Work Testing in Sugar Cane Cutters	50
XI	Relation Between Productivity and $\dot{V}O_2$ Max in 3 Groups of Sugar Cane Cutters	52

Page

XII Data on Maximum Work Capacity Test in Sugar Cane Cutters 56

XIII Occupational and Spare-Time Activity Groupings . . . 65

XIV Estimated Daily Dietary Intake of Sugar Cane Cutters 67

XV General Characteristics and Blood Chemistry of Patients in the Longitudinal Study 70

XVI Hematological Characteristics of Patients in Longitudinal Study 71

XVII Body Composition of Patients in Longitudinal Study . 72

XVIII Physical Work Capacity of Patients in Longitudinal Study 73

XIX Maximal Heart Rates in Subjects in the Longitudinal Study 75

XX Effects of Retesting 4 Weeks Apart on Exercise Performance of Patients in Longitudinal Study 76

XXI Changes in Physical Work Capacity During Nutritional (Protein) Repletion 78

XXII Changes in Blood Chemistry During Nutritional Repletion 80

XXIII Changes in Body Composition During Nutritional Repletion 81

Page

XXIV General Characteristics, Patients in Vertical Study 83

XXV Physical Work Capacity, Patients in Vertical Study 84

XXVI Body Composition, Patients in Vertical Study . . . 85

XXVII Hematological Data of Patients in Vertical Study . 86

XXVIII T_{max40} at Different Nutritional States as Evaluated by the Serum Albumin Level 88

LIST OF FIGURES

No.		Page
1.	Proposed relation of % $\dot{V}O_2$ max to endurance time in malnourished subjects	5
2A.	Subject at rest	10
2B.	Subject cutting sugar cane	10
2C.	Daily productivity data for two 3 month periods . .	31
3.	Pulmonary ventilation (BTPS) oxygen consumption (STPD) and cardiac frequency in response to cutting sugar cane in the morning and afternoon	36
4.	Regression equations of heart rate on oxygen consumption (STPD) in three groups of sugar cane cutters before and during work	37
5.	Energy cost during the 5 and 20 min. determinations while cutting sugar cane in the morning & afternoon .	45
6.	Rate of sugar cane cutting in kilograms/hr.	46
7.	Caloric cost of cutting cane per kilogram of cane cut	48
8.	Relationship of aerobic power to age of the subjects	55
9.	Means and standard deviations of observed and estimated sustained $\dot{V}O_2$ max during cutting of sugar cane	58

No. Page

10. Relationship between daily productivity of sugar cane cutters and their maximum work capacity expressed as aerobic capacity 60

11. Relationship between daily productivity and age of sugar cane cutters 62

12. Correlation between daily productivity and estimated sustained % $\dot{V}O_2$ max utilized in cutting sugar cane . . 63

13. Correlation between daily productivity and estimated sustained % $\dot{V}O_2$ max utilized in cutting sugar cane in the afternoon 64

14. Statistically significant relationship of aerobic power to serum albumin in undernourished subjects . . 90

15. Statistically significant relationship of aerobic power to weight/height ratios in undernourished subjects 91

16. Statistically significant relationship of aerobic power to the ratio of total body water/body weight in undernourished subjects 93

17. Statistically significant relationship of aerobic power to the fat free weight/body weight ratio in undernourished subjects 94

No. Page

18. Relationship of aerobic power to the extracellular water/body weight ratio in undernourished subjects 96

19. Plot of the reciprocols of aerobic power and the extracellular water/body weight ratio in undernourished subjects 97

20. Demonstrating lack of relationship between aerobic power and intracellular water/body weight ratio in undernourished subjects 98

21. Statistically significant relationship between aerobic power and the fat weight/body weight ratio in undernourished subjects 99

22. Statistically significant relationship between aerobic power and total body hemoglobin/body weight ratio in undernourished subjects 100

SYMBOLS

$\dot{V}O_2$	Oxygen consumption - L/min standard temperature and pressure dry (STPD)
$\dot{V}_E$	Pulmonary ventilation - L/min body temperature ambient pressure saturated (BTPS)
$\dot{V}CO_2$	Carbon dioxide production - L/min (STPD)
f_H	Cardiac frequency - beats/min
R	Ratio of $\dot{V}CO_2/\dot{V}O_2$
$\dot{V}O_{2max}$	Maximum oxygen consumption - L/min or $ml/Kg \cdot min^{-1}$ (aerobic power or capacity) STPD
$\%\dot{V}O_{2max}$	The percent of the maximum oxygen consumption utilized in a given task.
n or N	number of observations
$\bar{x}$	mean
S.D.	Standard deviation
t	Student "t" value for statistical comparisons
W/H or Wt/Ht	Body weight/height ratio - Kg/M
pcg	picograms
ng	nanograms
TBW	Total body water - L
ECF	Extracellular fluid - L
ICW	Intracellular water
CH	Coefficient of hydration

SYMBOLS (Continued)

FFW	Fat free weight - Kg
FW	Fat weight - Kg
FFS	Fat free solids - Kg
DS	Dry solids - Kg
$T_{max_{40}}$	Endurance time to exhaustion when working at 40% of $\dot{V}_{O_2max}$ - minutes

INTRODUCTION

The major goal of the first stages of this project is to assess whether or not it is possible to quantitate the economic impact of malnutrition in a workers' population of a given region. There are two basic working assumptions:

(a) That work productivity is quantitatively related to physical work capacity in certain types of work which tax the aerobic capacity of the subjects by close to 40% and thus can be classified as "heavy" work (1,2). These types of heavy work are commonplace in developing countries where a large fraction of the population depends on manual, agricultural or mining labor for survival.

(b) That physical work capacity is quantitatively related to the nutritional state (body composition) and/or to the nutritional history of the subject.

The first stages of the project have been directed to assess the validity of these two working hypotheses by:

(a) Studying the relationship between work productivity and physical work capacity in sugar-cane cutters, a labor force upon which depends a large fraction of the economy of the Valley of the Cauca in Colombia. In this study we have determined the oxygen cost per ton of cane cut for

each worker studied and a measure of average daily productivity obtained from the records of the employer. The average daily oxygen cost of sugar cane cutting can be calculated and expressed as an average rate of oxygen consumption required to maintain a given productivity. For most of the subjects the maximal oxygen consumption was also measured. The relative stress that sugar cane cutting represents for each worker can thus be assessed as the fraction of the $\dot{V}O_2$ max that must be sustained to achieve a given productivity. The relationship between work productivity and physical work capacity expressed as the percentage of the maximal aerobic power at which the subject must work was thus studied.

(b) Tests of the second working hypothesis, i.e., nutrition can be related to physical work capacity, have been done on the following rationale. Endurance at a given load depends on (i) 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 (ii) on 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). Astrand (3,4) has shown that endurance of 8 hours (one working day) cannot be achieved at relative loads higher than about 40% of maximal aerobic power. Furthermore, the 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 vs. $\dot{V}_{O_2}$ 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, resulting in different degrees of taxation on the subjects' aerobic reserves, or to changes in endurance time at the same relative work load. These concepts are

illustrated in Fig. 1.

Thus, specific objectives in this study are:

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

(b) Does the nutritional state influence the fatigability (maximal endurance time at the same relative work load)? These questions are being attacked in two groups of patients.

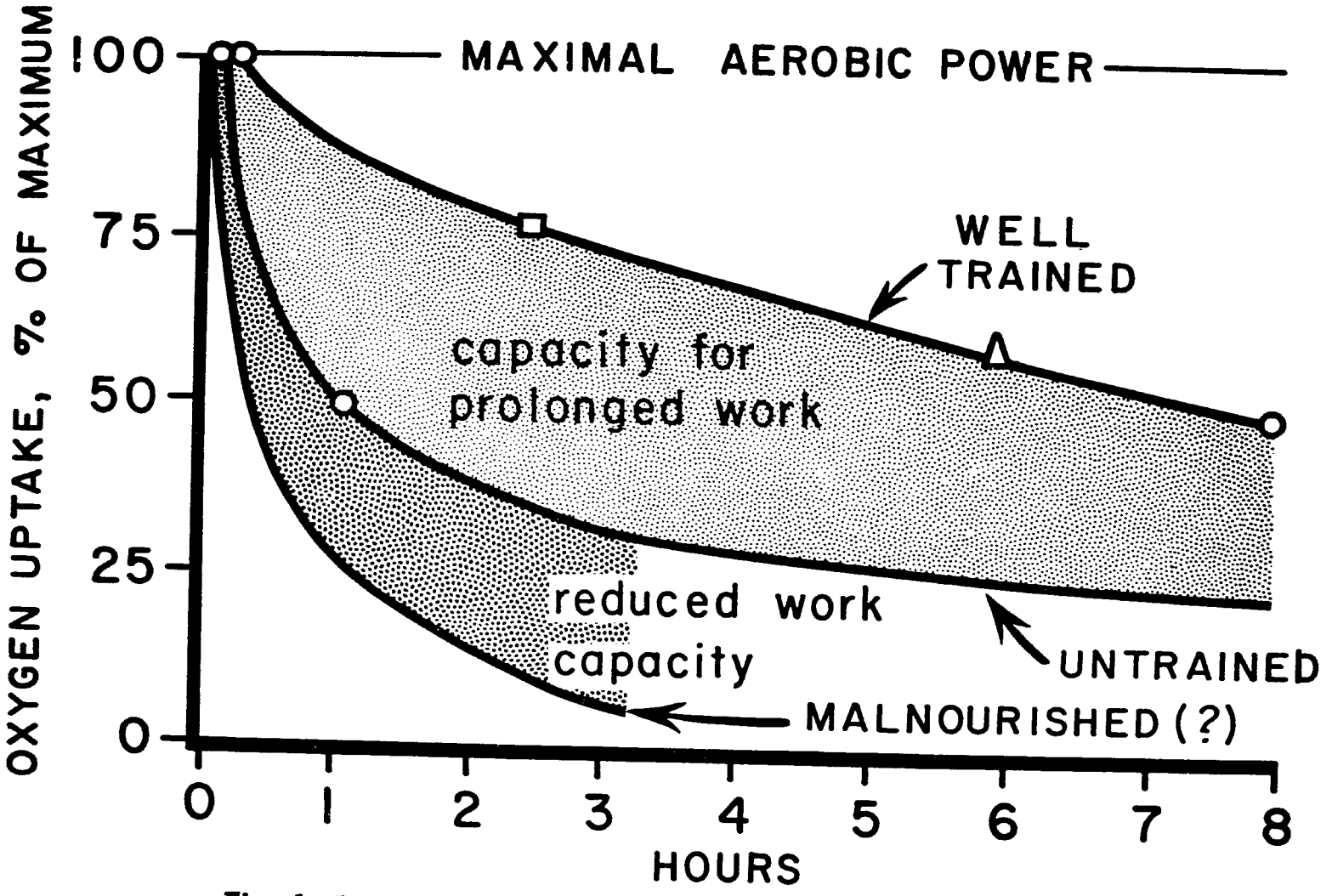

Fig. 1 Proposed relation of % $\dot{V}_{O2max}$ to endurance time in malnourished subjects (modified from Astrand and Rohdal (4))

MATERIALS AND METHODS

I. STUDIES IN SUGAR CANE CUTTERS

(A) Type of Work

The agricultural activity in the Valley of the Cauca in Colombia is in large part devoted to the growing and processing of sugar cane. The procedure of gathering the cane in the fields occurs in two steps. Gangs of cutters (corteros) are assigned to a field, each man being assigned to a "line" approximately 15 feet in width. Cutting starts at the edge of the field and moves toward the center. Each man cuts and de-leafs the cane and stacks it in a pile which follows him across the field. Each cutter marks his pile with his number, since the men are paid by the metric ton of sugar cane cut. At some later time (2-3 days) the cane is loaded in wagons which are then towed to the sugar mill. At the mill the cane is weighed and the weight recorded for the cutter. The loading is also done by hand and the loaders (alzadores) are likewise paid by the weight they load.

Work begins at about 6:30 a.m. and continues, with only brief stops for water, until noon. The men then take an hour for lunch. Work resumes at 1:00 p.m. and continues until approximately 3:30 p.m.

The two types of work appear to be quite different in intensity. Cutting is hot, heavy physical labor. Loading is accomplished by picking up the cane, one piece at a time, and tossing it up on the

wagon. Each piece of cane weighs 1-2 kg depending on the type of cane being cut. To date no physiological measurements have been made on the alzadores.

(B) Subject Selection

The data to be presented were obtained on 28 corteros. Seven were measured in the fields of a small sugar refinery called "La Quinta". This company hires a contractor who in turn organizes the men, keeps their records and pays them their wages. The subjects were selected purely on a voluntary basis.

The remaining 21 subjects were the direct employees of one of the largest sugar refineries in Colombia named "Central Castilla, Ltd.". Excellent records were available of their productivity and work history for the entire period of their employment. Subjects were selected on the basis of their average daily productivity for the previous 3 months, with an attempt to obtain equal numbers of good, average and poor workers. Since this was the first attempt to measure work in this type of laborer, we also tried to obtain a representative age span. The youngest was 18 and the oldest 56 years of age. An additional criterion was that no subject who was absent from work more than 2 days during the previous 3 months was chosen for the study. The experience of the men in cutting cane varied from a minimum of 4 months to a maximum of 15 years with a

majority reporting 3-4 years of experience.

(C) Measurements in the Field

Oxygen consumption and pulmonary ventilation were measured with a Kofranyi-Michaelis respirometer which was calibrated with a Model 3-PV Emerson Volume Controlled Ventilator. This ventilator allows for individual control of both frequency and tidal volume. The calibrations were carried out as described by Consolazio (5) up to ventilation rates of 60 L/min.

Aliquot samples of expired air were taken in a rubber balloon attached to the respirometer with the sampling valve set at 0.6%. Immediately following termination of a measurement, 50 cc of the sample were transferred to an oiled, glass syringe for storage. The rubber balloon, when not in use, was stored filled with expired air as recommended by the manufacturer.

Heart rates were taken with a Parks Telemetry System. The transmitter was placed in the cup of a men's athletic support worn around the waist with the transmitter at the back. The transmitter was then fixed in place by wrapping the subject's waist several times with an elasticized hospital bandage. Two electrodes were firmly fixed on the chest. The beep produced in the receiver by each heart beat was recorded on a portable cassette tape recorder

for counting later. Heart rates were counted for 30 seconds during each minute of the 5 minute data collection periods, averaged and expressed as beats/min.

Prior to preparing each subject, the equipment and its use was carefully explained. Also, he was instructed that while working he was to cut cane as was his usual custom, neither faster nor slower. After placing the equipment on the subject he was allowed to respire quietly at rest for 10 minutes in order to allow him to become accustomed to the mouthpiece and nose clamp, in an attempt to try to reduce the natural tendency of untrained subjects to hyperventilate. Then a 5-10 minute collection period ensued to determine resting values (Fig. 2A).

Following the resting measurements, the subject began to work on signal and worked steadily for 5 minutes (Fig. 2B). While work continued, the respirometer was turned on and data collection was made between the 5th and 10th minute of work. It has been shown that at submaximal work loads, heart rate and oxygen consumption plateau after about 2 minutes of work (6). At the end of the 5 minute collection period, the subjects stopped long enough to remove the rubber balloon and mouthpiece and recording of ventilation values from the respirometer. He then

A. Subject at Rest

B. Subject Cutting Sugar Cane

Fig. 2

continued working until the 16th or 17th minute when the mouthpiece and collection bag were replaced. A second collection was then made between the 20th and 25th minutes. Following the second collection period the apparatus was taken off the subject and he returned to his work.

During each period of testing the cane cut by the subject was carefully collected, counted and weighed on a Detecto Scale Balance having a 500 kg capacity. The accuracy of the balance was checked with 50 and 100 lb. standard weights and found to be accurate to less than 1%.

It was possible to make measurements on 3 men per day during July and August of 1972. Testing began on the first man about 7 a.m. and finished on the third at about 10 a.m. Consequently, the first man each day had not been working prior to the test whereas the second and third had been working about 1 and 2 hours respectively, before undergoing the testing procedure. In 25 of the 28 subjects, repeat measurements were made in the afternoon between about 1 p.m. and 4 p.m., using the same testing procedure as in the morning.

(D) Analysis of Gas Samples

At the end of a day of testing the stored expiratory gas samples were transported back to Cali for analysis. Oxygen and

carbon dioxide concentrations were measured in duplicate by gas chromatography (Model H-3, QuinTron Instruments). All gas analyses were done on the day of collection. With the data obtained it was then possible to calculate pulmonary ventilation, oxygen consumption, carbon dioxide production, respiratory quotient and energy expenditure.

(E) Testing in the Laboratory

Twenty-seven of the 28 subjects were transported to the Exercise Laboratory of the Universidad del Valle to undergo a maximum work test ($\dot{V}O_2$ max). The testing procedure is described in a later section of this report.

While at the laboratory, a nutritional history was taken on each subject by a trained nutritionist and an estimate made of their daily food intake. Each subject was interviewed and a daily activity schedule made out for classifying the occupational and spare-time physical activity as described by Saltin and Grimby (7).

The scapular, triceps and iliac crest skinfolds were measured utilizing Lange Skinfold Calipers. All measurements were made by the same observer. Three measurements were made at each site and averaged. Body density was estimated by the formula of Pascale, Grossman and Stone (8). Body fat was calculated by the formula of Brozek and Keys (9).

II. STUDIES IN MALNOURISHED PATIENTS

(A) Type of Patients

In a first group of patients covering a range of nutritional states (vertical study) maximal aerobic power and maximal endurance times are being studied in the hope of correlating parameters of body composition and nutritional state to physical work capacity.

In a second group of patients (longitudinal study) the effects of nutritional (protein) repletion on physical work capacity, body composition and blood chemistry are being studied.

The simultaneous study of these two groups will allow us to establish the relevance of the findings in the patients who are hospitalized for up to 4 months during their nutritional repletion (longitudinal study) to the general population as studied in the "vertical"group.

(B) Patient Selection Procedure

Social workers of the metabolic unit have been contacting adult males, 20-50 years old, devoted to agricultural manual labor in the rural areas of the Cauca Valley. This particular age range was chosen as representative of the "useful" age range for agricultural workers.

The objectives and procedures of the project are explained to the patients and a blood sample, height and weight are taken in the field.

Specific questions and examinations related to past illnesses, cough, sputum, chest pains, cyanosis, digital clubbing, shortness of breath, osteoarthritic pains or deformities, deafness, equilibrium or gait problems are asked about and reported by the social worker. The gross questionnaire calls attention to any ongoing or chronic disease. Two hundred and fifty such inquiries have been performed as of November 30, 1972. Patients are preselected on the basis of:

(a) A low albumin level (<3.5 gm%)

(b) Low total proteins (<7.5 gm%)

(c) Low cholesterol level (<200 mg %)

On the basis of the severity of the biochemical changes the patients are chosen for the longitudinal study (albumin <2.5 gm %, total proteins <6 gm %, cholesterol <120 mg %) for the vertical study, or discarded as possible subjects. Two patients with normal or near normal serum levels of albumin, total protein and cholesterol have also been included in the "vertical" group so as to cover a wide range of nutritional states.

Once a patient has been included in the study (either group) he is brought into the metabolic ward. A complete physical examination, clinical history, EKG, chest X-ray, sputum analysis, tuberculin test, serology, coporanalysis, blood count, blood chemistry, liver function tests, renal function tests and urinanalysis are taken.

If no pathology is found, except for the poor nutritional state, the patient is included in the study. Intestinal parasitism (ascaris, amoebas) and anemia have been frequently encountered associated with undernutrition and it has been impossible to discard such patients from the study.

In all patients, in addition to the blood count, hemoglobin and hematocrit, vitamin B_{12}, folic acid, serum iron, iron binding capacity, per cent transferrin saturation were determined and a bone marrow aspirate are taken.

Once a patient has been included in the study, analysis of urinary vitamins and of blood vitamins is ordered (in a 12 hour urine sample and a blood sample collected in the first hospital day).

The patient is placed on a protein diet similar to the one he takes at home (generally not exceeding 25 gm/day), according to the results of a nutritional survey.

