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LABORATORY REPORT No. 302

METABOLIC ASPECTS OF ACUTE STARVATION BODY COMPOSITION CHANGES

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Harry J. Krzywicki
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BIOENERGETICS DIVISION

DECEMBER 1966

US ARMY MEDICAL RESEARCH AND NUTRITION LABORATORY

FITZSIMONS GENERAL HOSPITAL
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Project Number: 3A014501B71R Research in Biomedical Sciences

Task No.: 02

Work Unit No.: 061 Work Performance and Body Composition as Related to Environment and Nutritional Status

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ABSTRACT

Laboratory Report No. 302
Project No. 3A014501B71R Research in Biomedical Sciences
Task No. 02
Work Unit No. 061 Work Performance and Body Composition as Related to Environment and Nutritional Status

Body composition changes were observed in six healthy, adult males 21 to 52 years of age, while fasting for 10 days. Fluid was available ad libitum.

The mean loss in body weight (7.30 kg) was densitometrically partitioned into a 3.6 kg loss of fat and a 3.7 kg loss in the fat free body mass, which included a loss of 0.86 kg of dry protein. The USAMRNL fat predicting nomogram described fat losses adequately; however, urinary potassium and creatinine excretion, or potassium-40 counting, exceeded densitometric estimates of the dry protein compartment by 13% and 22%, respectively.

The triceps and scapula skinfolds demonstrated the greatest decrease (24.1 and 21.6%) while extremity girths decreased from 9.8% to 3.2% with the circumferences of the waist and buttocks diminishing by 5.8%.

Blood, plasma, and red blood cell volumes were significantly lowered during the fast in accordance with the severe hypohydration that was exhibited. No sequelae were noted during and after 40 days of rehabilitation when body weight was virtually restored to control levels. Use of D_2O as a tracer to demonstrate total body water appeared to be inapplicable during the starvation phase of the study.

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BODY OF REPORT

Work Unit Number 061 Work Performance and Body Composition as Related to Environment and Nutritional Status

Metabolic Aspects of Acute Starvation
Body Composition Changes

PROBLEM:

No definitive studies have been made to ascertain the mental or physical effectiveness of the combat patrol soldier in situations where he is deprived of food for periods up to 10 days. Similarly, those minimal essential nutrients necessary to maintain such effectiveness remain to be delineated. Two previous papers in this series discuss the problems encountered by six adult males observed during a 10 day fast with only water and low-calorie fluids available (1, 2).

The objectives of the body composition measurements during the present study were to observe the gross changes which could be evaluated by anthropometry and potassium-40 counting, and to measure any alterations which may have occurred in the four major body components (i.e., water, fat, protein, and mineral) and which could be estimated by densitometric, chemical, or tracer techniques.

BACKGROUND:

Marked morphological changes are evident with long-term or semi-starvation and suggest drastic alterations of the body components. Body weight loss is an excellent index of the degree of undernutrition, but does not reflect specific changes in water, fat, protein, or mineral. Many reports cite only weight loss in relation to starvation or semi-starvation of obese subjects. Stevenson (3) reported that body fat decreases in greater proportion than protein with a concomitant retention of body water which was also reported by Keys, et al (4). Benoit, et al (5) recently presented data on seven obese fasting adult males, whose body weight decreased by 9.5 kg in 10 days. From potassium balance, they calculated that 65% of the loss in weight was attributed to lean body tissue with only a 35% loss in body fat. In contrast, men comsuming a 1000 Calorie ketogenic diet (containing 80% fat) lost only 6.6 kg of their body weight, 97% of this loss was attributed to fat, the remainder to protein. However, Benoit, et al (5) did not consider any changes that may have occurred in total body water.

McCance and Widdowson (6) reported that muscle tissue was greatly reduced in proportion to the loss of body weight of POWs, but Keys, et al (4) observed a decrease in body fat, body weight, and muscle tissue. They concluded that the muscle tissue loss was proportional to the body weight loss (4). Keys, et al (4) observations are in agreement with Stevenson's (3) work on completely starved rats. These authors felt that the total body weight loss was 37% greater than observed due to the major increase in water in the extracellular space. Keys, et al (4), reported a 41% overall increase in the plasma volume with a similar increase (43%) in extracellular fluid volume in their semi-starvation studies.