(C) Longitudinal Study

In patients included in the longitudinal study (severely malnourished) a pooled 4 day collection of urine and feces is done after 1 week on the low protein hospital diet, for N_2 balance and urinary creatinine output determinations.

The one week period is allowed to establish a steady state in N_2 input and output. Exercise testing or training is avoided in this period since experiments with two patients showed that nitrogen balance becomes 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 I). Upon termination of balance studies, body composition studies are initiated.

TABLE I

N_2 BALANCE BEFORE, DURING (EXERCISE TEST ON DAY 4) AND AFTER A $\dot{V}_{O_2}$ MAX TEST

g/day

	Days		
PATIENT	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

Body weight is determined to the nearest 25 gm. Total body water is determined by dilution of tritiated water (HTO). Extracellular water is estimated by thiocyanate dilution. Plasma volume is determined by Evans blue dilution. Total blood volume is calculated from plasma volume and venous hematocrit. This also allows for calculation of total body hemoglobin.

After exercise testing (to be described), the patients continued for 4 weeks on a low protein diet.

At the end of these four weeks, the nutritional evaluation protocol, body composition and exercise studies are 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 is started with an isocaloric diet providing 100 gm of protein per day. Four weeks after the start of nutritional repletion the testing protocol is repeated.

The same protocol is repeated 8 weeks after and when possible 12 weeks after the start of nutritional repletion.

(D) Vertical Study

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

In a first group of 9 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 II). 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 III).

TABLE II

N_2 BALANCES IN SUBJECTS IN VERTICAL STUDY

Averages of days 3 to 7 in the Hospital
(20-25 g/protein per day)

PATIENT	N_2 Balance g/day
MT	-1.36
MAC	- .97
RCh	-2.11
RI	- .29
MT	-1.87
Mean	-1.32
S.D.	0.73

TABLE III

N_2 BALANCES BEFORE AND AFTER EXERCISE

gm/day

PATIENT	Before	Before	3 Days After	15-20 Days After
IM	+ .892	+ 1.189	+ 1.080	+ 1.110
RU	+ 1.323	+ .661	+ 1.230	+ 1.310
RC	+ 1.850	+ .795	+ 1.037	+ .605
Mean	+ 1.355	+ 0.882	+ 1.116	+ 1.008

(E) Summary of Criteria for Patient Selection

1. Body weight low for height, age, and sex or presence of edema

2. Serum albumin

Severely malnourished (longitudinal study)	<2 gm%
Subgroup I in vertical study	2-2.5
Subgroup II in vertical study	2.6-3
Subgroup III in vertical study	3.1-3.5

3. Total serum protein

Severely malnourished (longitudinal study)	<6 gm %
Subgroup I in vertical study	6-6.5
Subgroup II in vertical study	6.6-7
Subgroup III in vertical study	7.1-7.5

4. Serum cholesterol

Severely malnourished (longitudinal study)	<120 mgm %
Subgroup I in vertical study	121-150
Subgroup II in vertical study	151-170
Subgroup III in vertical study	171-200

5. Absence of cardiopulmonary abnormalities

ECG, exercise ECG normal

Rx chest normal

6. Absence of osteoarthritic abnormalities

7. Absence of neurological abnormalities

8. Absence of acute or chronic diseases of any kind

(F) Exercise Testing

This protocol is designed (a) to determine maximal aerobic power (b) to determine maximal endurance time at submaximal loads.

(1) Reproducibility of exercise tests

In ten 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, (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 two minutes up to exhaustion (10-12). This was done on two occasions separated by one week. Results were expressed as the ratio 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 nine 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 five subjects working at more than 90% of their $\dot{V}_{O_2}$ max and enduring less than one hour, reproducibility was good: $\bar{r} \pm SE = 1.02 \pm .15$, $n = 5$).

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

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 (13). These conditions would be difficult to reproduce in "normal" subjects.

(2) <u>Exercise Protocol</u>

a. Training 3 mph - 2.5% grade - 5-10 min

b. Training 3 mph - 2.5% grade - 5-10 min

c. Training 3 mph - 2.5% grade - 5-10 min

d. $\dot{V}_{O_2}$ max test

Rest. Collect V_E x 1' and measure F_{EO_2} and F_{ECO_2}, heart rate, respiratory frequency.

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

EKG at rest.

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.

e. Active recovery at 2 mph 0% grade for 2 min. Rest.

f. 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.

g. Recovery

h. Rest

i. $\dot{V}_{O_2}$ submax II

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

Same as submaximal test I.

Although initially proposed, venipuncture, cardiac output and breathholding $D_{L_{CO}}$ 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.

(3) Criteria for Maximal

A controversial point is the criteria for maximal in exercise testing of patients (14).

a. In the $\dot{V}_{O_2}$ max test, we have always reached plateau or decreases in the rate of oxygen consumption when reaching a

supramaximal 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 V_E and a decrease in F_{EO_2} upon reaching maximal $\dot{V}O_2$.

b. At submaximal loads the criteria for exhaustion and maximal endurance are:

i. Heart rate within 5 beats of maximal as determined in the maximal test.

ii. Inability to follow the treadmill.

iii. Abrupt increases in $\dot{V}_E$.

In one severaly 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 where observed at maximal load and frequent PVC's immediately upon recovery.

(G) Statistical Analyses:

Statistical comparisons between groups were made on an unpaired basis and within groups on a paired basis. In either case the null hypothesis was rejected at the 5% level. All data are presented as means and standard deviations or, in the case of the regression and correlation analyses, as regression equations and correlation coefficients.

RESULTS AND DISCUSSION

I. STUDIES ON SUGAR CANE CUTTERS

(A) Productivity

The productivity data of the subjects in this study are presented in Tables IV and V. Of the 7 subjects from La Quinta, productivity data was available on only 5. The other 2 subjects had been loading cane part of the time. For the remaining 5, data were available for only 3 weeks, during the approximate period in which they were tested. The data from Central Castilla are for a much longer period of time and therefore more reliable (Table V). The subjects were selected for testing partially on the basis of the data for the 3 month period of April through June. However, they were all measured during the latter part of July and August.

Figure 2C is a histogram of the productivity data for the two 3 month periods and shows that there was a statistically significant ($p < 0.001$) increase in average daily productivity from April through June to July through September. Since the subjects were tested in the latter period only, these figures for productivity were used in subsequent analyses.

TABLE IV

PRODUCTIVITY DATA FROM SUGAR CANE CUTTERS AT LA QUINTA

BASED ON 3 WEEK AVERAGE

NAME	METRIC TONS/DAY
Roboan Martinez	4.697
Jorge Rivas	4.462
Osbaldo Benitez	3.962
Elueterio Candelo	3.652
Jose de la Luz Angulo	3.310

TABLE V

PRODUCTIVITY DATA FROM SUGAR CANE CUTTERS AT CENTRAL CASTILLA

	April, May, June			July, August, September		
	Total Metric Tons	Days Worked	Daily Productivity tons/day	Total Metric Tons	Days Worked	Daily Productivity tons/day
.ge Pazcuaza	233,755	74.5	3.138	223,955	63.0	3.555
Cupertino Vallejo	148,795	57.5	2.588	204,450	70.5	2.900
Pedro Fernandez	226,475	70	3.235	258,900	70.5	3.672
Luis Cubides	228.980	59.5	3.848	207,430	54.5	3.806
Jose Patino	204.900	70	2.927	241.360	69.0	3.498
Gerardo Zamora	274.560	63.5	4.324	321.155	61.5	5.222
Samuel Bastidas	235.400	75	3.139	265.155	66	4.018
Julio Cuastumal	172.500	57	3.026	240.155	68.0	3.532
Antonio Andrade	59.850	28	2.138	173.520	74	2.345
Jose Gonzalez	162.065	57	2.843	255.940	72.0	3.555
Isadeo Riascos	268.400	69	3.890	295.315	73	4.045
Teofilo Caicedo	253.420	73	3.472	268.390	71	3.780
Jorge Samuel Molina	107.040	43	2.489	259.700	65	3.995
Alfredo Noguera	265.955	66.5	3.999	241.900	61.5	3.933
Ruben Lopez	194.010	42	4.619	215.190	46.5	4.628
Dario Rosero	162.255	66	2.458	151.415	45.0	3.365
Vicente Maya	246.360	59	4.176	353,875	75.5	4.687
Gilberto Maldonado	139,045	56	2.483	222,950	74.5	2.993
Adolfo Gonzalez	150,635	51	2.954	247,485	72.0	3.437
Antonio Salazar	154,665	61	2.535	227,190	76	2.989
Jose Antonio Valencia	181,665	50	3,633	317,375	70.5	4.502

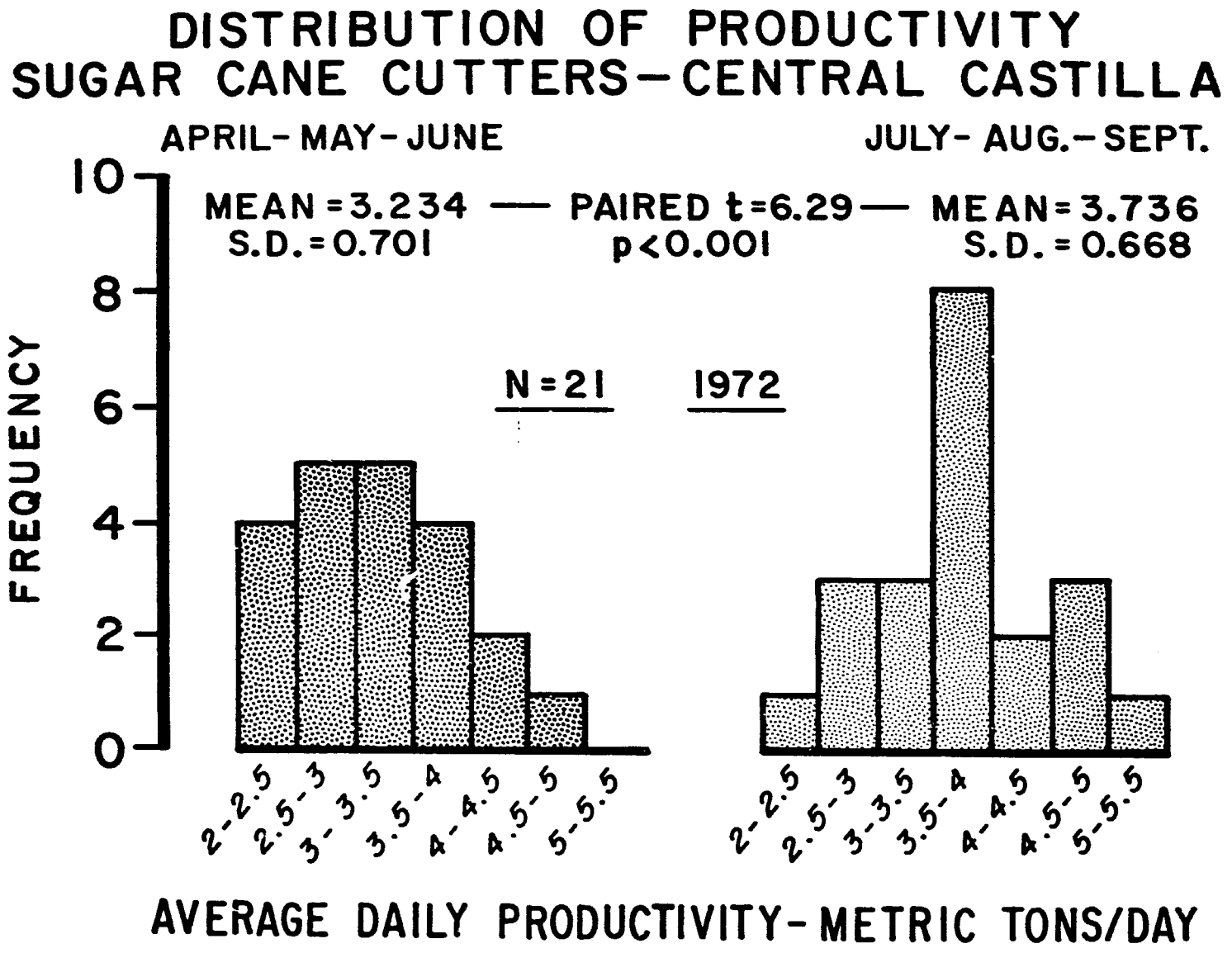

Fig. 2C Daily productivity data for two 3 month periods.

The reason for the shift in productivity is not clear at the moment. It could be related to weather, since during April, May and June there is usually more rain than during July, August and September. Central Castilla maintains a small meteorological station on the grounds and detailed records are kept of rainfall, daily temperature, etc. We plan to investigate this relationship. Another possibility is the type of cane cut. Some fields are burned prior to cutting and the men have a higher productivity when cutting burned cane. All the men in this study were cutting green, unburned cane during the actual test periods. However, no information is available on the relative amounts of green vs. burned cane cut during the two productivity periods.

Officials of the company, as well as the field boss in charge of the cutters, classify each man as good, average or poor based on their productivity records as well as subjective impressions. It has been shown that in lumberjacks, who are also paid on a productivity basis, there is a relationship between aerobic power (maximum work capacity) and earnings with those having higher values for aerobic power earning more money (15). For these reasons, the present subjects were ranked according to productivity and divided into three groups. Group I consists of the 9

TABLE VIA

PHYSICAL CHARACTERISTICS OF SUGAR CANE CUTTERS

		Age Years	Height cm	Weight Kg	Wt/Ht Kg/m	S.A.* M^2
Group I	n	9	9	9	9	9
	$\bar{x}$	33.3	168.8	62.3	36.91	1.72
	S.D.	9.6	6.2	6.9	3.90	0.11
Group II	n	9	9	9	9	9
	$\bar{x}$	26.3	165.5	57.5	34.85	1.64
	S.D.	9.3	3.4	3.5	1.89	0.06
Group III	n	10	10	10	10	10
	$\bar{x}$	30.9	164.6	61.0	37.06	1.66
	S.D.	8.4	4.8	7.2	3.62	0.11
Total	n	28	28	28	28	28
	$\bar{x}$	30.2	166.2	60.4	36.3	1.67
	S.D.	9.2	5.1	6.2	3.31	0.10

*Body Surface Area

TABLE VIB

PHYSICAL CHARACTERISTICS OF SUGAR CANE CUTTERS

		SKINFOLD THICKNESS						
		Triceps mm	Scapular mm	Iliac mm	Specific Gravity	Body Fat %	Body Fat Kg	Lean Body Mass Kg
Group I	n	8	8	8	8	8	8	8
	$\bar{x}$	5.2	10.0	5.6	1.067	14.0	8.7	53.3
	S.D.	1.4	3.8	1.2	0.002	0.8	1.5	5.8
Group II	n	9	9	9	9	9	9	9
	$\bar{x}$	5.0	8.8	6.1	1.067	14.1	8.1	49.6
	S.D.	0.6	1.9	1.9	0.002	0.8	0.7	3.0
Group III	n	10	10	10	10	10	10	10
	$\bar{x}$	6.7	12.0	6.9	1.065	15.0	9.2	51.8
	S.D.	2.1	5.4	3.3	0.004	1.6	1.9	5.5
Total	n	27	27	27	27	27	27	27
	$\bar{x}$	5.7	10.3	6.2	1.066	14.4	8.7	51.5
	S.D.	1.7	4.1	2.3	0.005	1.2	1.5	4.9

* Body Surface Area

top producers having an average daily output of 4.473 ± 0.403 metric tons/day. Group II was also composed of 9 men with an average productivity value of 3.716 ± 0.163 tons/day while Group III was made up of the 10 lowest producers having a daily production of 3.105 ± 0.382 tons/day. The two men from La Quinta, for whom productivity data were not available, were placed in Group III on the basis of the field boss's opinion that they were very poor workers.

(B) Arthropometric Data

The physical characteristics of the sugar cane cutters employed in this study are presented in Tables VIA and B. There were no statistically significant differences among the groups in any of the values and so the data are also presented as combined averages. The values are within normal ranges, although the men are somewhat smaller in stature and weight than a similar age group of randomly selected subjects would be in this country.

(C) Heart Rates

The heart rates at rest and during work are presented in Table VII and illustrated in Figs. 3 and 4. In the morning and at rest in the afternoon there was no statistically significant differences among groups so they were averaged

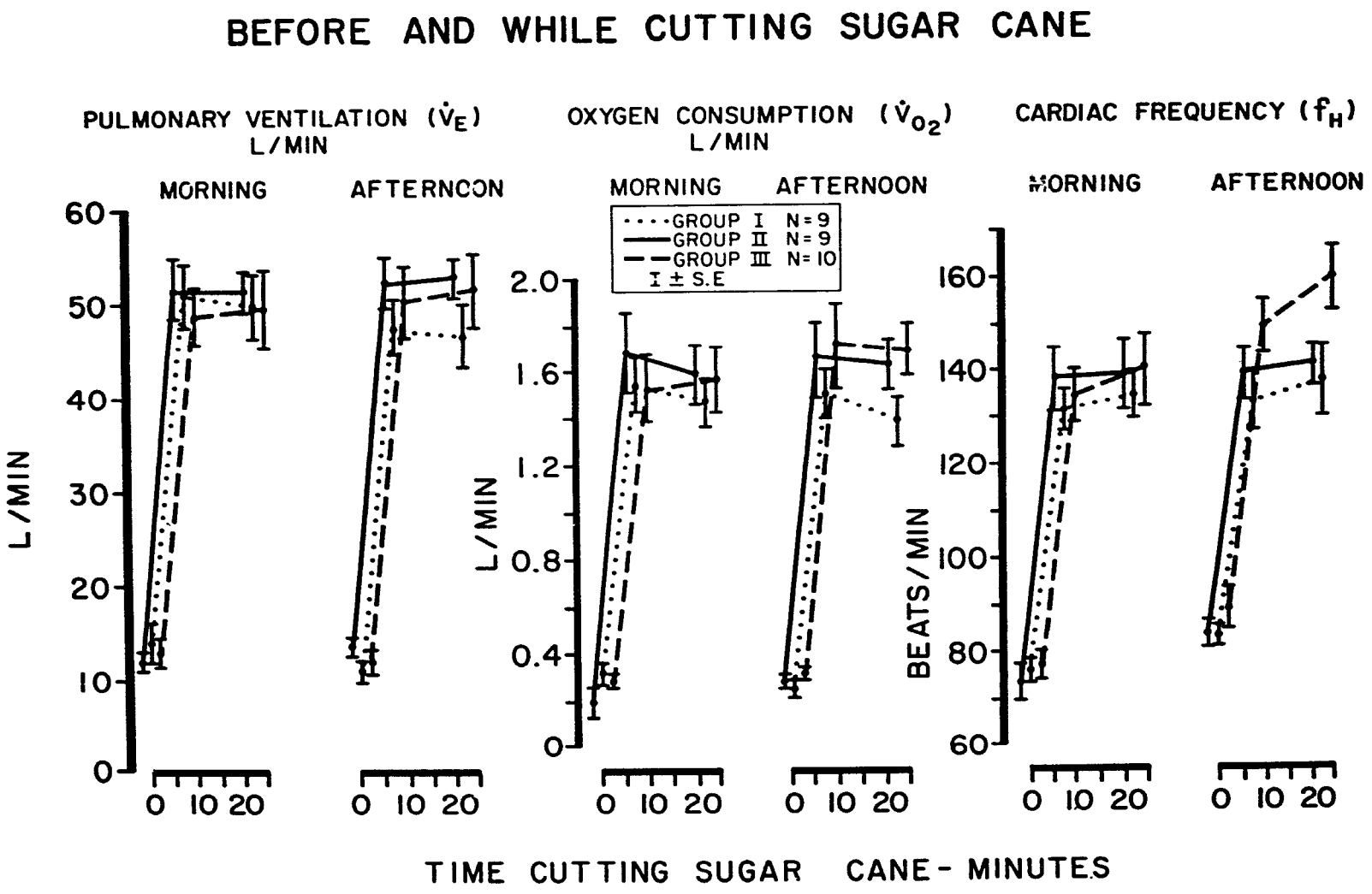

Fig. 3 Pulmonary ventilation (BTPS) oxygen consumption (STPD) and cardiac frequency in response to cutting sugar cane in the morning and afternoon.

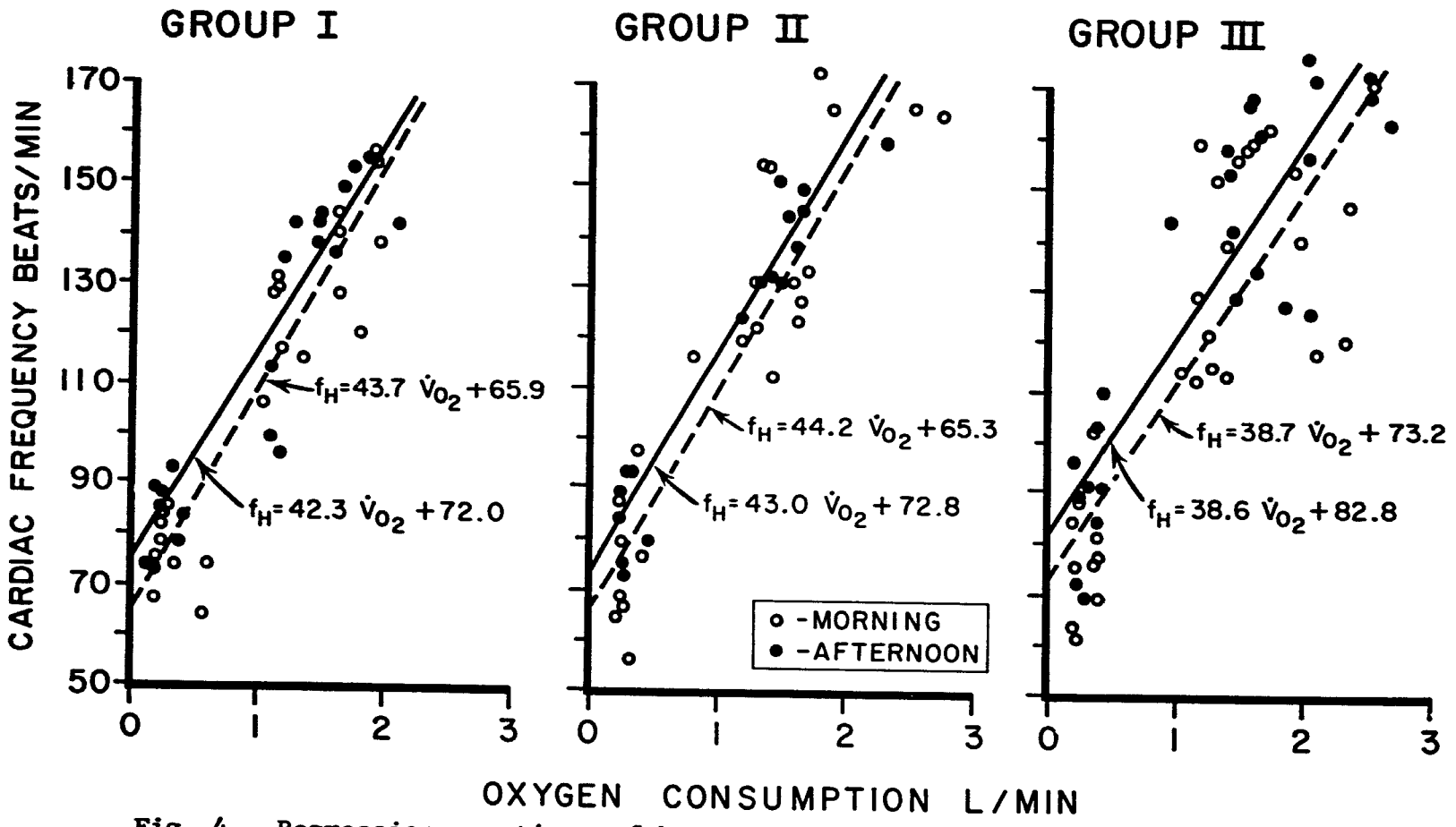

Fig. 4 Regression equations of heart rate on oxygen consumption (STPD) in three groups of sugar cane cutters before and during work. Solid lines are for values obtained in the afternoon, broken lines in the morning.

TABLE VII

HEART RATES AT REST AND DURING CUTTING OF SUGAR CANE (beats/min)

	MORNING			AFTERNOON		
	Rest	5 min	20 min	Rest	5 min	20 min
			GROUP I			
n	9	9	8	9	8	6
$\bar{x}$	76	131	134	83*	133	138
S.D.	7	13	14	7	19	20
			GROUP II			
n	9	8	8	7	6	4
$\bar{x}$	73	138	139	84*	139	141
S.D.	13	20	22	8	13	9
			GROUP III			
n	10	10	8	9	9	7
$\bar{x}$	78	135	140	89*	148	159**
S.D.	12	17	21	13	16	18

* Significantly different from resting values in A.M. ($P<0.02$)

** Significantly different from Group II ($P=0.05$)

and are presented in Table VIII. However, the values for Group III are higher than the other groups and were statistically significant during the 20 minute measurement in the afternoon, suggesting that the men with lower productivity were undergoing more cardiovascular stress than the others.

The resting values in the afternoon also were significantly higher ($p<0.02$) than the resting measurements in the morning (Table VIII and Fig. 3) in all groups.

Fig. 4 shows the regression equations for heart rate on oxygen consumption in the morning and afternoon. A statistical comparison of the slopes, showed that there were no significant differences between mornings and afternoon in any of the 3 groups of subjects (Table IX). One can then compare the intercepts as a measure of the displacement of one line in relation to the other. The wide variability of the data was such that comparison of the intercepts on an individual group basis did not reveal any differences between morning and afternoon. However, if one combines all of the points in the three groups, statistical comparison of the intercepts reveals that the regression line for the data obtained in the afternoon is significantly higher than that obtained in the morning ($P<0.001$). This means that at the same level of oxygen consumption (work load) the heart

TABLE VIII

		MORNING			AFTERNOON		
			Cutting Cane			Cutting Cane	
		Rest	5 min	20 min	Rest	5 min	20 min
·diac	n	28	27	24	25		
:quency	$\bar{x}$	76*	135	138	86		
;)	S.D.	11	16	19	10		
:ts/min	Range	56-102	113-165	112-165	72-110		
·gen	n	28	27	28	24	24	23
ısumption	$\bar{x}$	0.272*	1.579	1.530	0.287*	1.624	1.579
$)_2$)	S.D.	0.163	0.408	0.376	0.090	0.413	0.312
:in STPD+	Range	0.180-0.559	1.114-2.739	0.891-2.520	0.177-0.459	0.943-2.676	1.093-2.417
·gen	n	28	26	24	24		
ıse	$\bar{x}$	4.01*	11.71	10.73	3.37		
$)_2$/fH)	S.D.	1.59	2.64	3.93	1.02		
/min/beat	Range	2.14-8.73	8.60-17.70	8.72-15.27	2.00-5.81		
lmonary	n	28	27	28	26	26	24
ntilation	$\bar{x}$	12.83*	51.34	50.12	12.06*	49.66	50.44
;)	S.D.	5.10	8.03	10.26	3.41	9.92	9.77
:in BTPS‡	Range	7.99-32.33	38.18-68.14	30.39-64.14	6.33-22.72	33.48-68.66	27.89-67.00
ntilation	n	28	27	28	24	24	23
ıivalent	$\bar{x}$	4.44*	3.26	3.34	4.43*	3.17	3.33
E/100cc $\dot{V}O_2$)	S.D.	1.05	0.47	0.51	1.22	0.45	0.35
	Range	2.46-6.89	2.23-4.02	2.27-4.14	2.66-6.94	2.17-3.95	2.71-3.88

* Significantly different from work values ($P < 0.05$)
\+ Standard temperature and pressure, dry
‡ Body temperature, ambient pressure, saturated

TABLE IX

"t" VALUES FOR COMPARISON OF SLOPES AND INTERCEPTS OF THE REGRESSION LINES OF HEART RATE ON OXYGEN-CONSUMPTION IN GROUPS I, II AND III OF SUGAR CANE CUTTERS PRESENTED IN FIG. 4

SLOPES

A.M.

	I	II	III
II	0.10		
III	0.74	0.79	

P.M.

	I	II	III
II	0.14		
III	0.60	0.77	

INTERCEPTS

A.M.

	I	II	III
II	0.15		
III	1.64	1.60	

P.M.

	I	II	III
II	0.24		
III	2.45*	2.36*	

* $P<0.05$

rate is higher in the afternoon than the morning. This is probably related to higher ambient temperatures prevalent in the afternoon. Table X presents ambient temperatures measured with an unshielded thermometer at the start of each test period. It can be seen that the afternoon temperatures are all significantly higher than the morning temperatures during each of the 3 test periods. Williams et al (16) have shown that at high ambient temperatures, heart rates are higher at the same work loads than at comfortable temperatures.

Table IX also shows the statistical comparisons of the intercepts among the 3 groups for both morning and afternoon. Although the value for Group III in the morning was higher than for either Group I and Group II it was not statistically significant. However, in the afternoon the intercept for Group III was significantly higher than both Group I and II ($P<0.05$). This again indicates that the poorer producers were working under more cardiovascular stress than the others.

(D) Oxygen Consumption and Pulmonary Ventilation

Oxygen consumption and pulmonary ventilation values are illustrated in Fig. 3. The response to work was approximately the same, there being no statistically significant differences among the 3 groups. Neither were there significant differences between the 5 and 20 minute values in the morning and afternoon and the measurements made in the morning were not significantly different from those obtained in the afternoon. The combined values are presented in Table VIII. It can be seen that the work increased the oxygen consumption to about 1.5 L/min and the pulmonary ventilation to approximately 50 L/min. The significant decrease in ventilation equivalent during work indicates that the subjects were hyperventilating slightly during the resting measurements in spite of our precaution to prevent this. However, this is not unusual in untrained subjects.

(E) Energy Expenditure and Rate of Cutting Sugar Cane

The amount of energy expended in cutting sugar cane can be estimated by knowing the oxygen consumption and the caloric equivalent for oxygen. An exercise R value of 1.00 was assumed and the caloric equivalent of 5.047 utilized in the

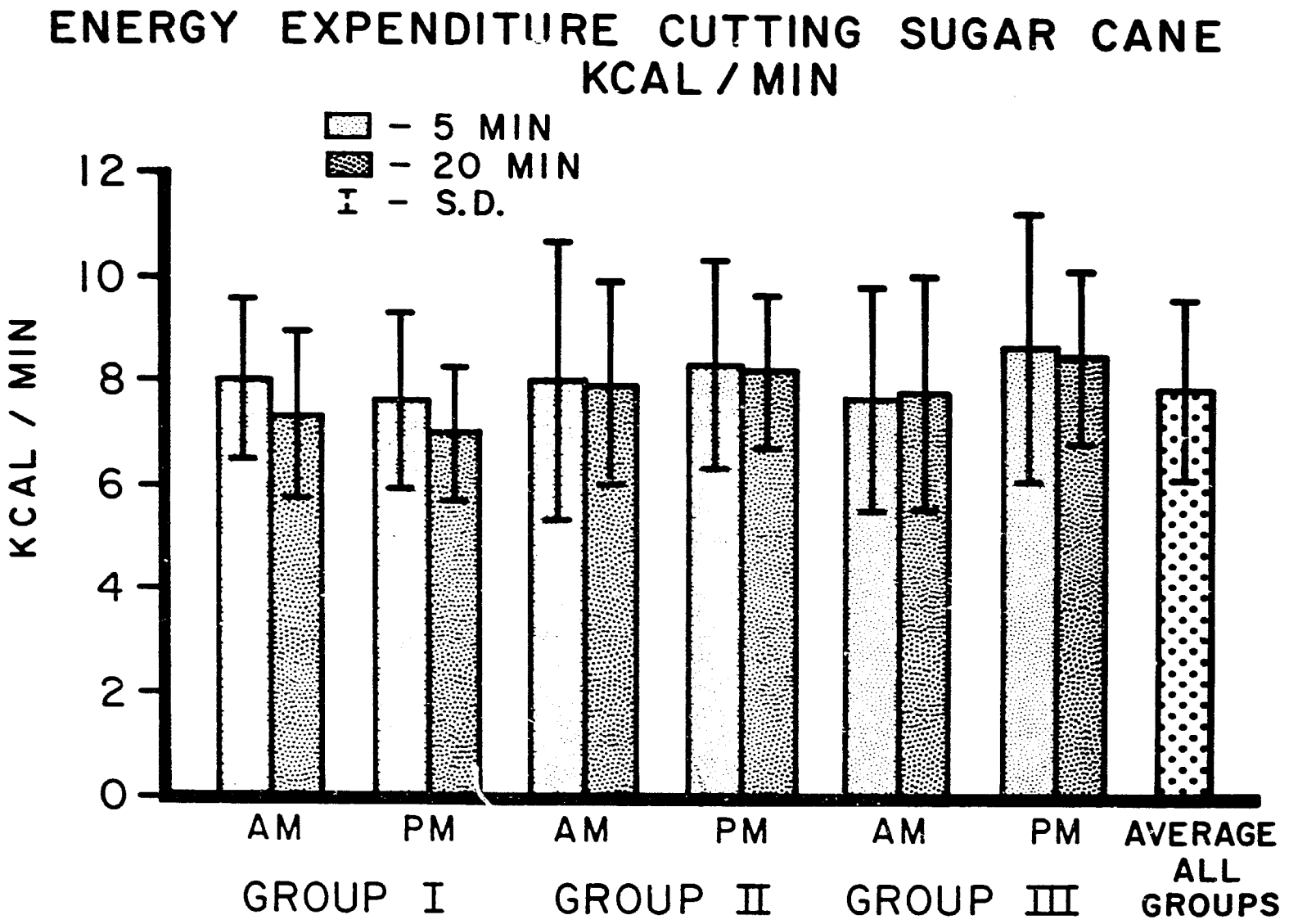

Fig. 5 Energy cost during the 5 and 20 min. determinations while cutting sugar cane in the morning and afternoon.

calculation of energy expenditure expressed as K cal/min. Fig. 5 shows the results in all three groups during the 5 and 20 minute measurements in the morning and afternoon. Since there were no statistically significant differences between the two measurements (between morning and afternoon tests nor among the groups), the values for each subject were averaged and a mean and standard deviation of all of the subjects calculated. The results show that the work of cutting sugar cane results in an energy expenditure of 7.89±1.71 Kcal/min. According to Durnin and Passmore (2) this would classify sugar cane cutting as "heavy" industrial work.

The cane which was collected and weighed during each period of measurement was expressed as Kilograms of cane cut/hour and is illustrated in Fig. 6. It can be seen that in all 3 groups the rate of cane cutting tended to be higher in the afternoon than morning and that in Group II and III this achieved statistical significance. Since there were no differences among the 3 groups all data were averaged and it can be seen that the rate of cane cutting was significantly higher in the afternoon than in the morning ($p<0.001$).

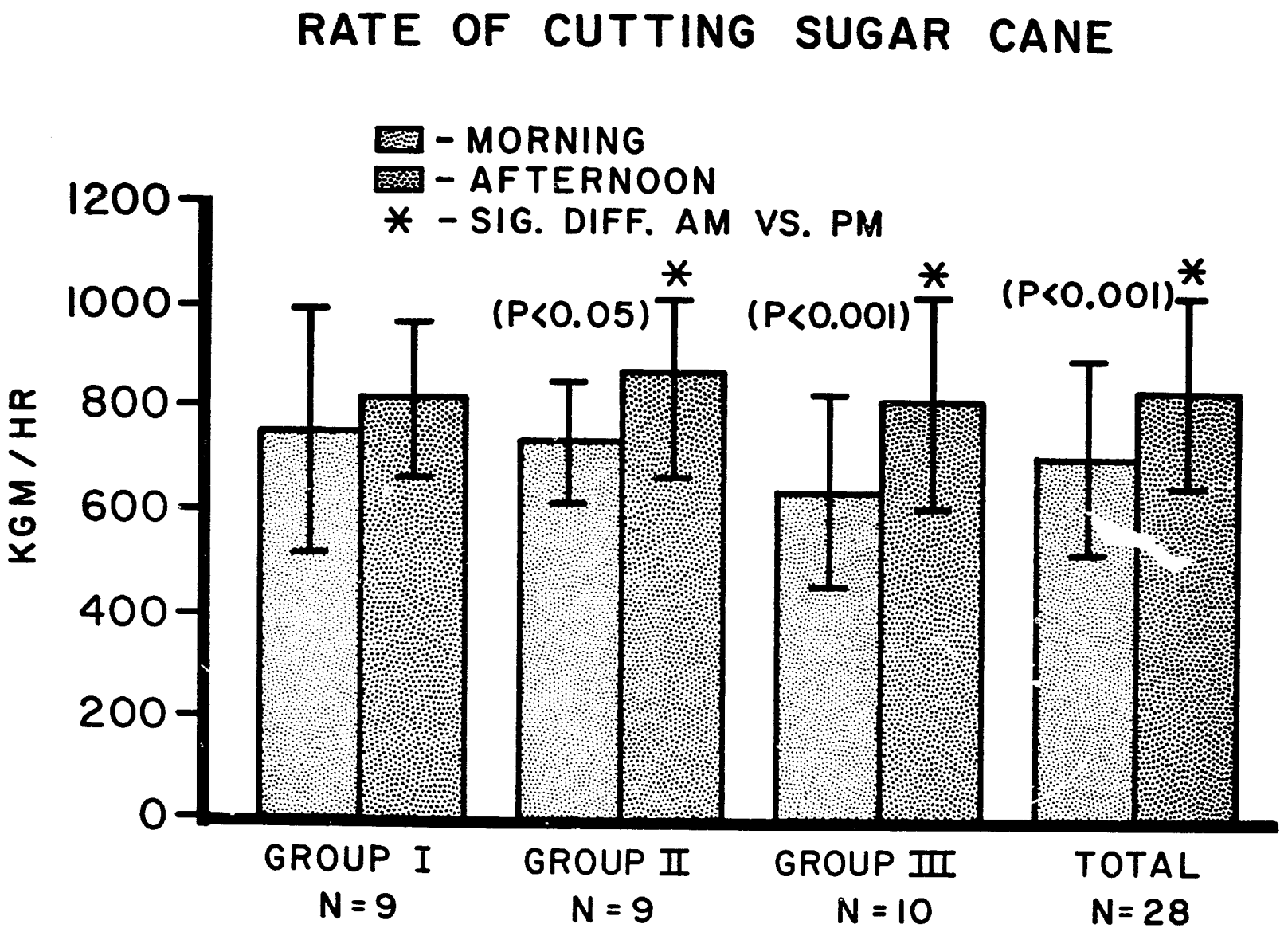

Fig. 6 Rate of sugar cane cutting in Kilograms/hr.

The rate of cane cutting/hr if multiplied by the usual 8 hour working day gives values for productivity which are much higher than the daily productivities of any of the men (Tables IV and V). This means that in spite of the observer's admonition to cut cane at their accustomed rate, the men were actually cutting cane at a faster rate during the testing periods than they could sustain during the entire day. This is no doubt the result of being the center of attention, wishing to please and just a dash of "machismo."

Knowing the rates of energy expenditure and of cane cutting, it is a simple calculation to obtain the energy expenditure/Kg of cane cut. These results are illustrated in Fig. 7. It is evident that the energy cost of cane cutting when expressed in terms of the weight of cane cut is less in the afternoon than in the morning. This means that in the afternoon there is a higher efficiency since oxygen consumption and, therefore total energy expenditure, did not change in the afternoon while the rate of cane cutting increased. In other words the men were able to cut more cane at the same metabolic cost. It can be seen that in Group III the afternoon values were not significantly different from those measured in the morning.