Spencer, et al (7) described the metabolic changes associated with starvation in three obese adult females and suggested that increased fluid loss reflected those obligatory losses associated with increased excretion of sodium, calcium, and ketone bodies. However, their subjects showed no signs of clinical dehydration (7). Greenleaf and Sargent (8) studied voluntary dehydration in man and concluded that there is a range of body water, plus or minus an arbitrary set point, within which functional deterioration does not occur. It was suggested that a diminished water content of the body is desirable in certain stress situations.

APPROACH TO THE PROBLEM:

The subjects were six healthy, adult males whose ages ranged from 21-52 years. After a 4 day control period, the men fasted for 10 days and were then rehabilitated for 4 days on an ad libitum food intake. A final measurement was made after 40 days of rehabilitation. The subjects were housed in the Metabolic Ward of this Laboratory during the entire study, which was staffed by medical and nursing personnel.

Nude body weights were observed daily, upon arising and after voiding, using a Homs Full Capacity Beam Scale.* Body density was computed from body volume as measured by Allen's, et al (9) direct water displacement technique and corrected for the residual volume of the lung by the modified Rahn, et al (10) method using a nitrogen analyzer (Nitralyzer**), intestinal gas was ignored in the calculation. Body volume, blood volume, and total body water determinations were measured during the control period, on Days 5 and 9 of the fast, and after 4 and 40 days of rehabilitation. Blood volume determinations were made by the infusion of Evans Blue dye (T-1824) as reported by

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* Homs Full Capacity Beam Scale, Model 150, KTHM, Homs Scale Co., Burlingame, California.

** Nitralyzer, Model 300 AR, Med-Science Electronics, Inc., St. Louis, Missouri.

Constable, et al (11). The estimation of total body water using deuterium oxide was patterned after the method of von Hevesy (12) as modified by Edelman and Moore (13). The concentration of the orally ingested D_2O was determined in the urine after a four hour equilibration period after the method of Arnett and Duggleby (14) using a MicroTek Gas Chromatograph.* Total body potassium was determined by measurement of potassium-40 at the Colorado State Public Health Department after the method of Marinelli (15). Forty-five minute counts were made on each subject in a whole body counter (NaI crystal) described elsewhere (16).

Selected anthropometric measurements were made and included the arm and scapula skinfold thicknesses as designated by the Committee on Nutritional Anthropometry (17), 4 bony diameters as suggested by Trotter (18), 2 bony diameters as well as 4 soft tissue diameters as reported by Maresh (19, 20) and 6 body extremity circumferences as reported by Behnke, et al (21).

RESULTS:

Body weights declined rapidly in all of the subjects during the first 5 days of the starvation period and showed an average loss of 4.06 kg or 5.3% of their total body weight (Table I, Fig. 1). At the end of Day 10 of fasting, the average weight loss was further decreased by 3.24 kg for a total loss of 7.3 kg which represented a 9.5% loss of total body weight. Upon rehabilitation, the average body weights increased rapidly and showed a gain of 5.40 kg by Day 4; however, further rehabilitation resulted in an additional average body weight gain of 0.64 kg after 40 days of refeeding. On this date the subjects averaged 1.26 kg less than their control body weight.

The observed body density, as measured by water displacement, showed a slight increase (Table II, Fig. 1) from a mean of 1.045 gm ml^{-1} for the control period to 1.054 on Day 5 of starvation, but then decreased to 1.050 gm ml^{-1} after 10 days of starvation (subject Mc was not measured at this time and his density was approximated as 1.050). The subjects showed a further lowering of body density (indicative of increased body fat stores) after 4 days of refeeding and then became somewhat leaner during the remainder of the rehabilitation period (1.051 gm ml^{-1} at 40 days).

Total body fat burdens, as calculated from observed body density, decreased in all six subjects as shown in Table III, Fig. 1. The mean loss of body fat after 5 days of fasting was 3.8 kg or 18.5% of the estimated total body fat. With continued fasting, body fat showed an

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*Gas Chromatograph, MicroTek Instrument Co., Baton Rouge, Louisiana.

0.2 kg increase by Day 10 which now represented only a 17.4% loss of fat. With refeeding, estimated body fat rose to 18.1 kg after 4 days and was found to have decreased slightly to 17.8 kg after 40 days of rehabilitation, or 2.7 kg less than the control values.