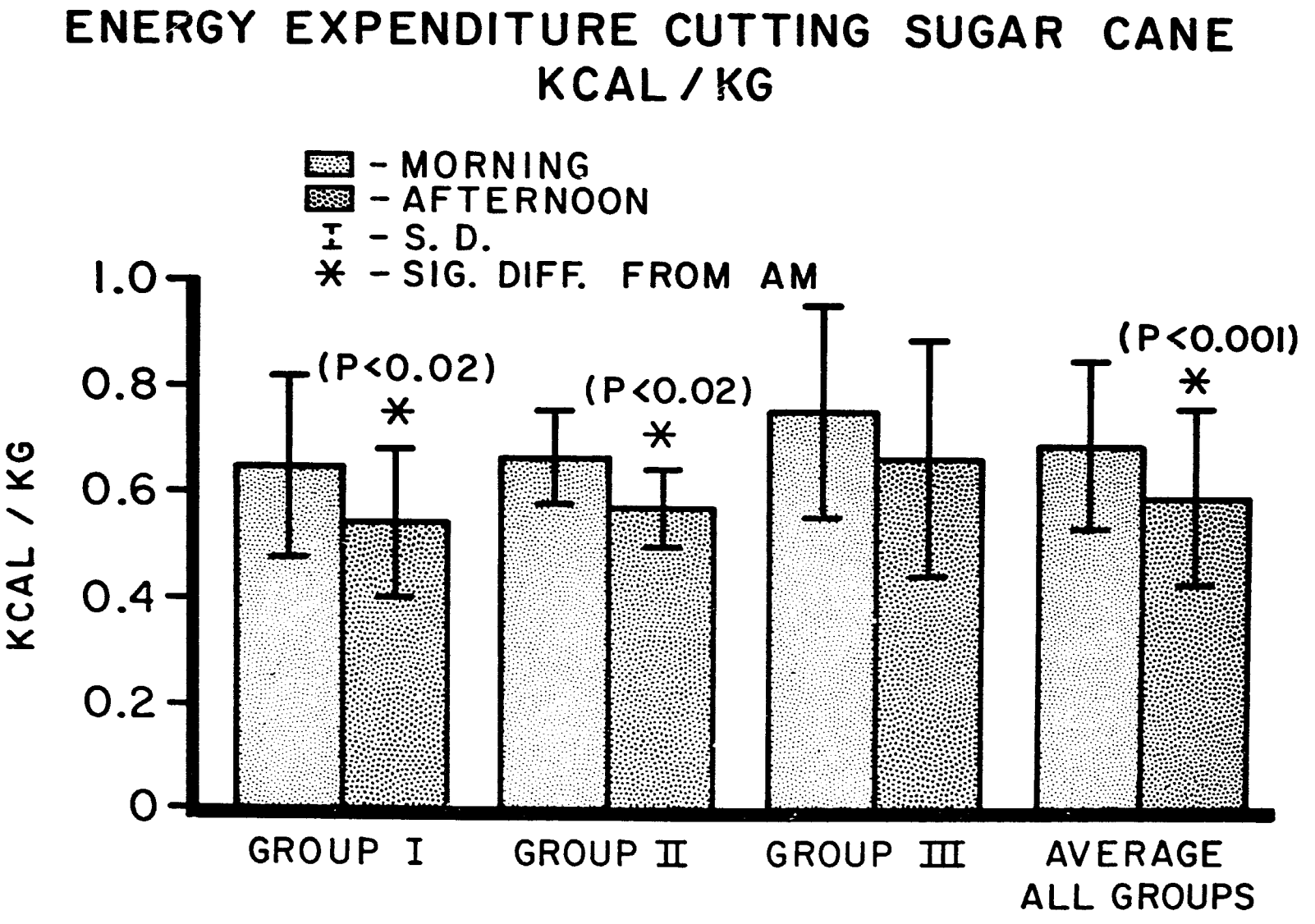

Fig. 7 Caloric cost of cutting cane per Kilogram of cane cut.

Also, while not statistically significant, the mean values for this group are higher than for the other two groups in the afternoon. This may be indicative of a failure on the part of these subjects to reduce their efficiency sufficiently.

Williams, et al (16) have shown that, at equivalent submaximal work loads, oxygen consumption is lower in the heat than at comfortable environments. Our data demonstrates that during the higher afternoon temperatures (Table X) the oxygen consumption was the same but the work load was higher resulting in an increased efficiency. These results, then, are in accord with those of Williams et al (16). They attributed their results to one of two possible explanations. First "that the rate of enzyme reaction is related to substrate temperature." The body temperatures of their subjects were indeed, increased. We have no body temperature measurements in our subjects but can safely assume that they were probably also increased. They state "the lower oxygen intake could therefore be interpreted as a significant, although small, increase in mechanical efficiency of work in heat compared with comfortable conditions."

TABLE X

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			
$\bar{x}$	25.2	26.5	27.5	32.7*	32.9*	32.2*
S.D.	3.0	3.0	2.2	2.4	3.4	3.8
			GROUP II			
$\bar{x}$	24.9	26.2	27.4	31.0*	32.4*	32.8*
S.D.	2.7	2.4	2.2	1.4	1.5	2.1
			GROUP III			
$\bar{x}$	25.6	27.6	28.5	32.7*	32.4*	32.6*
S.D.	3.9	4.2	4.3	2.4	2.4	2.7

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

The second possible explanation proposed by Williams et al (16) was that since cardiac output did not change in the heat and that part of this output would have to be diverted to dilated blood vessels in the skin, it therefore followed that working muscles would be relatively more anaerobic at equivalent submaximal work loads in the heat than at comfortable environmental temperatures. Thus the "measured oxygen intake during work could be lower in proportion to the increased oxygen debt incurred." They found that, in their subjects, blood lactates increased at significantly lower levels of oxygen intake without change in pyruvate indicating that the increased lactate can be attributed to anaerobic metabolism. These concepts could as well explain the present data on sugar cane cutters.

(F) Maximum Oxygen Consumption (Aerobic Power)

A measurement of $\dot{V}O_2$ max was made in 27 of the 28 sugar cane cutters. Because we believed that 4 of these did not fit the criteria for maximum effort set out in the methods section, the results of their $\dot{V}O_2$ max test were discarded. The values for the 3 groups are presented in Table XI. Group I had a $\dot{V}O_2$ max of 2.567±0.446 L/min, Group II 2.709±0.264 L/min, and Group III 2.396±0.262 L/min. Statistical comparisons

TABLE XI

RELATION BETWEEN PRODUCTIVITY AND $\dot{V}O_{2max}$

IN 3 GROUPS OF SUGAR CANE CUTTERS

	Productivity Tons*/day	$\dot{V}O_2$ (max) L/min	$\dot{V}O_2$ (max) ml/Kg min^{-1}
GROUP I			
n	9	7	7
$\bar{x}$	4.473	2.567	43.5
S.D.	0.403	0.446	8.0
GROUP II			
n	9	8	8
$\bar{x}$	3.716	2.709	47.0
S.D.	0.163	0.264	4.5
GROUP III			
n	8	8	8
$\bar{x}$	3.105	2.396	40.2
S.D.	0.382	0.262	5.1

*Metric Tons $^{+}p<0.05$

Statistical Data

"t" Values

Productivity (Tons/day)

	I	II	III
II	5.47^{+}		
III	6.91^{+}	3.88^{+}	

$\dot{V}O_{2max}$ (ml/Kg min^{-1})

	I	II	III
II	1.02		
III	0.91 (2.07)	2.80^{+}	

of the 3 groups are shown on the lower right of Table XI. Comparisons were made of the values for aerobic power (ml/Kg·min It can be seen that Group III has a significantly lower $\dot{V}_{O_2}$ max than Group II but not Group I (T=0.91). However, one of the subjects in Group I was 56 years old and had an aerobic power of 29 ml/Kg·min^{-1} which was outside of 3 standard deviations from the mean of 45.9±5.1 which resulted from the remaining 6 subjects in that group. Comparison of Group I and III then yielded a "t" value of 2.07 which was closer to the value of 2.18 required for statistical significance It may be that a few more subjects in each group will improve the statistics.

Table XI also presents the average daily productivity of each worker which were, of course, all significantly different from each other.

$\dot{V}_{O_2}$ max data vary from country to country and laboratory to laboratory (4). These values are approximately average or slightly above average for normal values obtained in this country. However, we do not as yet have data for normal, sedentary Colombians with which to compare these measurements. Data on normal, sedentary Colombians are currently being collected.

Fig. 8 shows the relationship between aerobic power and age in our subjects. It is well known that aerobic power decreases with age (3) and our data also show this. A recent calculation of 700 observations of $\dot{V}O_2$ max taken from 17 publications in the literature gave a regression line of y=-0.398x+56.592 (17). Our data are very close to these values (Fig. 8).

Table XII presents resting and maximum values for pulmonary ventilation, oxygen consumption, cardiac frequency and oxygen pulse as well as the maximum work rate achieved. Except for the above mentioned difference between Groups III and II in $\dot{V}O_2$ max there were no statistically significant differences among the 3 groups.

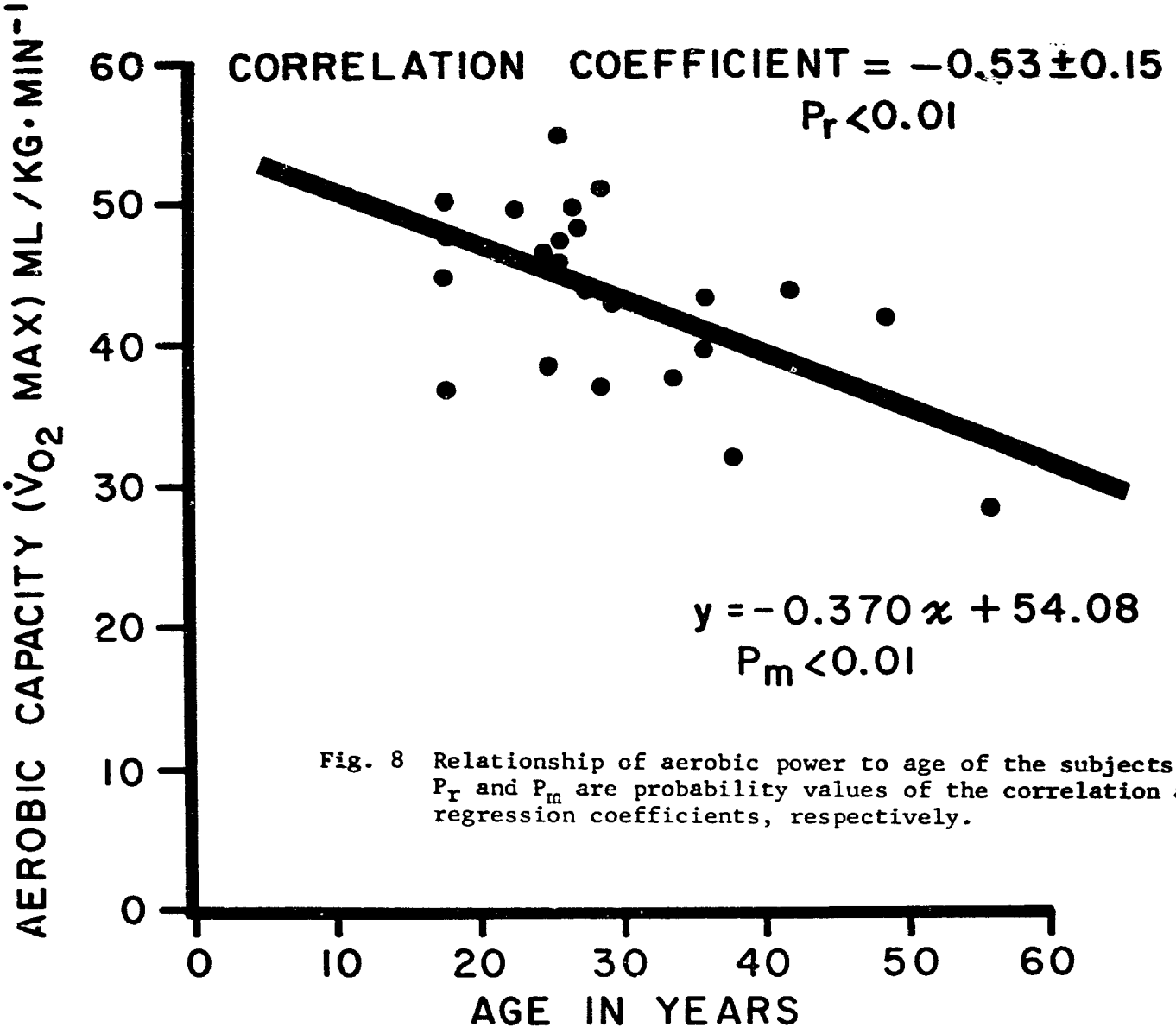

Fig. 8 Relationship of aerobic power to age of the subjects. P_r and P_m are probability values of the correlation and regression coefficients, respectively.

TABLE XII

DATA ON MAXIMUM WORK CAPACITY TEST IN SUGAR CANE CUTTERS

	Pulmonary Ventilation L/min*		Oxygen Consumption L/min**		Cardiac Frequency/min		Oxygen Pulse L/beat		Maximum Work
	Rest	Max.	Rest	Max.	Rest	Max.	Rest	Max.	KgM/min
					GROUP I (n=7)				
$\bar{x}$	8.198	102.742	0.188	2.566	62	177	3.03	14.42	1209
S.D.	1.372	9.009	0.034	0.446	12	10	0.69	2.38	122
					GROUP II (n=8)				
$\bar{x}$	11.119	110.637	0.243	2.697	60	186	4.18	14.62	1190
S.D.	6.237	15.873	0.100	0.288	10	12	1.94	2.13	134
					GROUP III (n=8)				
$\bar{x}$	10.488	92.172	0.228	2.396	65	178	3.50	13.59	1100
S.D.	6.402	20.746	0.068	0.262	12	21	0.66	2.38	210

* BTPS
** STPD

(G) Percent $\dot{V}_{O_2}$ max

From the maximum oxygen intake and the observed oxygen consumption during work the % $\dot{V}_{O_2}$ max was calculated. During the test periods there were no statistically significant differences among the 3 groups. Consequently, the data were averaged and are presented in Fig. 9. During each of the 2 test periods in the morning and afternoon the men were working at approximately 60% of their maximum oxygen consumption. This value is too high to be sustained for long periods (1,2). Also, it was evident from the data on the rate at which the men were cutting cane and their daily productivity that they were working harder during the periods of measurement than they sustained for the entire 8 hour day. From the data on oxygen consumption, cane weight and daily productivity the estimated oxygen consumption which would have to be sustained for the eight hour period of work was calculated and expressed as % $\dot{V}_{O_2}$ max. These data are shown in Fig. 9 also. It can be seen that in the morning the men were working at an estimated sustained % $\dot{V}_{O_2}$ max of about 40%. There was no significant difference between values calculated from the 5 and 20 minute data. However, the afternoon values were

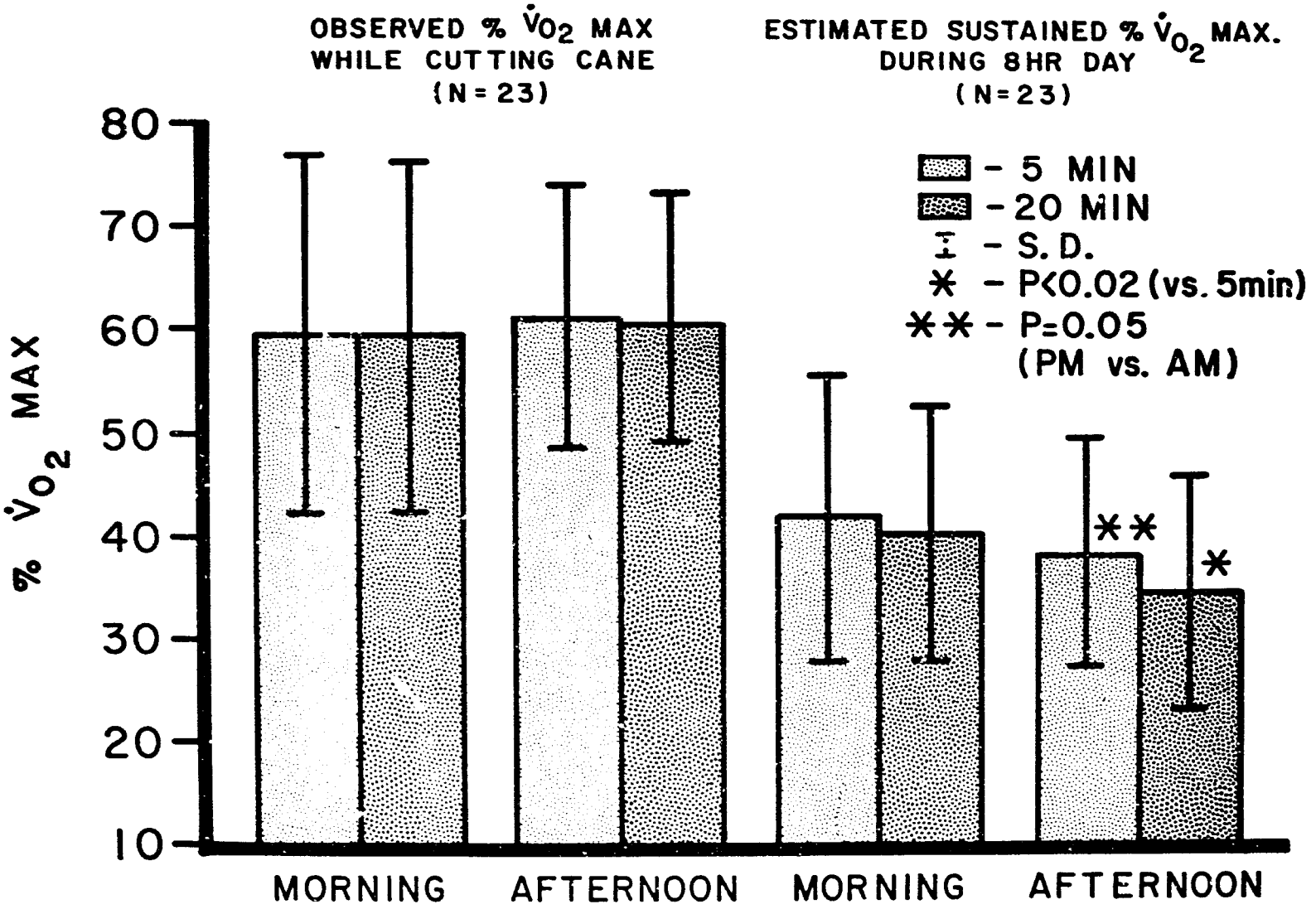

Fig. 9 Means and standard deviations of observed and estimated sustained $\dot{V}_{O_2}$ max during cutting of sugar cane.

significantly lower due to the higher rate of cutting sugar cane in the afternoon (Fig. 6) and the increased efficiency of work in the afternoon heat (Fig. 7), resulting in a decreased need for utilization of the maximum oxygen consumption available to them.

The values obtained in the morning are perhaps more indicative of the % $\dot{V}O_2$ max utilized in cutting cane on a sustained basis since officials at Central Castilla were unanimous in the opinion that the cutters cut 60-75% of their daily productivity prior to the noon meal. A 40% $\dot{V}O_2$ max level of oxygen consumption is about the maximum which can be sustained for any length of time (1,2).

(H) Productivity and Aerobic Power ($\dot{V}O_2$ max)

One of the original premises for the present work was that work productivity is related to physical work capacity. This relationship in our subjects is illustrated in Fig. 10 where average daily productivity is plotted against aerobic capacity ($\dot{V}O_2$ max). The variability of the data is such that there is no statistically significant relationship in this group of subjects. One explanation for this may lie in the deliberate selection of a wide range of ages for our

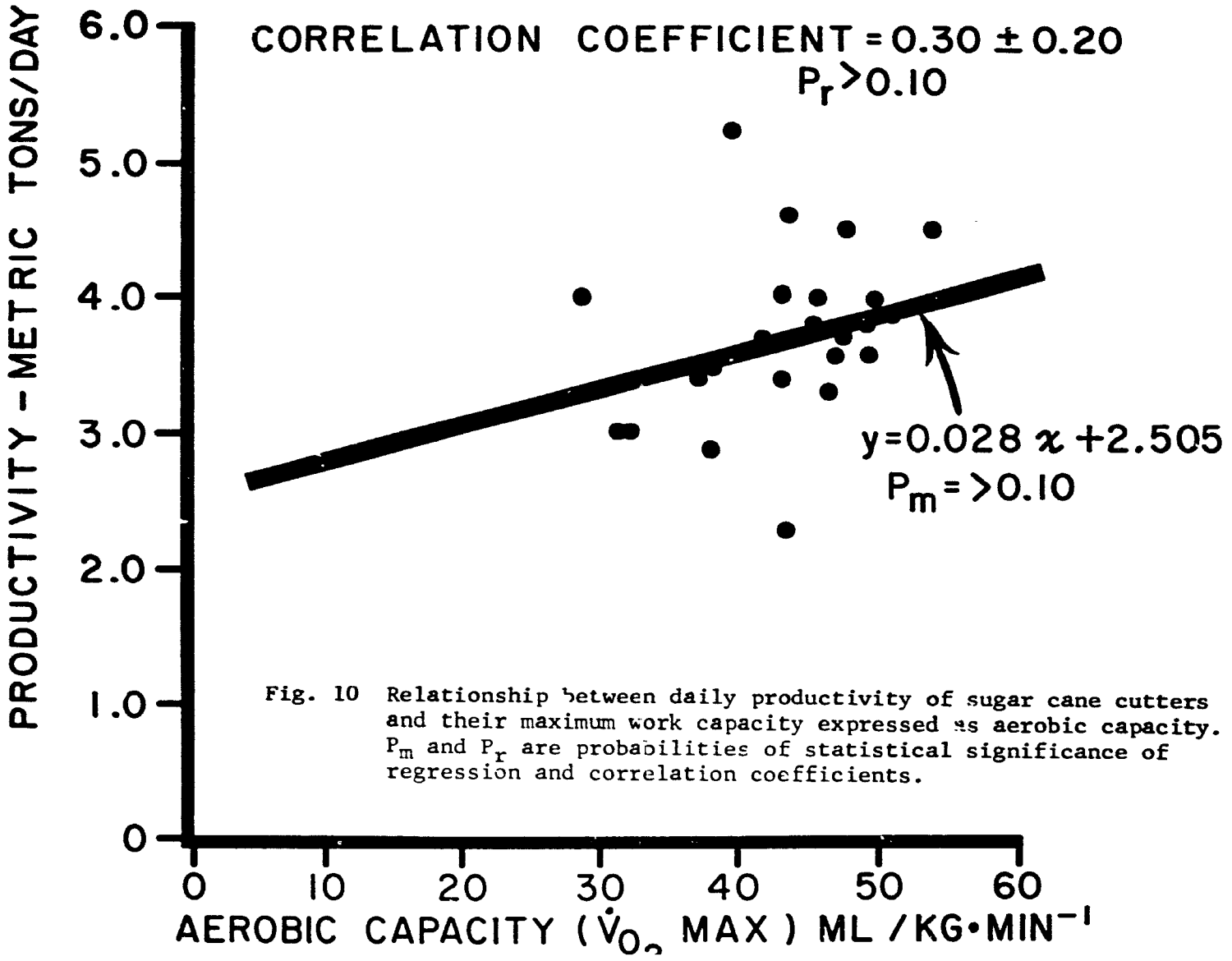

Fig. 10 Relationship between daily productivity of sugar cane cutters and their maximum work capacity expressed as aerobic capacity. P_m and P_r are probabilities of statistical significance of regression and correlation coefficients.

subjects. It may well be that a narrower range of subject ages and as broad a range of productivity would show a positive relationship. In spite of the lack of statistical significance shown in Fig. 10, other data in this report (heart rate, $\dot{V}O_2$ max in the 3 groups) are indicative of a relationship between productivity and physiological responses to work.

Fig. 11 presents the relationship between productivity and the age of the subjects. There is no significant correlation.

Thinking that a correlation between daily productivity and the estimated sustained % $\dot{V}O_2$ max utilized in cutting sugar cane might exist, the statistical calculations were done. The results are presented in Figs. 12 and 13 and demonstrate that no correlation exists.

(I) Activity Levels

Using the activity levels classifying system described by Saltin and Grimby (7) the men were categorized into one of four groups as described in Table XIII. Of the 28 subjects, activity levels were estimated in 27. All of these were, of course, placed in Group IV of the occupational activity

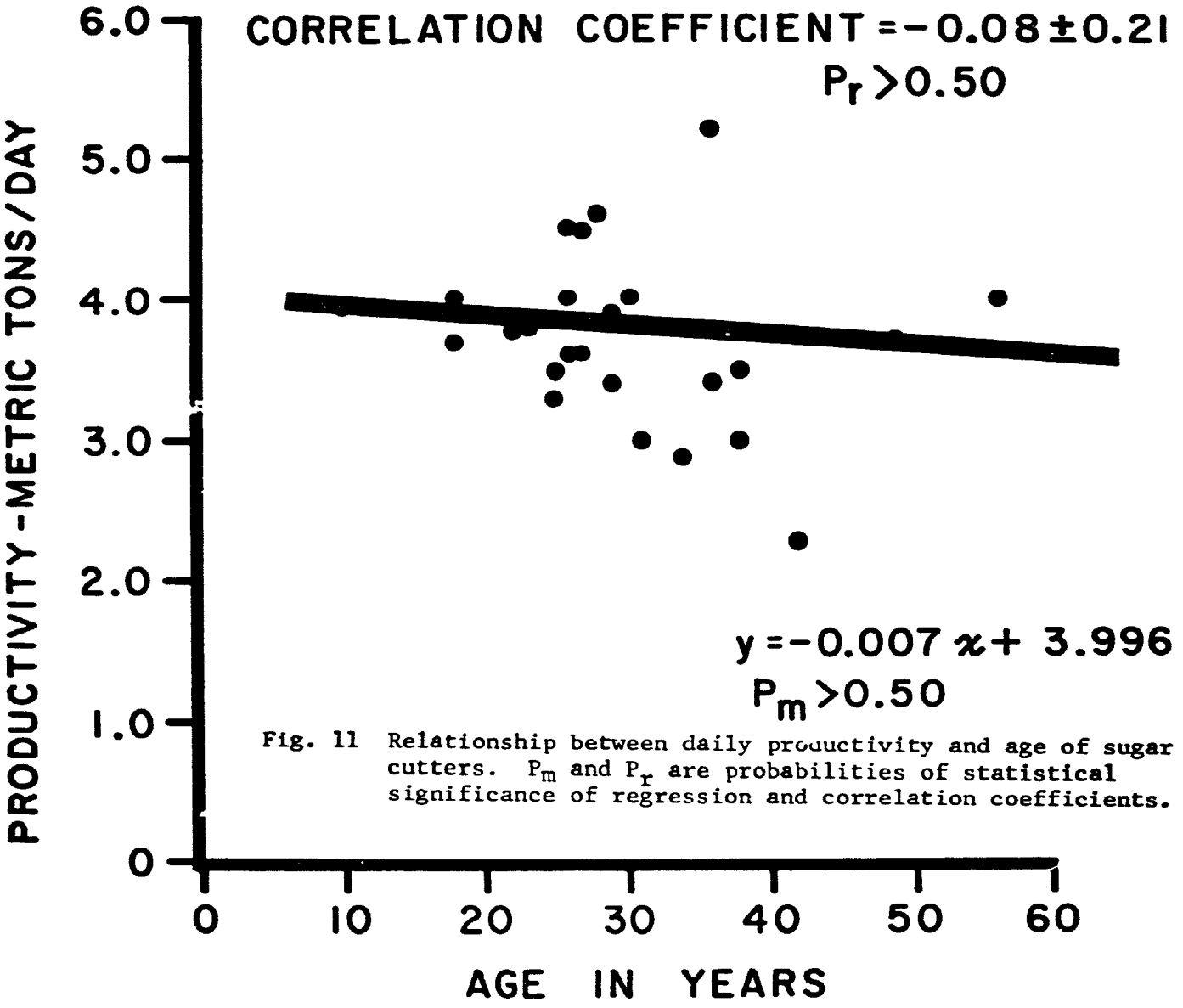

Fig. 11 Relationship between daily productivity and age of sugar cane cutters. P_m and P_r are probabilities of statistical significance of regression and correlation coefficients.

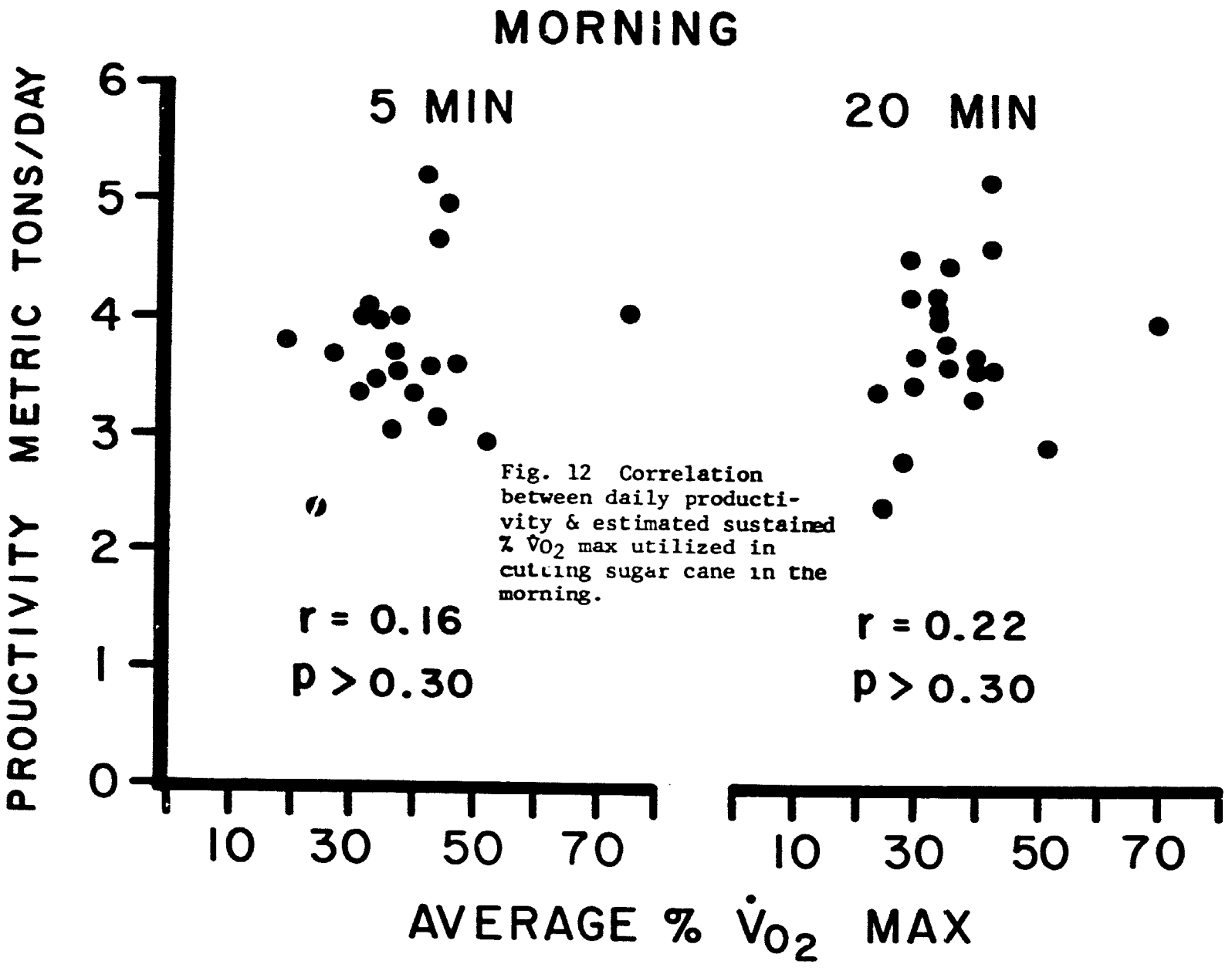

Fig. 12 Correlation between daily productivity & estimated sustained % $\dot{V}_{O_2}$ max utilized in cutting sugar cane in the morning.

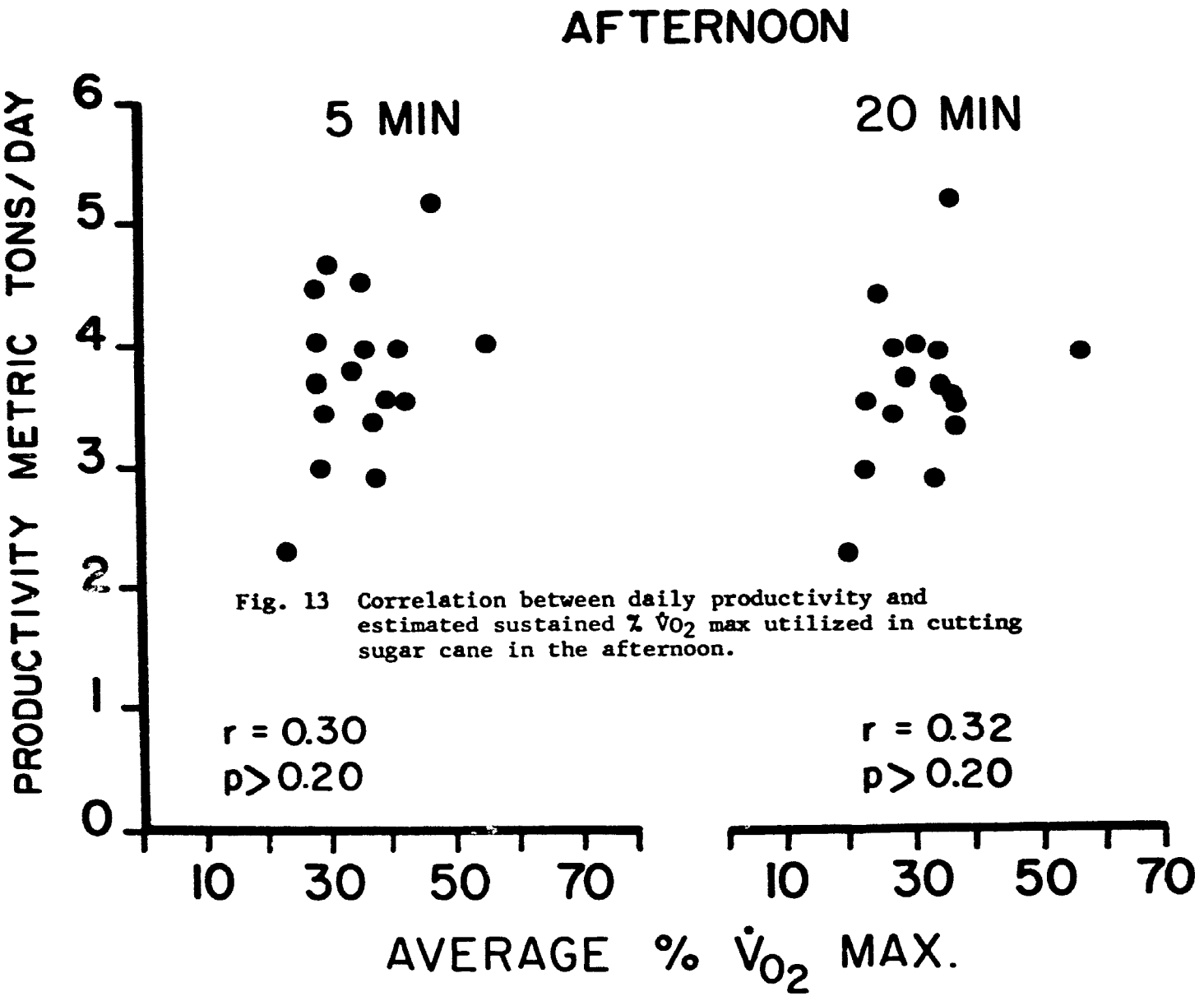

Fig. 13 Correlation between daily productivity and estimated sustained % $\dot{V}_{O_2}$ max utilized in cutting sugar cane in the afternoon.

TABLE XIII

OCCUPATIONAL AND SPARE-TIME ACTIVITY GROUPINGS
FROM SALTIN & GRIMBY (7)

OCCUPATIONAL ACTIVITY

GROUP I	Predominantly sedentary, sitting:	desk worker, watch maker, sitting assembly-line worker (light goods)
GROUP II	Sitting or standing, some walking:	cashier, general office worker, light tool and machinery worker, foreman
GROUP III	Walking, some handling of material:	mailman, waiter, construction worker, heavy tool and machinery worker
GROUP IV	Heavy manual work:	lumberjack, dock worker, stone mason, farm worker, ditch digger

SPARE-TIME PHYSICAL ACTIVITY

GROUP I	Almost completely inactive:	reading, TV watching, movies, etc.
GROUP II	Some physical activity during at least 4 hours per week:	riding a bicycle, or walking to work, walking or skiing with family, gardening
GROUP III	Regular activity:	such as heavy gardening, running, calisthenics, tennis, etc.
GROUP IV	Regular hard physical training for competition:	in running events, soccer, racing, European handball, etc. Several times a week

classification. In the leisure-time activity classification, 19 were in Group I, 7 in Group II and 1 in Group III. Consequently, in their off hours, sugar cane cutters are, by and large, a fairly sedentary group.

Knowing the energy expenditure of cutting cane (Kcal/Kg) and the average daily productivity it is possible to estimate the total caloric expenditure for an 8 hour work day. However, since the energy expenditure was significantly less in the afternoon than morning (Fig. 8) we used the morning value to calculate the total energy expenditure for 4 hours and the afternoon value for 4 hours and summed them. In this way it was possible to estimate in 24 men that the total caloric expenditure for their 8 hours of work was 2413±555 Calories/day.

(J) Dietary Histories

The information derived from the dietary histories taken by the nutritionist in the metabolic ward of the University Hospital is presented in Table XIV. Since there were no statistically significant differences among 3 groups the data are also presented as total averages, standard deviations and ranges.

TABLE XIV

ESTIMATED DAILY DIETARY INTAKE OF SUGAR CANE CUTTERS

	Estimated Daily Intake					
	Protein			Fat	Carbo-hydrate	Estimated Caloric Intake
	Gm/day	%Animal	%Vegetable	Gm/day	Gm/day	Cal/day
			GROUP I			
n	8	8	8	8	8	8
$\bar{x}$	70.1	31.8	68.2	43.9	522.5	2754.
S.D.	11.3	9.4	9.4	13.6	65.0	374.
Range	50-83	14-41	59-86	25-60	425-602	2295-3210
			GROUP II			
n	9	9	9	9	9	9
$\bar{x}$	75.2	38.7	61.3	50.9	556.0	3288.
S.D.	11.56	8.1	8.1	12.3	187.8	637.
Range	55-95	31-58	42-69	35-75	346-948	2360-4670
			GROUP III			
n	10	10	10	10	10	10
$\bar{x}$	73.2	36.2	61.8	41.2	554.7	2930.
S.D.	12.2	7.1	7.1	9.9	112.0	399.
Range	51-94	23-49	51-77	28-53	313-702	2319-3471
			TOTAL			
n	27	27	27	27	27	27
$\bar{x}$	72.9	36.4	63.6	45.2	545.6	2997.
S.D.	11.4	8.4	8.4	12.2	128.8	517.
Range	50-83	14-58	42-69	25-75	313-948	2319-4670

The results indicate that daily protein intake is adequate by U.S. standards. The recommended daily dietary allowances of the Food and Nutrition Board, National Academy of Sciences - National Research Council for a man 18 to 35 years old, weighing 70 Kg. and having a height of 175 cm is 70 gms/day (18). Considering the fact that the subjects in this study were smaller than the "standard" man by U.S. criteria (Table VIA), the 73 gms/day intake is probably adequate. However, the estimated daily caloric intake of about 3000 Calories/day would seem to be low considering

1) Recommended daily caloric intake for the above described "Standard" man is 2900 cal/day for persons "normally active in a temperate climate (18)."
2) The average daily caloric cost of 8 hours of cutting sugar cane is 2413 Calories/day without considering the caloric cost to the individual of activities performed for the rest of the day.