Table IV shows a comparison of body fat changes as estimated from the densitometric measurements and those changes as calculated from the USAMRNL nomogram as described by Chinn and Allen (22). Although the individual values calculated by the two methods vary from 0.2 kg to 1.4 kg, the mean estimated changes agree within 0.1 kg.

Allen, et al (9) described a prediction equation for estimating the residual mass after removal of all water, fat, and mineral from the body, consisting of dry protein with traces of tissue electrolytes and carbohydrates. Changes in this residual mass labeled "dry protein" are shown in Table V, Fig. 1. The average dry protein decreased by only 0.12 kg after 5 days of starvation, but then declined more rapidly for a total loss of 0.86 kg after 10 days. This represented a 7.45% loss in the dry body protein stores. After 4 days of rehabilitation, this mass increased by 0.89 kg and surpassed control values by 0.20 kg after 40 days of refeeding.

The data in Table VI represents changes in the total body water of the subjects during the study. From Moore's, et al (23) predicting equation, the mean total body water at the onset of starvation was 43.05 kg and constituted 56.20% of the mean body weight. Spurious values were obtained for total body water on Days 5 and 10 of the starvation period. The control values are somewhat higher than values predicted by Moore's equation. If one can accept that 50% of the rapid body weight gain during the first thirty-six hours of rehabilitation was composed of retained body water, then one can assume the severe loss of body fluids evidenced on Day 10 to be obligatory hypohydration associated with severe mineral and urea losses (Table VI, Fig. 1).

A simple aspect of gross body composition changes is presented in Table VII which summarizes marked changes in selected anthropometric measurements during the starvation period. The circumference of the biceps showed the greatest decrease (9.8%), followed by the waist and buttocks (5.8%). The forearm and calf circumferences demonstrated the least change (3.4 and 3.2%, respectively). The skinfold thicknesses also showed a marked decrease of 24.1% for the scapula and 21.6% for the triceps after 10 days without food.

Potassium-40 counting of the subjects was made at five intervals during the study. The data presented in Table VIII, as total body potassium, failed to show the comparable loss of body potassium as was exhibited in the urinary excretion of potassium during the starvation period. However, the mean of five counts for each subject served as a base for incorporating losses in body potassium from urinary excretion for estimating changes in body protein. The data in Table IX shows changes in body potassium when expressed on a body weight basis. Trends in potassium burdens on a gm/kg basis resembled those exhibited by the total body potassium, namely an increase as starvation progressed for 5 days, a decline with early rehabilitation, and a subsequent increase over control values after 40 days of refeeding.

Urinary losses of sodium, potassium, and creatinine remained fairly high during the first 7 days of starvation (Table X, Fig. 2). Potassium excretion during the control period averaged 2.12 gm/day and was gradually decreased to 1.12 gm/day by Day 10 of the fast. The daily excretion averaged 1.52 gm/day. Sodium losses approximated 2.99 gm/day for the control period and were gradually reduced to 1.52 gm/day, after 10 days of starvation, with a mean daily excretion of 1.87 gm/day (Fig. 2).

Other methods of estimating the dry residual protein mass of the body were utilized and are presented in Table XI. From observed body potassium and creatinine excretion, using Chinn's (24) predicting equation, the mean change in the dry protein mass was 0.99 kg compared to 0.86 kg estimated from body density and 1.11 kg calculated from potassium-40 counting on the control day and corrected for urinary excretion.

Significant changes were observed in blood, plasma, and red cell volumes and are summarized in Table XII, Fig. 3. The mean blood volume of the six subjects decreased from 6266 ml to 4128 ml after 10 days of fasting, or a reduction of 34.1% from control values. Plasma volumes were reduced from 3844 to 2300 ml and the red cell volumes from 2422 to 1828 ml, decreases of 40.2 and 24.5%, respectively. No significant changes were observed during the initial 4 days of refeeding; however, after 40 days these volumes were only slightly less than the control values (Fig. 2).

DISCUSSION:

Although Keys, et al (4) have described changes that occurred during semi-starvation for periods of 12 to 24 weeks, and numerous reports have discussed long and short term fasting studies in obesity (3, 5, 7), very few, if any, comprehensive studies of changes in body composition have been reported in normal subjects fasting for a 10 day or longer period. It has become quite apparent that most indirect techniques for estimating the water, fat, protein, and mineral components of the body have been conducted primarily on normal subjects, making the interpretation of the data difficult in studies under such abnormal conditions as a 10 day starvation period.