We do not have enough information to estimate the total caloric expenditure for a 24 hour period in these men and so cannot conclude that their caloric intake is inadequate. But the suspicion exists.

II. STUDIES IN MALNOURISHED PATIENTS

Five patients have been included in the longitudinal study as of November 30, 1972. Four of them are still under study and only initial data are available. Only one subject has finished all tests. Three to five additional patients will be admitted in this group by January 15, 1973.

(A) Basal Data

The general characteristics of these patients are given in Table XV. Hematologic data are presented in Table XVI and initial body composition data in Table XVII. Physical work capacity values of these subjects are shown in Table XVIII.

All patients show a reduced weight/height ratio as compared to normal subjects in the rural Colombian population (19). All have albumin levels below 2.5 gm %, low total serum proteins and low cholesterol levels. From the standpoint of body composition, all show an increased percentage of total body water (TBW). Three of them show pronounced increases in extracellular space per kg, simultaneously with a low to moderate degree of clinical edema. The percentage of fat per kg is much reduced in all subjects. The hydration coefficient (20) of the fat free body in all cases exceeds the normal value.

TABLE XV

GENERAL CHARACTERISTICS AND BLOOD CHEMISTRY
OF PATIENTS IN THE LONGITUDINAL STUDY

Initial Data

Patient	Age (years)	Weight (kg)	Height (m)	W/H	Serum Albumin (g%)	Serum Protein (g%)	Serum Cholesterol (mg%)
VN	46	46.75	1.65	28.33	1.3	4.4	95
RU	32	31.75	1.45	21.89	2.3	5.7	105
RC	32	51.75	1.68	30.80	1.6	4.5	110
IM	50	45.3	1.55	29.22	1.8	5.1	111
MCh	43	49.7	1.53	32.48	1.8	5.3	123
Mean	40.6	45.05	1.57	28.54	1.8	5.0	109
S.D.	8.2	7.85	0.09	4.04	0.4	0.6	10

TABLE XVI

HEMATOLOGICAL CHARACTERISTICS OF PATIENTS
IN LONGITUDINAL STUDY

Initial Data

Patient	Hb g%	Htc %	Blood Volume ml	Blood Volume ml/kg	Total Hb g/kg	% Trans.	Vit B_{12} pcg/ml	Folic Acid ng/ml
VN	10.4	33	3530	75.5	7.85	8.5	660	1.2
RU	13.3	37	2950	92.9	12.34	51.1	260	3
RC	12.66	41	4341	83.9	10.62	44.7	610	5.1
IM	8.5	27	3879	85.6	7.28	1.1	>900	5.9
MCh	13.6	39	4557	91.7	12.47	33.3		5.8
Mean	11.69	35.4	3851	85.9	10.11	27.7		4.2
S.D.	2.18	5.6	643	6.98	2.45	22.0		2.0

TABLE XVII

BODY COMPOSITION OF PATIENTS IN LONGITUDINAL STUDY

Initial Data

Patient	TBW[1] / kg	ECF[2] / kg	ICW[3] / kg	ICW / TBW	ECF[4] / ECF_{pred}	CH[5**]	FFW[6] / kg	FW[7] / kg	FFS[8] / kg	D.S.[9] / kg
VN	.776	.516	.260	.335	1.710	.8	.962	.030	.193	.224
RU	.713	.361	.370	.506	1.200	.745	.979	.020	.248	.269
RC	.722	.447	.280	.385	1.490	.78	.948	.065	.209	.273
IM	.772	.417	.369	.465	1.388	.775	.997	.003	.224	.227
MCh	.724	.342	.382	.527	1.140	.74	.981	.018	.257	.275
Mean	0.741	0.417	0.332	0.444	1.386	0.768	0.973	0.027	0.226	0.254
S.D.	0.030	0.07	0.057	0.082	0.230	0.024	0.020	0.022	0.026	0.026

1. Total body water - L/kg
2. Extracellular Fluid - L/kg
3. Intracellular water - L/kg
4. ECF predicted = 0.3 (Body weight) (20)
5. CH = Coefficient of hydration according to Moore (20)
6. Fat free weight - Kg/Kg
7. Fat weight - Kg/Kg
8. Fat free solids - Kg/Kg
9. DS = Dry solids

TABLE XVIII

PHYSICAL WORK CAPACITY OF PATIENTS
IN LONGITUDINAL STUDY

Initial Data

Patient	$\dot{V}O_2$ ml/min	Aerobic Power ml/Kg·min^{-1}	Max. f_H b/min	Max $\dot{V}_E$ l/min	Max O_2 Pulse ml/beat	Max $\dot{V}_E$ l/l $\dot{V}O_2$	T_{max40} min
VN	827	18.75	167	43.5	4.95	52.6	273
RU	868	25.64	184	71.7	4.75	82.6	491
RC	1188	25.40	180	99.1	6.60	83.4	491
IM	1206	26.60	190	92.0	6.34	76.3	400
MCh	1560	31.26	183	76.0	8.52	48.7	432
Mean	1129.80	25.53	180.8	76.46	6.23	68.72	417.4
S.D.	297.70	4.47	8.53	21.58	1.52	16.78	89.72

The intracellular water (ICW) per kg reflects low values as well as the ratio ICW/TBW. Total dry solid and fat free solids per kg are also reduced. The aerobic capacity is much reduced and in no case exceeds 32 ml/kg min. Maximal endurance at comparable relative work loads varies widely but is comparable to those in normal subjects in 4 out of the 5 patients. Maximal heart rates are on the average similar to those expected for subjects of similar ages (21) (Table XIX).

(B) Effect of Training, Learning or Sedentary Activity on Successive Exercise Tests.

The $\dot{V}_{O_2}$ max and maximal endurance of four patients has been measured during the second week in the hospital, and then at the seventh week in the hospital, while receiving a low protein (20 gm/day) diet. The results are given in Table XX. Thus far, we have only seen a small, variable and probably insignificant effect of training due to the exercise tests performed 4 weeks before, on the physical capacity measured at the 7th week, while receiving a low protein diet (20 gm/day). Also, bed rest or sedentary life in the metabolic ward for 4 weeks does not seem to have any significant further deleterious effect on the physical work capacity of these severely mal-

TABLE XIX

MAXIMAL HEART RATES IN SUBJECTS

IN THE LONGITUDINAL STUDY

Initial Data

Patient	Age	Expected[1] max f_H	Observed max f_H	$\frac{\text{max } f_H}{\text{expected}}$
VN	46	175	167	.954
RU	32	187.5	184	.981
RC	32	187.5	180	.960
IM	50	170	190	1.110
MCh	43	180	183	1.010
Mean	40.6	180	180.8	1.003
S.D.	8.23	7.71	8.53	0.064

[1]According to Astrand (21)

TABLE XX

EFFECTS OF RETESTING 4 WEEKS APART ON EXERCISE PERFORMANCE OF PATIENTS IN LONGITUDINAL STUDY.

Patient	$\dot{V}O_{2\,max}$		Aerobic Power		Ratio	T_{max40}		B. Weight	
	2nd week	7th week	2nd week	7th week	Week7/Week2	2nd week	7th week	2nd week	7th week
	ml/min		ml/kg·min			min		kg	
RC	1188	1437	25.64	31.40	1.22	491	446	51.75	45.65
RU	868	950	25.40	26.46	1.04	491	491	31.75	35.90
IM	1206	998	26.60	22.40	0.84	400	420	45.30	44.55
MCh	1560	1257	31.26	25.49	0.81	432	415	49.70	49.70
Mean	1205.50	1160.5	27.22	26.44	0.98	453.5	443.0	44.62	43.95
S.D.	282.77	228.39	2.73	3.73	0.19	45.23	34.77	9.00	5.81

nourished patients with an already reduced aerobic power. Some weight gain was noted in some of these patients, while loss of edema and weight loss was noted in others. These changes in body composition might relate to small changes (≅ 10%) sometimes noted in aerobic power (Table XX).

(C) Effects of Protein Repletion on Physical Work Capacity, Body Composition and Blood Composition.

As of November 30, 1972, one patient has completed 9 weeks of nutritional repletion (100 gm/day protein). Two patients have completed the 7 week basal period and have already been for 3 weeks in the repletion period. Two more patients have just completed the 7 weeks of the basal, low protein period. Changes in maximal oxygen consumption, aerobic power and maximal endurance upon protein repletion are illustrated in Table XXI for the one patient who had completed 8 weeks of repletion.

The initial increase in $\dot{V}_{O_2}$ max observed after 4 weeks repletion seem to have occurred in association with

a) a decrease in "dead" weight of the subject related to the loss of edema (↓ in % TBW, ↓ in % ECF).

b) an increase in total muscle mass, as reflected by the increase in total dry solids, the increase in % ICW and also the increased daily creatinine output/kg.

TABLE XXI

CHANGES IN PHYSICAL WORK CAPACITY
DURING NUTRITIONAL (PROTEIN) REPLETION

SUBJECT V.N.

	Basal	4 Weeks of Repletion	8 Weeks of Repletion
$\dot{V}_{O_2}$ max ml/min	810	1270	1545
Aerobic Cap ml/Kg·min^{-1}	18.75	29.17	29.65
$T_{max_{40}}$ min	275	266	240

The further increase in $\dot{V}_{O_2}$ max observed 4 weeks after, during the 9th week of repletion, seemed to be associated with a progressive increase in muscle mass. From the 4th to the 9th week of repletion there did not seem to be major changes in the quality of the body mass being built but only in its quantity. Significantly, maximal oxygen consumption per kg of body weight (aerobic power) did not change from the 5th to the 9th week of repletion.

Aerobic capacity although improved with 8 weeks of nutritional repletion remained however at relatively low values. At this time the fat depots of the subject remain also at low values. Whether limiting supplies of substrates (fats or carbohydrates) are important at this stage in determining maximal aerobic capacity remains to be determined.

The changes in blood and body composition observed in this patient are summarized in Tables XXI thru XXIII. A near normal albumin level with somewhat low serum total protein and cholesterol levels was observed after 8 weeks of repletion.

Data of the 4 subjects which have only completed the basal period have been commented on. In summary:

TABLE XXII

CHANGES IN BLOOD CHEMISTRY
DURING NUTRITIONAL REPLETION

PATIENT V.N.

	Basal	5 Weeks of Repletion	9 Weeks of Repletion
Hb. (g%)	10.4	9.3	9.8
Hb total/kg (g/kg)	7.85	8.92	8.72
% transferin	5	8.5	2.45
Vit B_{12} (pgm/ml)	660	625	625
Folic A (ng/ml)	1.2	2.4	2.3
Serum Albumin (g%)	1.3	3.3	4.0
Total Protein (g%)	4.4	6.6	6.9
Cholesterol (mg%)	95	168	153
B. Weight (kg)	46.75	45.5	51.5

TABLE XXIII

CHANGES IN BODY COMPOSITION
DURING NUTRITIONAL REPLETION

PATIENT V.N.

		Repletion	
	Basal Period	5th Week	9th Week
Body Weight (kg)	46.75	45.5	51.5
Creatinine Output (mg/kg.day)	10.99	13.82	16.42
Total Body Water (l/kg)	.776	.724	.690
Extracellular (tiocianate) Space (l/kg)	.516	.398	.372
Intracellular Water (l/kg)	.260	.326	.318
Fat Free Weight (kg/kg)	.969	.992	.986
Fat Weight (kg/kg)	.031	.008	.014
Fat Free Solids (kg/kg)	.193	.268	.296
Total Solids (kg/kg)	.224	.275	.310

1) There does not seem to be any training effects in the subjects by performing the batteries of exercise tests 1 month apart.

2) Body composition, and blood chemistry show little change during the stay in the metabolic ward for 4 weeks on a low (20-25 gm/day) protein diet.

(D) Vertical Group

Studies in 6 patients in this group have been completed. Two more patients have been admitted and are under study. We expect to study 9 more patients in this group as of April, 1973. This group of 17 patients together with the basal data of the 8 patients in the longitudinal group, will provide a total of 25 patients covering a wide range of nutritional states as found in the general working rural population of this region.

General characteristics and blood composition data on the 6 patients already studied in this group are given in Table XXIV. Physical work capacity data are shown in Table XXV, body composition data in Table XXVI, and hematologic studies in Table XXVII.

TABLE XXIV

GENERAL CHARACTERISTICS

PATIENTS IN VERTICAL STUDY

Patient	Age Years	Weight Kg	Height m	W/H	Albumin g%	Total Prot. g%	Cholesterol mg%
RCh	37	45.5	1.59	28.61	2.50	5.9	140
CT	44	56.35	1.54	36.59	2.90	6.3	115
RI	35	45.80	1.60	28.62	3.15	5.85	101
MT	20	54.25	1.55	35.00	3.90	7.9	210
MAC	47	56.50	1.61	35.09	4.15	6.9	132
MB	31	54.25	1.52	35.50	4.10	7.0	158
Mean	35.67	52.11	1.57	33.24	3.45	6.64	142.67
S.D.	9.67	5.10	0.04	3.62	0.69	0.78	38.45

TABLE XXV

PHYSICAL WORK CAPACITY

PATIENTS IN VERTICAL STUDY

Patient	$\dot{V}O_{2max}$ ml/min	Aerobic Power ml/kg·min^{-1}	Max f_H b/min	Max $\dot{V}_E$ l/min	Max O_2 Pul. ml/beat	Max $\frac{\dot{V}_E}{\overline{VO_2}}$ l/l	T_{max} 40 min
RCh	935	19.54	171	89.7	5.46	95.93	491
CT	1909	33.90	200	101.7	9.54	53.27	209
RI	1452	30.97	192	106	7.56	73.00	138
MT	2608	47.94	198	112.1	13.17	42.98	63
MAC	2368	40.82	176	77.9	13.45	32.89	151
MB	2988	55.33	192	114.3	15.56	38.25	433
Mean	2043.33	38.08	188.17	100.28	10.79	56.05	247.50
S.D.	763.25	12.76	11.91	14.03	3.90	24.12	173.51

TABLE XXVI

BODY COMPOSITION

PATIENTS IN VERTICAL STUDY

Patient	TBW kg	ECF kg	ICW kg	ICW TBW	ECF ECF	C.H.	FFW kg	FW kg	FFS kg	D.S. kg
RCh	.758	.38	.380	.501	1.293	.76	.997	.002	.239	.241
C.T.	.690	.314	.376	.545	1.046	.73	.945	.054	.255	.310
RI	.695	.32	.371	.533	1.236	.75	.927	.007	.232	.304
MT	.652	.30	.350	.537	1.006	.735	.887	.1126	.235	.348
MAC	.687	.30	.380	.555	1.014	.735	.931	.068	.246	.315
MB	.617	.30	.313	.507	1.013	.73	.846	.233	.228	.382
Mean	0.683	0.32	0.362	0.530	1.101	0.74	0.922	0.079	0.239	0.317
S.D.	0.046	0.03	0.026	0.020	0.128	0.01	0.050	0.085	0.010	0.047

See Table XVII for meaning of symbols.

TABLE XXVII

HEMATOLOGICAL DATA OF PATIENTS

IN VERTICAL STUDY

Patient	Hb g%	Blood vol. ml	Total Hb g/kg	%Transferin	Vit. B_{12} pcg/ml	Folic Acid ng/ml
RCh	11.9	3601	9.40	3.3	397	9.6
CT	7.9	4595	6.44	21.2	330	18.3
RI	8.8	3826	7.36	4.6	600	4.2
MT	16.35	4319	13.01	33.3	255	>20
MAC	16.45	6020	17.52	25.2	558	6.1
MB	16.45	5833	17.67	28.15	358	16
Mean	12.98	3718.67	11.90	19.29	416.33	
S.D.	4.0	2226.90	4.96	12.53	134.95	

(E) Relationship between Nutritional State and Endurance at Identical Relative Work Loads.

Initial data of the 5 patients in the longitudinal group and of the 6 patients studied thus far in the vertical group, have been pooled providing a relatively wide range of nutritional states as reflected by a range of serum albumin values varying between 1.3 and 4.2 gm %.

Maximal endurance time at 40% load (t_{max40}) in each patient has been calculated as described in the methods section. The results can be segregated into two groups, independently of the serum albumin level, a group with t_{max40} of 400-500 min and a group with t_{max40} of less than 300 min. (Table XXVIII). Thus t_{max40} is independent of nutritional state but dependent on another variable. The only markedly different trait found in these two groups of subjects was their willingness to cooperate in the tests. Whether this behaviour reflects a specific physical limitation, training or plain motivation has been, so far, impossible to determine. However, the most important conclusion is that t_{max40} is independent of nutritional state and thus is a variable which need not be considered in evaluating the impact of nutrition on productivity.

TABLE XXVIII

$T_{max_{40}}$ AT DIFFERENT NUTRITIONAL STATES AS EVALUATED BY THE SERUM ALBUMIN LEVEL

Serum Albumin gm%	Level $T_{max_{40}}$ >400 min	$T_{max_{40}}$ <300 min
1.3		273
1.6	491	
1.8	400	
1.8	432	
2.51	491	
2.75	491	
2.9		209
3.15		138
3.30		263
3.90		63
4.10	433	
4.15		151

(F) Relationship of Maximal Aerobic Power to Nutritional State.

Nutritional state as reflected by two readily measured parameters, weight/height ratio and serum albumin levels has been related to maximal aerobic power in the same 11 patients. The relationships found are described in Figs. 14 and 15. It can be observed that at weight/height ratios below 32-30 kg, aerobic capacity is limited to values not exceeding 30 ml/kg min^{-1}. Also, at serum albumin levels below 3 gm%, aerobic capacity does not exceed 30 ml/kg min. At serum albumin levels around 4 gm%, probably a near maximal serum albumin concentration, aerobic capacity varies widely above 30 ml/kg·min the highest value thus far found being 55.3 ml/kg·min.

It can be concluded that chronic undernutrition severely limits aerobic capacity; the lowest value thus far encountered being 18.75 ml/kg min, in a severely malnourished subject (1.3 gm% serum albumin, weight/height ratio of 28.2 kg/m and presenting moderate clinical edema). While serum slbumin concentration and weight/height ratios may serve as limiting value indicators of aerobic power, are there any other parameters of body composition or nutritional state which

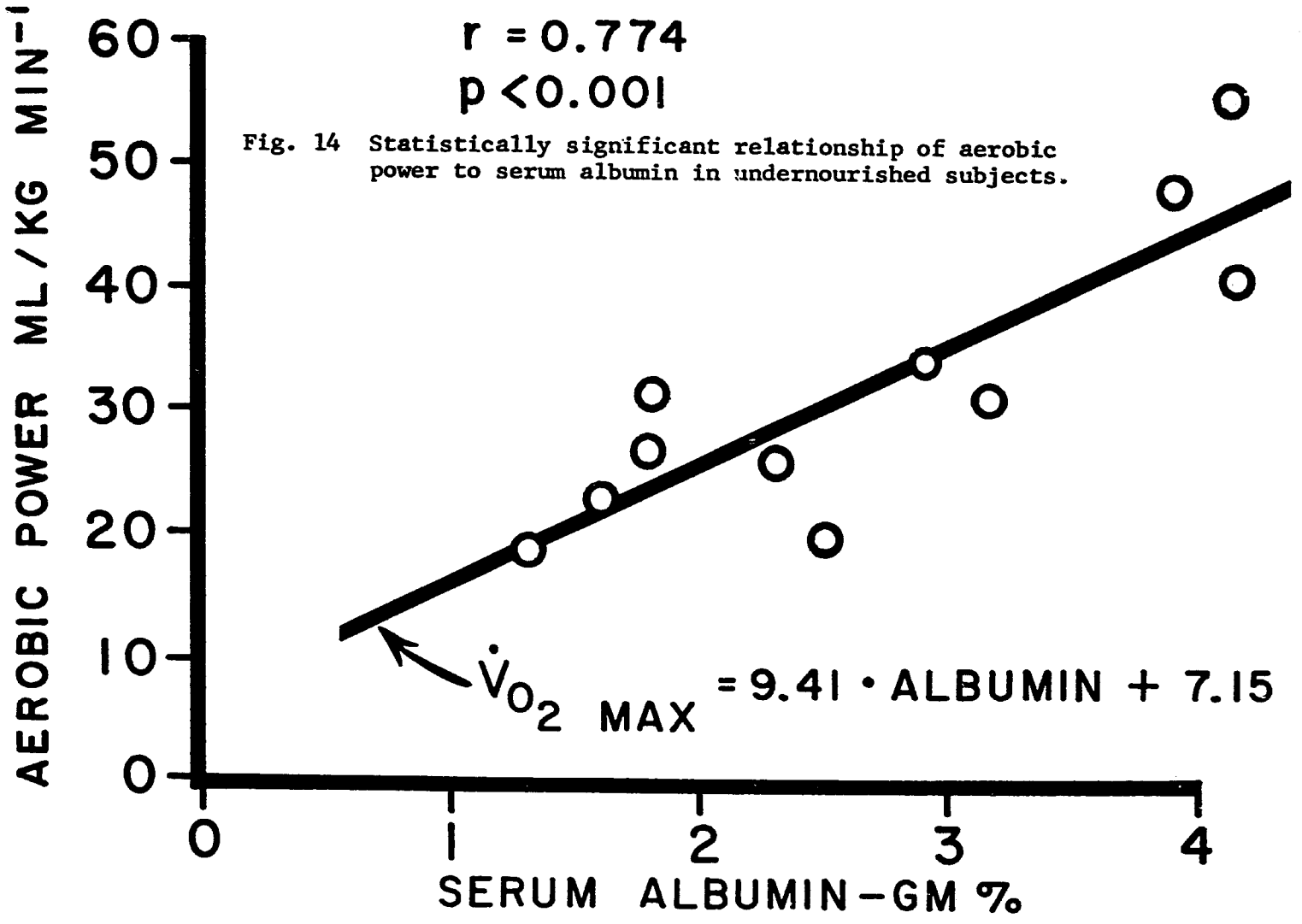

Fig. 14 Statistically significant relationship of aerobic power to serum albumin in undernourished subjects.