The rapid loss of body weight observed during 10 days of starvation (Table I) parallels observations reported by Benedict (25) in his study of a single subject that had lost 12.2 kg (20.5% body weight loss) over a period of 31 days. Keys, et al (4) showed body weight losses of 17.0 kg (24.3%) after 24 weeks of semi-starvation. Normal individuals, starved for 1 - 3 days averaged body weight losses of 1.2 kg/day as reported by Benedict (25) and Johnson (26). Stevenson (3), Gellene, et al (27), Bloom (28), and Unger, et al (29) studying starving obese subjects for long periods of time reported body weight losses of 1 - 3 kg/day. Bloom (28) and Duncan, et al (30) have advocated complete starvation for the treatment of obesity; however, Benoit, et al (5) and Spencer, et al (7) have observed that starvation results in large losses of lean body tissue as reflected by the urinary nitrogen excretion.

Since an 0.001 density unit change can be interpreted to reflect an 0.4% change in body fat as per cent body weight, the 0.009 unit increase in body density observed after 5 days of starvation represents a fat loss equivalent to 3.6% of the body weight. After 10 days of starvation, body density decreased by 0.005 units which now represented only a 1.6% loss of fat as per cent of body weight as compared to control values. During rehabilitation, body density was further lowered, demonstrating an increase in body fat; however, as rehabilitation progressed, the subjects were leaner in terms of body density. The fat estimating equations that were used were derived from normal subjects and seem to be most applicable for the control and late rehabilitation periods of the study.

During starvation, great changes are observed in the water, protein, and fat content of the body. With such changes in each of these components working simultaneously, it may be difficult to assess the density of the individual components contribution to the total body density. Keys, et al (4) attempted to correct for compositional changes in the skeleton as well as for the edema that developed in his subjects after 24 weeks of semi-starvation. They found only an 0.8% difference between body fat as estimated and as corrected by the changes in the soft tissue components of the skeleton and interstitial water during control, but after 12 weeks of semi-starvation, these corrections amounted to 1.2% in estimates of body fat.

The loss of body fat estimated densitometrically was 3.8 kg or 18.5% of the total body fat stores (Table III). Keys, et al (4) subjects were leaner by 8 kg and had a mean body fat burden of 9.64 kg which was reduced to 5.02 kg after 11 weeks of semi-starvation representing a 52.0% loss of total body fat. Benoit, et al (5) reported losses of 3.41 kg of fat in seven obese subjects fasting for 10 days, which approximated one-third of the total weight loss.

Although they considered the remainder of the body weight loss to be lean body tissue, these investigators failed to measure total body water losses (5). Bloom (28), Duncan, et al (30), and Drenick, et al (31) reported body weight losses of 0.41 to 1.18 kg per day in obese patients with starvation periods of up to 160 days, but no mention was made of any attempt to partition body weight losses into fat, water or protein compartments.

The estimated loss of body fat calculated from Allen's, et al (32) prediction equation which considers height, body weight, age, and scapula skinfold averaged 3.4 kg which compared well with the mean of 3.5 as determined densitometrically. However, on an individual basis, the greatest deviation appeared in subject LN (age 20) who was rather muscular and subject KR (age 49), an obese individual. Failure of Allen's, et al (32) equation to predict individual values does not preclude its use in estimating body fat in large populations.

Allen, et al (32) also showed from his densitometric studies by water displacement, that a dry residual protein, designated M_3, could be expressed as M_3 = Mass-Fat (0.202). The six subjects who fasted for 10 days showed a decrease of 0.86 kg in this body compartment as determined by body density observations. On a hydrated basis, assuming 78% water in the fat free, bone mineral free mass, the body protein stores were then depleted by 3.91 kg. Benoit, et al (5) reported that seven obese subjects lost 6.2 kg of the lean body mass during a 10 day fast. His approximation was roughly one-third higher than our values, but one must remember that these authors (5) did not consider body water changes. The ratio of the dry protein mass to that of body fat falls within the limits described by von Dobeln (33) in three of the young subjects. One young man and the two older men had ratios above 2.0, an indication of increased body fat burdens.

The anticipated changes in total body water associated with severe sodium and potassium depletion as well as possible hormonal influences, could not be measured by the deuterium oxide techniques. Since problems in the measurement of body water using deuterium oxide were not anticipated, no other methods for determining total body water were utilized.