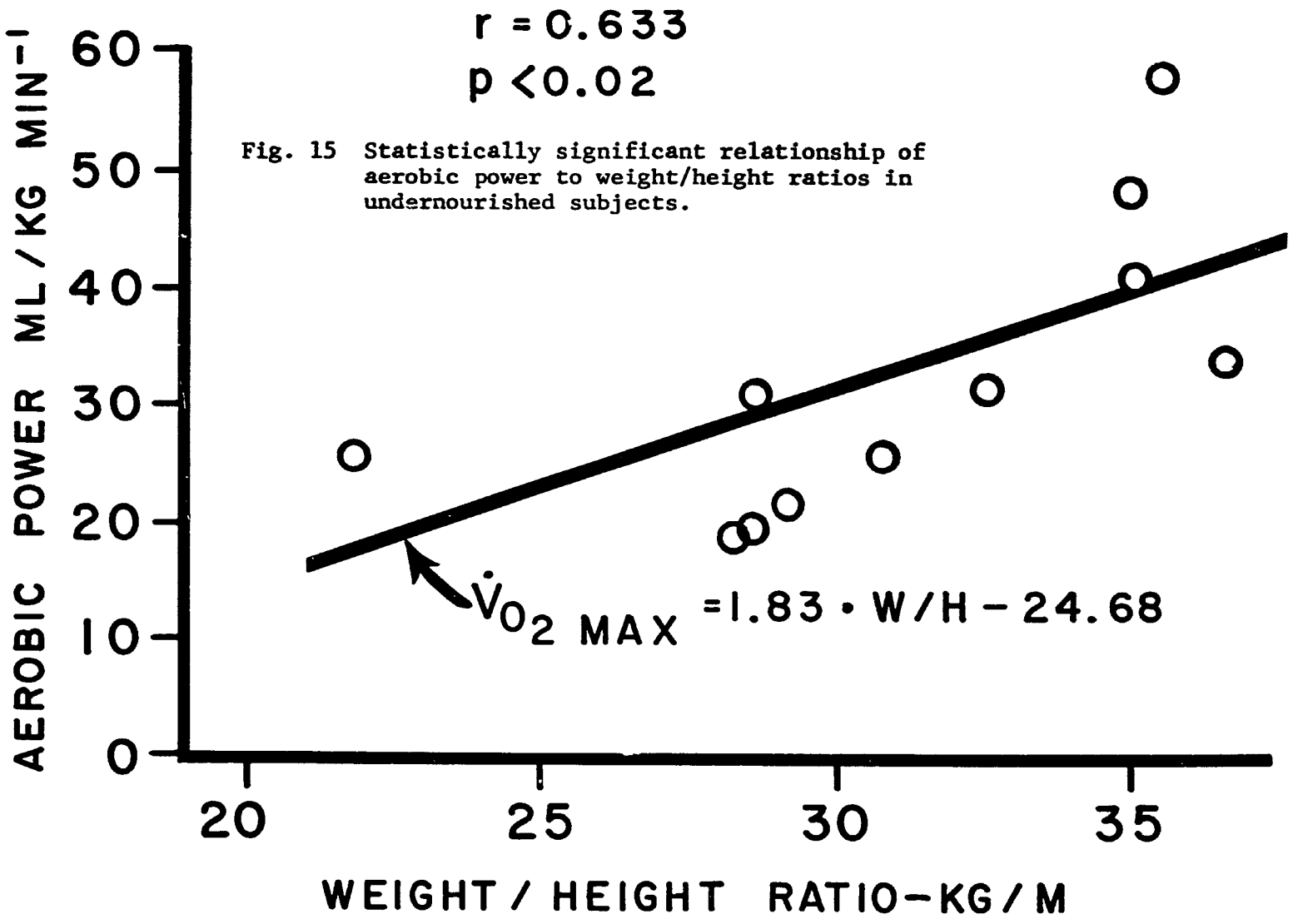

Fig. 15 Statistically significant relationship of aerobic power to weight/height ratios in undernourished subjects.

can be correlated with maximal aerobic power?

(G) Relationship of Total Body Water to Maximal Aerobic Power

As shown in Fig. 16 a linear, inverse relationship was found between TBW/kg and aerobic capacity in the severely undernourished and the marginal patients so far studied. Increases in the % of TBW associated with poor nutritional state might relate to:

a) decreases in total body fat.

b) decrease in cell body mass (intracellular water and metabolically active dry solids) with unchanged or less diminished extracellular water, thus resulting in a relative excess of extracellular and total body water per kg.

c) Overhydration, i.e., excess extracellular fluid.

That the first two types of changes (a and b) in body composition do occur at varying degrees of undernutrition is suggested by the following observations. In patients with serum albumin levels above 4 gm % maximal aerobic capacity varied more or less in direct proportion to the fat content per kg. Increase in % TBW were due in these subjects to a decreasing percentage of total body fat (Fig. 17).

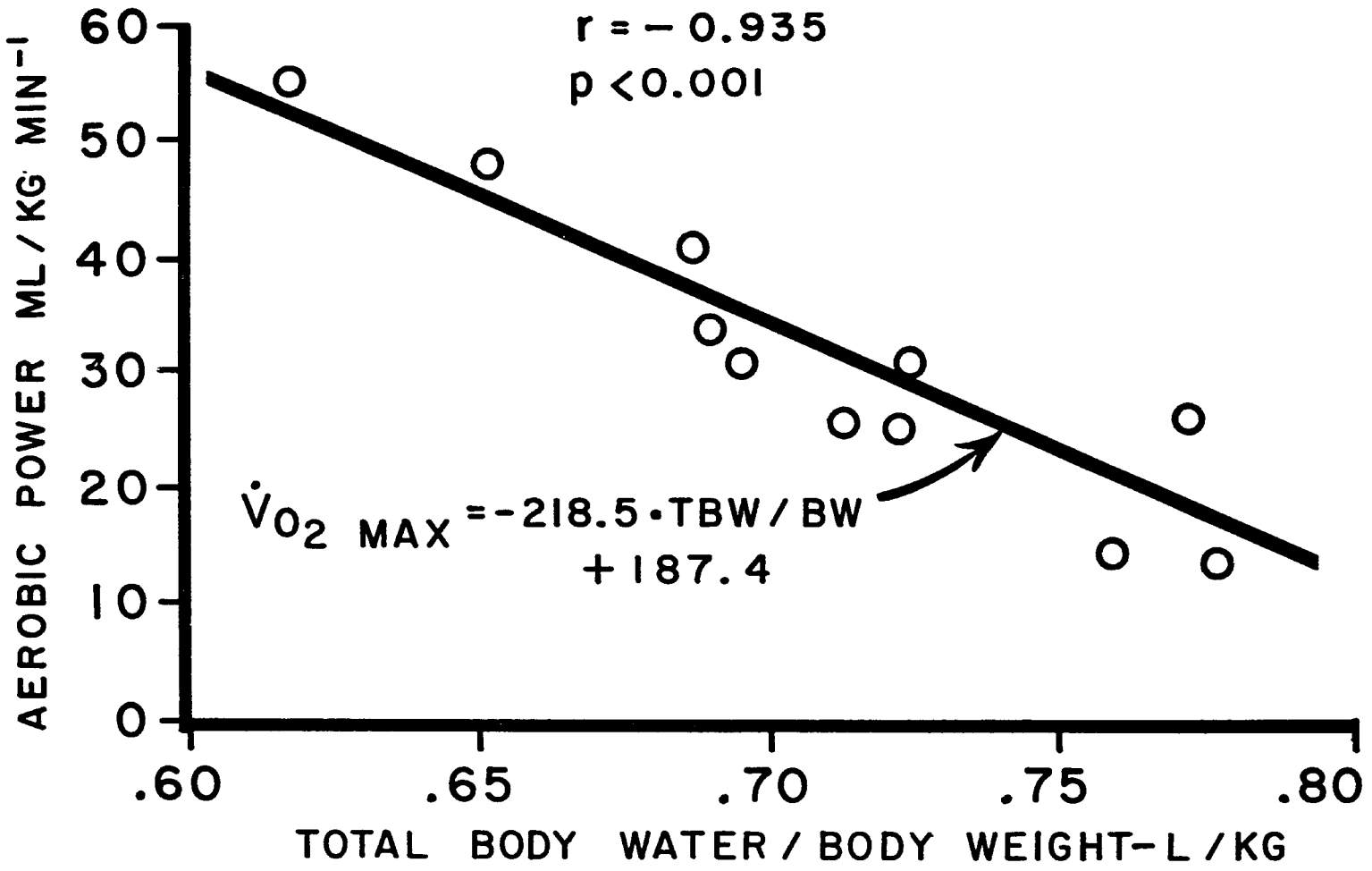

Fig. 16 Statistically significant relationship of aerobic power to the ratio of total body water/body weight in undernourished subjects.

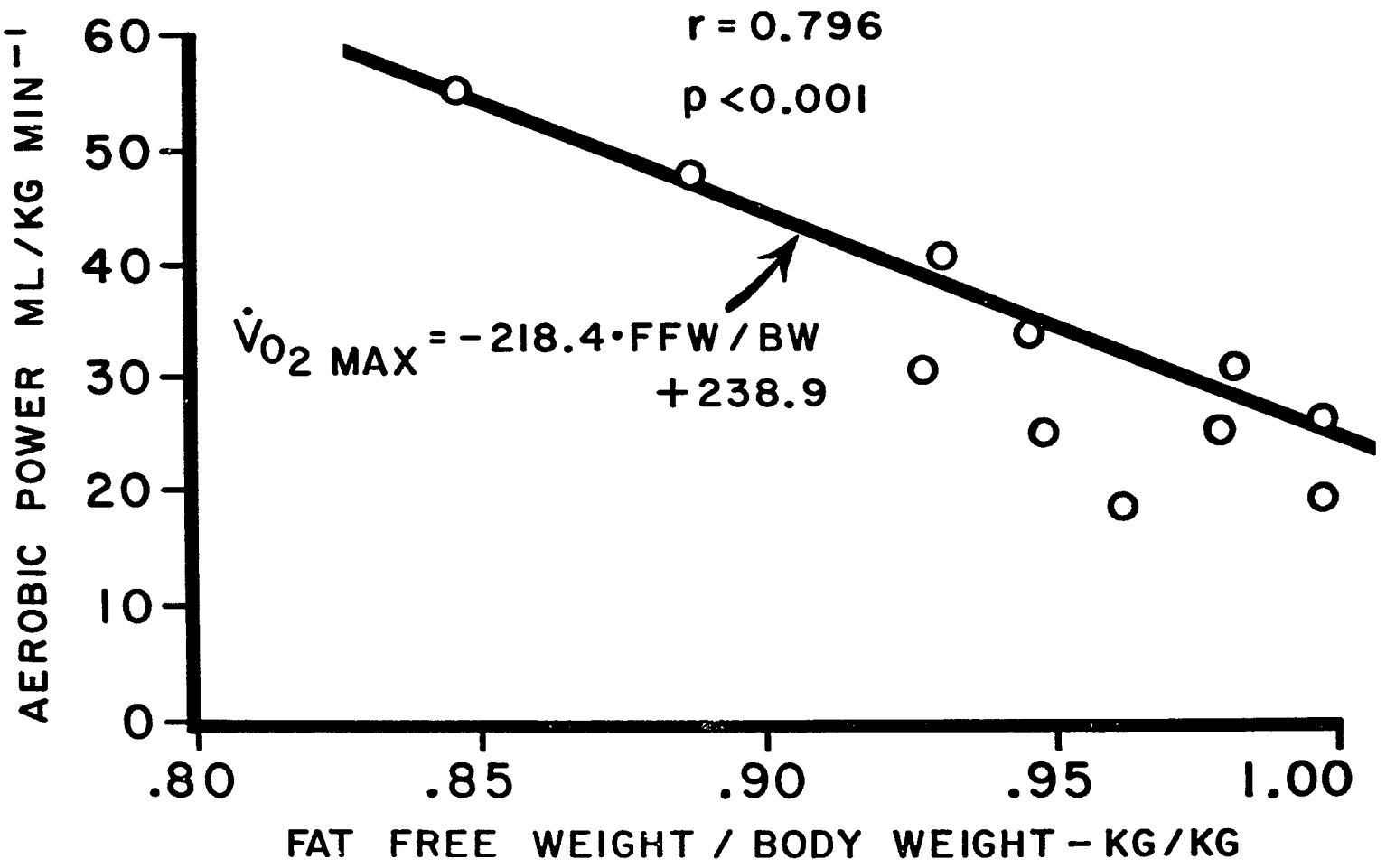

Fig. 17 Statistically significant relationship of aerobic power to the fat free weight/body weight ratio in undernourished subjects.

In eight patients, with serum albumin levels below 4 gm%, and low percentage fat content in their bodies (.5 - 6%) increasing percentages of TBW were found associated with increasing percentage of ECW.

The relationship of aerobic power to other bodily parameters related to the nutritional state of the subject are shown in Figs. 18 through 22. In Fig. 18 the plot of aerobic power on the extracellular water/body weight ratio gives a curvilinear relationship which can be linearized by plotting the reciprocal of the 2 variables as shown in Fig. 19. The latter gives a highly significant correlation coefficient of -0.785 ($p<0.001$) indicating that a relative increase in the extracellular water, a condition associated with malnutrition, results in a reduced ability to perform maximal exercise.

As shown in Fig. 20, there does not appear to be any significant correlation of aerobic power with the intracellular water/body weight ratio. However, in Figs. 21 and 22 one can see that aerobic power is significantly correlated with both the fat weight/body weight ratio and total body hemoglobin/body weight ratio.

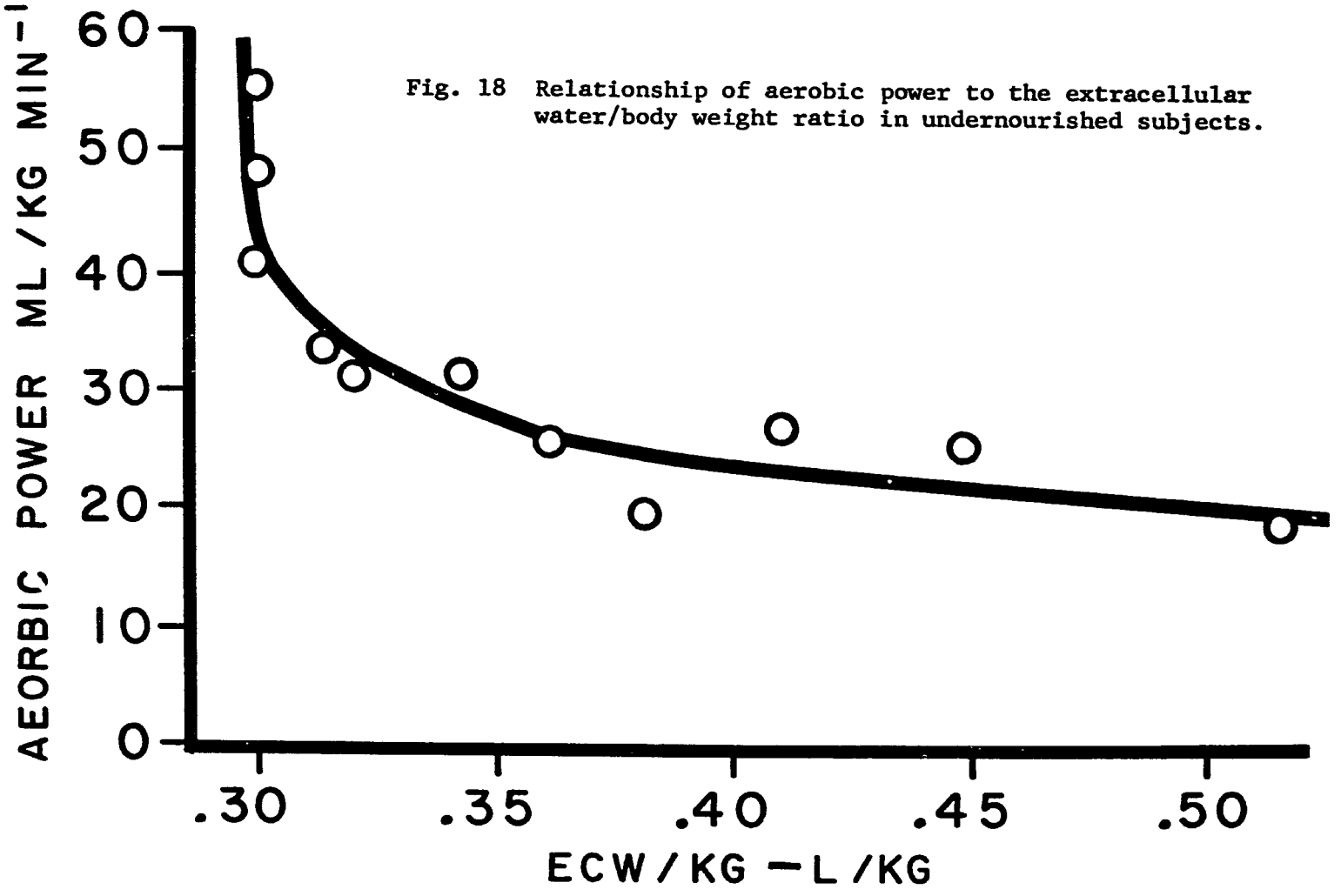

Fig. 18 Relationship of aerobic power to the extracellular water/body weight ratio in undernourished subjects.