For reasons not yet determined, the estimated total body water as predicted from Moore's, et al (23) estimating equation were appreciably lower than the observed results, for both the control period and the 40 days of rehabilitation. After 5 and 10 days of fasting, incongruously high values were obtained. It was later observed in two normal adult males that D_2O appeared in blood serum within 7 - 14 minutes after ingestion. It appears that the equilibration period for mixing of D_2O with body water (normally taken as 3 - 3-1/2 hours) was inadequate. It then seemed logical to assume that part of the rapid increase of body weight during the first 36 hours of rehabilitation was due to water retention in the tissues. Such assumptions were based mainly on water balance measurements reported by Consolzaio, et al (1) who estimated that the 3.95 kg body weight gain could be attributed to water retention. In addition, no clinical evidence of edema (such as turgidity of the skin) was observed in these subjects. Keys, et al (4) observed signs of edema in his semi-starved subjects.

The anthropometric changes observed with 10 days of fasting approximated one-half the decrease reported by Keys, et al (4) after 12 weeks of semi-starvation. The biceps circumference showed the greatest change (9.8%) decrease, followed by the 5.8% decrease in circumference of the waist and buttocks with the smallest decrease observed in the forearm and calf girths (3.4 and 3.2%, respectively). Keys, et al (4) semi-starved subjects lost 18.4% of the biceps girth, the waist diminished by 8.8% and the calf circumference by 9%. The skinfolds in the present study are of particular interest since they showed the greatest decrease which may reflect the loss of subcutaneous fat. Numerous studies cite skinfold thickness measurements as an excellent index of obesity, but none show the great changes which occur during starvation as reported in the present study.

At first glance, the potassium-40 counting data (Table VIII) appeared unreconcilable in that the mean total body potassium increased by 6.1 gm after 5 days of starvation with an additional 1.2 gm gained by Day 10, during which time potassium was being excreted at the rate of 1.52 gm/day for a total loss of 15.2 gm. After refeeding adequate quantities of potassium for 4 days of rehabilitation, mean values by gamma counting decreased 11.5 gm to further confuse the interpretation of the data (4.6 gm below control level); however, a subsequent increase beyond control value was observed after 40 days of rehabilitation.

Meneely in 1961 (34), quoted Anderson's and Langham's data as having coefficients of variation of ± 7 - 14% about the means presented in their age versus grams per kilograms by sex. Assuming that the normal amount of potassium in the body is approximately 150 gm, the range of potassium at the 95% confidence level is ± 21 to 42 gm which obviously makes potassium-40 counting a non-useful criterion for practical medical applications. Christian, et al (35) noted the total body potassium of one of his control subjects as 133.5 ± 4.2 gm, with a 2 S.D. variation ranging from 125 to 145 gm potassium over a 300 day period, which represented a lean body mass change of ± 1.6 kg or ± 3.1%.

The State of Colorado Public Health Department's total body counter was accepted as capable of estimating body potassium for a normal sized individual to be 150.0 ± 7.9 gm potassium at the 90%

confidence limit or ± 5% error. At the 95% confidence level or 2 S.D., it is evident that the values presented in Table V fall within the prescribed limits of the counter. The measurement of potassium-40 during this study was made with the assumption that perhaps some application of the data might have been used.

In our data, an analysis of variance showed critical significant differences to be noted between the control day and Days 5 and 10 of starvation, and Day 5 of fasting versus Days 4 and 40 of rehabilitation. The only plausible explanations for these differences could be the inherent limits of the counter or the masking of gamma radiation due mainly to changes in the fat and water content of the body which may have changed the amount of radiation absorbed.

Typical values for the total body potassium of the subjects in terms of age (subjects CN and KR - age 50, while the remaining four subjects ranged from 20 - 24 years) were observed for the control period as reported by Sievert (36) and Oberhausen and Onstead (37) on a gm/kg basis (Table IX). The increase in body potassium with 5 and 10 days of fasting may reflect the concentrating of body potassium due to a decrease in body weight; however, an explanation is difficult for Day 40 of refeeding. Potassium-40 counting still remains a valuable tool for estimating the lean body mass or body fat under normal conditions and has been used profitably by many investigators.