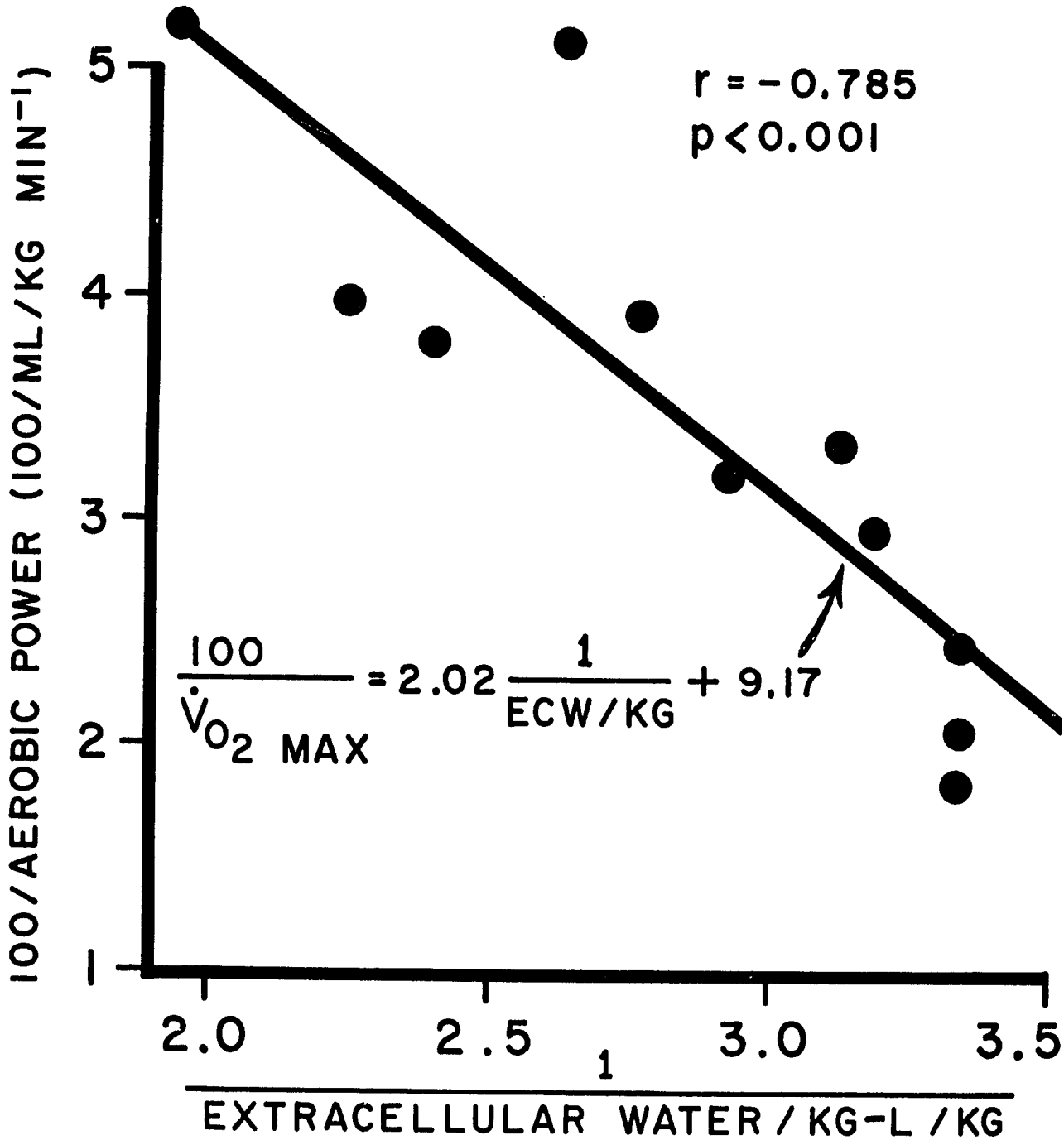

Fig. 19 Plot of the reciprocals of aerobic power and the extracellular water/body weight ratio in undernourished subjects.

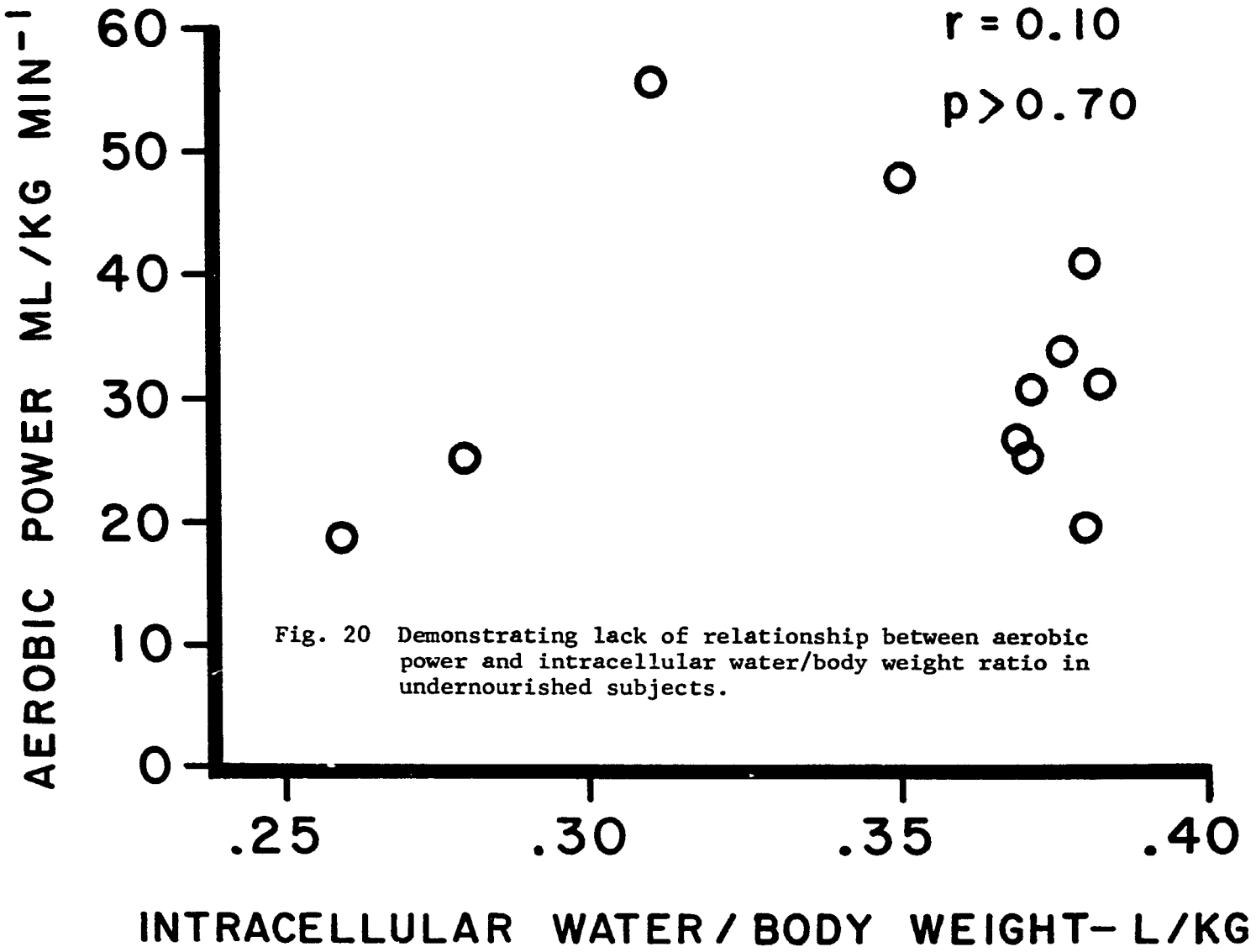

Fig. 20 Demonstrating lack of relationship between aerobic power and intracellular water/body weight ratio in undernourished subjects.

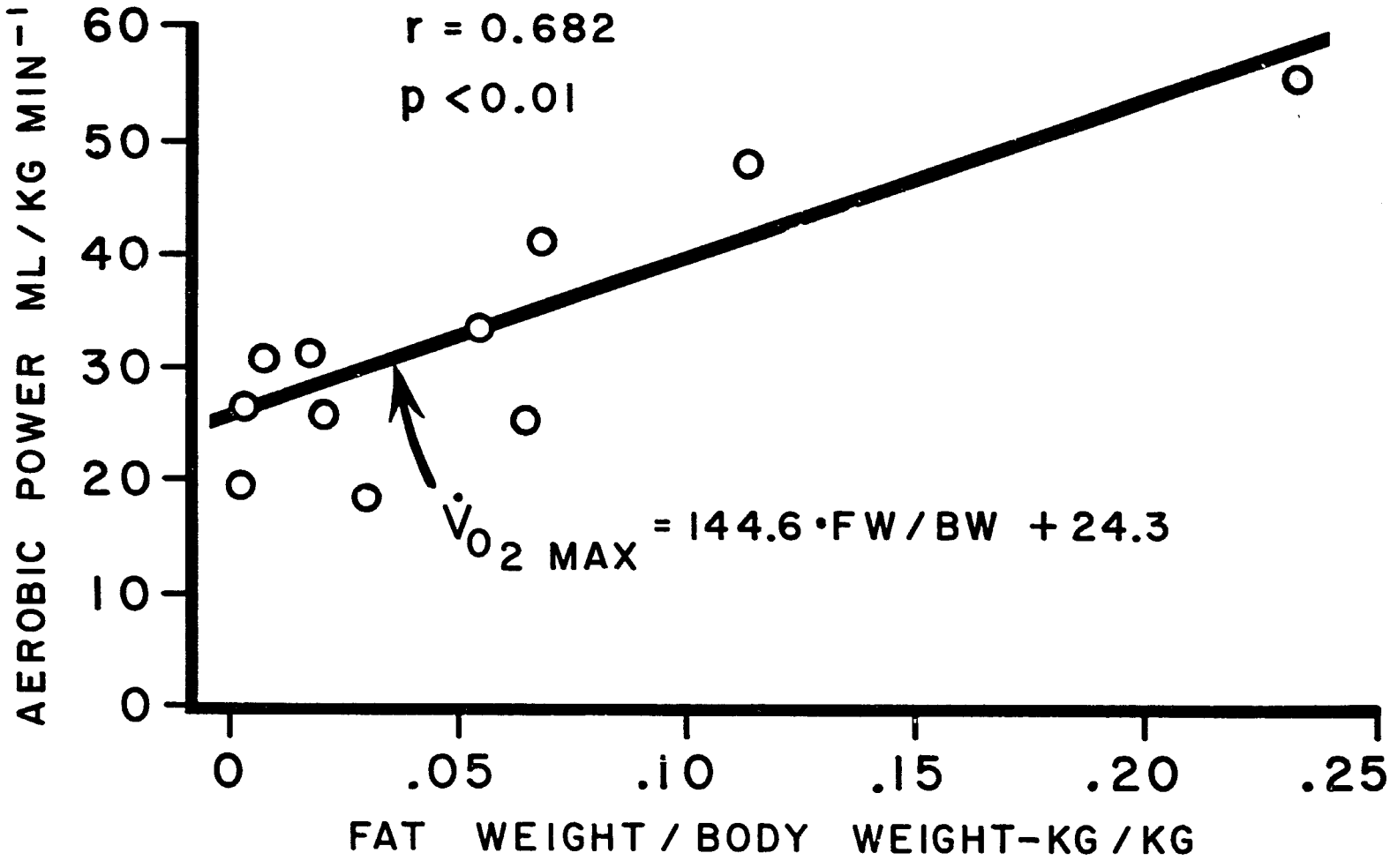

Fig. 21 Statistically significant relationship between aerobic power and the fat weight/body weight ratio in under-nourished subjects.

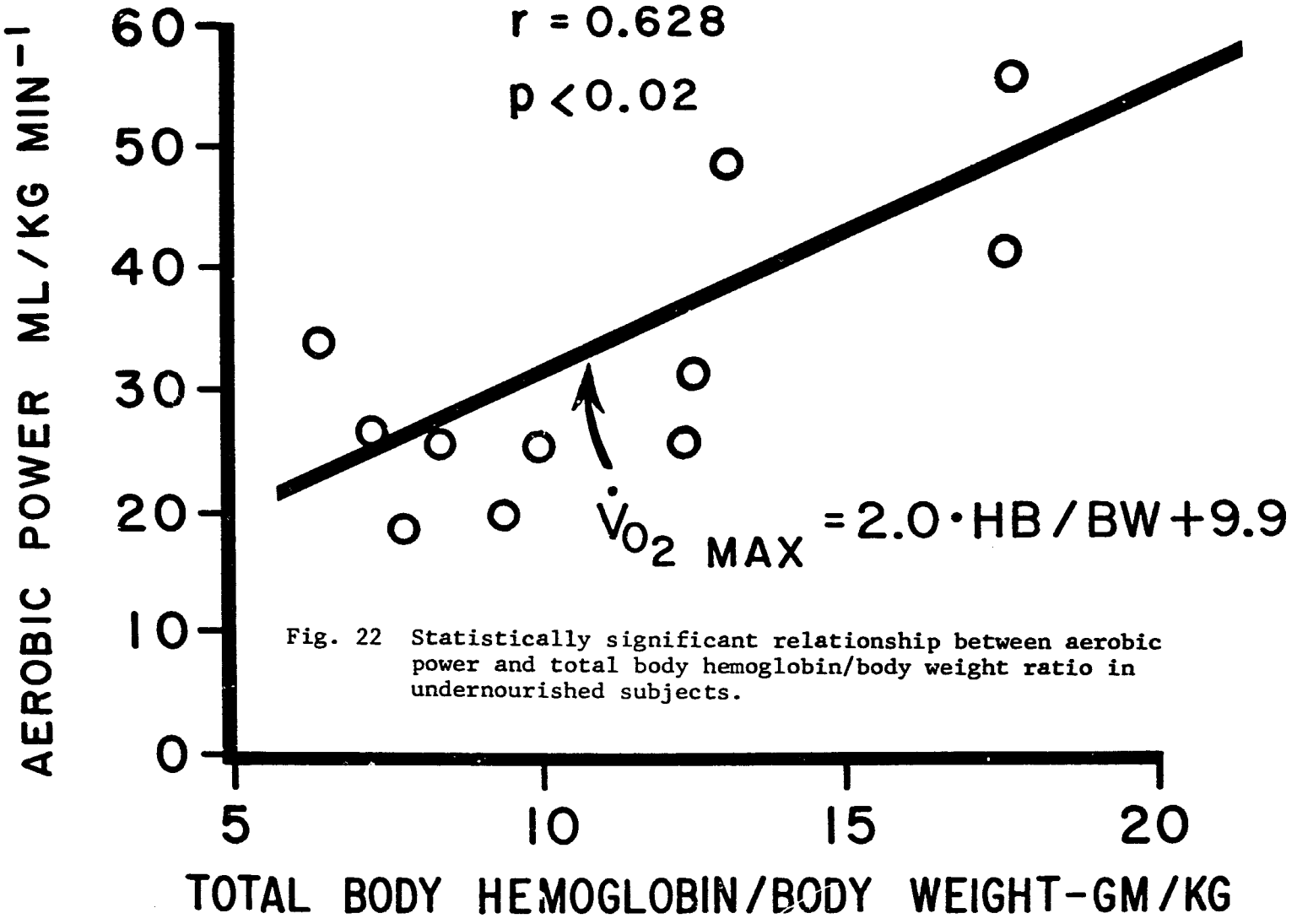

Fig. 22 Statistically significant relationship between aerobic power and total body hemoglobin/body weight ratio in undernourished subjects.

In the less severely undernourished subjects, ICW/kg increasing up to .465 L/kg as fat content decreased while ECW/kg was relatively constant at .3 L/kg. In very severely malnourished patients ICW/kg decreased reaching the lowest value (.21 L/kg) in a malnourished patient with clinical edema. Fat free solids per kg followed the same pattern as TBW/kg. These changes in body composition seem to reflect a progressive involvement of 1) depot tissues and 2) active metabolic tissue as malnutrition increases in severity. Simultaneously correlated with these changes in body composition there seems to occur a progressive deterioration of maximal aerobic power. These data seem to suggest that at moderate stages of chronic undernutrition, absence of tissue deposits of fat (and perhaps also of carbohydrates) might be limiting factors or associated changes that correlate with decreases in maximal aerobic power. As the intensity of the nutritional defect progresses in severity, reduction in cell body mass further compromises aerobic power.

Unfortunately there is no information on the changes in support tissue weight in these malnourished subjects. Thus calculation of the exact extent of the changes in cell body mass and of the hydration coefficient of metabolically active tissue cannot be carried out at present. This would require measurements of total body K, for which we have no provision in this project since the required equipment is not available. However, the possibility that muscle biopsy could provide valid information on this matter is being considered. These body composition studies suggest that the ability of the tissues to utilize oxygen may be the factor limiting the aerobic power of undernourished subjects. Final and direct proof of this point could come from evaluation of maximal cardiac output (and thus of stroke volume and A-$\dot{V}O_2$ difference) in malnourished and repleted patients. This requires development of a technique that would allow us to determine cardiac output during performance of maximal work. Modification of the breath hold acetilene method of Cambden and Forster (22) and Johnson (23) is being tried at present with this purpose. Thus this initiates the start of the mechanistic approach to the problem of limitations of physical work capacity in undernutrition.

SUMMARY AND PRELIMINARY CONCLUSIONS

I. STUDIES ON SUGAR CANE CUTTERS

1. The original hypothesis that productivity of sugar cane cutters is related to their ability to perform maximal exercise ($\dot{V}_{O_2}$ max) has not been sustained as yet by the present data. However, there are indications from the heart rate data, the $\dot{V}_{O_2}$ max results as well as measurements on efficiency of cane cutting that the men classified as poor producers are under more physiological stress than the other subjects, while cutting sugar cane.
2. Cutting sugar cane increases heart rate to about 135 beats/min, oxygen consumption to approximately 1.5 L/min and pulmonary ventilation to about 50 L/min. The energy cost is 7.8 Kcal/min which classifies this type of work as "heavy".
3. At the same work level (oxygen consumption) cutting sugar cane results in higher heart rates in the afternoon than in the morning probably because of the increased ambient temperature in the afternoon.
4. In the higher afternoon temperatures, the energy expenditure per kilogram of cane cut is lower indicating an increased physiological efficiency.

5. During the test periods it was observed that the subjects were working at approximately 60% of their maximum ability to perform work. This is higher than can be sustained throughout the entire work day. Calculations based on daily productivity indicate that the estimated, sustained % $\dot{V}O_2$ max was approximately 40%, which is about the maximum level that can be sustained for an 8 hour day.
6. It was estimated that the daily caloric cost of cutting sugar cane was about 2400 Cal/8 hour day.
7. Dietary histories indicated that daily protein consumption was adequate and that total caloric consumption was about 2900 Cal/day.

II. STUDIES IN MALNOURISHED PATIENTS

1. Aerobic capacity is much reduced in undernourished subjects.
2. With varying degrees of undernutrition there are varying degrees of compromise in aerobic capacity.
3. With nutritional (protein) repletion there is an improvement in physical work capacity in spite of the sedentary conditions prevailing during the repletion period and independently of any training or learning effects of the exercise tests performed.

4. Improvement in aerobic capacity with protein repletion goes along with a) a decrease in the percentage of total body water, b) an increase in the percentage of dry solids which represents, on the one hand the gain in active metabolic tissue (muscle mass) and on the other the repletion of depot tissues.
5. Poor nutritional intake seems to alter the aerobic reserve of the organism but does not seem to alter the ability to endure a given submaximal relative work load.
6. Maximum oxygen consumption (aerobic power) is significantly correlated with serum albumin, weight/height ratio, total body water/body weight ratio, fat free weight/body weight ratio, extracellular water/body weight ratio, fat weight/body weight ratio and total body hemoglobin/body weight ratio, all of which are indices of the nutritional state of the subjects. The data show clearly that poor nutrition reduces the physical work capacity of the subjects.

FUTURE STUDIES

1. Completion of enough number of studies with both groups of patients to make the data statistically valid for our population.

2. Continue the field studies to determine more clearly the relationship between physical work capacity and productivity in the "corteros" cutting different types of cane (burned vs. unburned and different varieties of cane) with cane lifters (alzadores) and if possible with mine workers.

3. To test the relationship between productivity and aerobic power in corteros which have just started working and thus are less selected than the population studied thus far. Also to restrict the age span of the subjects to reduce variability.

4. To better define the relationships between body composition and physical work capacity.

   a. by measurements of total body K, if possible.

   b. by introducing muscle biopsy so as to actually measure the active tissue hydration coefficient.

5. To begin to understand how and why undernutrition alters aerobic power.

   a. by measurements of maximal cardiac output, maximal heart rates, stroke volume and maximal oxygen extraction by the tissues.

b. by studying free fatty acid and glucose levels and if possible their turnover during maximal exercise.

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