Folin, et al (38) postulated that the daily excretion of creatinine was related to the active protoplasmic mass of the body and over the years creatinine has been used to measure indirectly the fat free mass. Chinn (24) recently related creatinine and total body potassium for estimating the muscle and non-muscle protein of the body and the data in Table X show the urinary excretion of potassium and creatinine which were used in Chinn's (24) prediction equations. For comparative purposes, estimates of the changes in body protein during 10 days of starvation, from densitometry, potassium and creatinine excretion, and potassium-40 counting (Table XI) showed the least mean loss of body protein to have been observed densitometrically. Potassium and creatinine excretion predicted a larger loss by 0.13 kg of protein and the estimated loss by potassium-40 counting was 0.25 kg more than that observed by densitometry. The individual values, however, reflect disparity among the techniques in that, unlike the mean values, they show no trends. Potassium and creatinine underestimated the densitometrically estimated values in two subjects and overestimated in two others. The 68.1 mEq potassium/kg lean body mass coefficient derived by Forbes and Lewis (39) was a mean of four cadaver values ranging from 66.8 to 72.8 mEq potassium/kg lean body mass. If the highest value were used, then the estimates of body protein would be slightly lowered to reflect the densitometric values. Myhre and

Kessler (40) felt potassium-40 estimates of lean body mass were underestimated in the older age groups. It is suggested that the validity of Chinn's (24) predicting equation be further evaluated on human subjects. As mentioned previously, all indirect methods of estimating body composition components were accomplished on normal subjects.

The decrease in blood plasma volumes described by Consolazio, et al (1) are reported here (Table XII) for further emphasis in that they reflect changes that contributed to or are allied with the severe hypohydration of the body that occurred with acute starvation of 10 days. Similar changes were reported by Bloom, et al (28), Taylor, et al (41), and Rapoport, et al (42). The decrease in the red cell mass also indicates the involvement of this compartment as a source of energy during food deprivation.

SUMMARY:

Body composition changes were observed in six healthy, adult males 21 to 52 years of age, while fasting for 10 days. Fluid was available ad libitum.

The mean loss in body weight (7.30 kg) was densitometrically partitioned into a 3.6 kg loss of fat and a 3.7 kg loss in the fat free body mass, which included a loss of 0.86 kg of dry protein. The USAMRNL fat predicting nomogram described fat losses adequately; however, urinary potassium and creatinine excretion, or potassium-40 counting, exceeded densitometric estimates of the dry protein compartment by 13% and 22%, respectively.

The triceps and scapula skinfolds demonstrated the greatest decrease (24.1 and 21.6%) while extremity girths decreased from 9.8% to 3.2% with the circumferences of the waist and buttocks diminishing by 5.8%.

Blood, plasma, and red blood cell volumes were significantly lowered during the fast in accordance with the severe hypohydration that was exhibited. No sequelae were noted during and after 40 days of rehabilitation when body weight was virtually restored to control levels. Use of D_2O as a tracer to demonstrate total body water appeared to be inapplicable during the starvation phase of the study.

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TABLE I
STARVATION STUDY, 1965
Changes in Body Weight, kg

	Control	Starvation		Rehabilitation	
	Mean of 4 Days	Day 5	Day 10	Day 4	Day 40
CN	92.46	87.00	83.47	88.10	90.52
DF	84.19	80.36	76.09	81.33	81.01
KR	82.73	78.42	74.96	80.51	80.19
Mc	70.03	66.07	63.70	69.17	71.00
SN	67.92	64.54	61.72	67.92	68.38
LN	66.03	62.55	59.58	64.90	64.69
Mean	77.22	73.16	69.92	75.32	75.96
Mean Loss (kg)		-4.06	-7.30		
Mean Loss (%)		-5.3%	-9.5%		

TABLE II

STARVATION STUDY, 1965

Changes in Body Density, gm ml^{-1}

	Control Mean of 4 Days	Starvation Day 5	Starvation Day 10	Rehabilitation Day 4	Rehabilitation Day 40
CN	1.024	1.025	1.022	1.023	1.030
DF	1.060	1.069	1.070	1.054	1.071
KR	1.033	1.050	1.045	1.037	1.043
Mc	1.043	1.052		1.050	1.046
SN	1.046	1.054	1.048	1.057	1.054
LN	1.064	1.071	1.067	1.072	1.066
Mean	1.045	1.054	1.050	1.047	1.051
Mean Change		.009	.004		
% Change		0.8	0.22		

TABLE III
STARVATION STUDY, 1965
Changes in Body Fat, kg

	Control Mean of 4 Days	Starvation Day 5	Starvation Day 10	Rehabilitation Day 4	Rehabilitation Day 40
CN	32.7	30.6	30.2	31.7	29.6
DF	15.9	12.6	11.6	13.4	12.0
KR	25.9	18.6	19.6	23.7	21.7
Mc	18.8	15.0	15.0	16.6	18.0
SN	17.4	14.1	15.1	13.9	15.0
LN	11.6	9.2	9.9	9.3	10.8
Mean	20.5	16.7	16.9	18.1	17.8
Mean Loss		-3.8	-3.6		
Mean Loss %		-18.5	-17.4		

TABLE IV
STARVATION STUDY, 1965
Estimated Loss of Body Fat, (kg)

	From Body Density	From USAMRNL Nomogram
CN	2.5	2.2
DF	4.3	4.5
KR	6.3	5.0
Mc	3.8	3.2
SN	2.3	2.5
LN	1.7	3.1
Mean	3.6	3.4

TABLE V
STARVATION STUDY, 1965
Changes in Dry Protein, kg

	Control	Starvation		Rehabilitation	
	Mean of 4 Days	Day 5	Day 10	Day 4	Day 40
CN	12.05	11.40	10.75	11.40	12.30
DF	13.81	13.70	13.03	13.72	13.93
KR	11.88	12.08	11.19	11.48	11.82
Mc	10.34	10.31	9.54	10.63	10.71
SN	10.18	10.19	9.41	10.90	10.78
LN	11.00	10.77	10.17	11.27	10.88
Mean	11.54	11.41	10.68	11.57	11.74
Mean Loss		-0.12	-0.86		
Mean Loss %		-1.04	-7.45		

TABLE VI
STARVATION STUDY, 1965
Total Body Water as Percent Body Weight

	Control	Starvation	
	Mean of 4 Days	Day 5	Day 9
CN	49.6	60.1	63.6
DF	55.9	70.7	78.3
KR	52.4	71.3	79.2
Mc	59.3	57.4	
SN	60.4	67.2	92.8
LN	60.5	75.0	

TABLE VII
STARVATION STUDY, 1965
Percent Decrease in Selected Anthropometry
After 10 Days of Starvation

	CN	DF	KR	Mc	SN	LN	Mean
<u>Circumferences</u>							
Biceps	10.9	10.5	9.8	9.6	8.9	9.4	9.8
Waist	5.4	5.9	4.5	6.0	7.4	5.5	5.8
Buttocks	2.7	14.5	4.1	3.3	4.2	6.3	5.8
Forearms	2.1	6.2	2.1	4.0	3.9	2.6	3.4
Calf	1.9	5.5	2.9	6.2	1.1	1.6	3.2
<u>Skinfold Thickness Measurements</u>							
Scapula	27.1	17.7	32.0	20.6	22.1	25.2	24.1
Triceps	12.9	31.3	24.3	24.6	17.8	18.5	21.6

TABLE VIII
STARVATION STUDY, 1965
Changes in Total Body Potassium (gm) from Potassium-40 Counts

	Control	Starvation		Rehabilitation	
		Day 5	Day 10	Day 4	Day 40
CN	114.1	120.5	114.8	110.5	123.4
DF	140.3	149.0	146.9	135.0	146.5
KR	128.4	132.3	138.2	125.5	139.6
Mc	123.0	128.8		111.3	136.1
SN	124.3	128.2	128.1	127.6	135.5
LN	130.9	138.9	142.7	125.7	134.8
Mean	126.8 ± 8.7	132.9 ± 9.8	134.1 ± 12.8	122.6 ± 9.7	136.0 ± 3.2

TABLE IX
STARVATION STUDY, 1965
Changes in Body Potassium
gm potassium/kg Body Weight

	Control	Starvation		Rehabilitation	
		Day 5	Day 10	Day 4	Day 40
CN	1.23	1.38	1.36	1.26	1.40
KR	1.55	1.69	1.82	1.56	1.74
SN	1.82	1.99	2.06	1.88	1.95
Mc	1.74	1.95		1.61	1.91
DF	1.68	1.85	1.90	1.66	1.83
LN	1.97	2.22	2.37	1.94	2.08
Mean	1.665	1.847	1.902	1.652	1.818

TABLE X
STARVATION STUDY, 1965
Daily Potassium, Sodium, and Creatinine Excretion in Urine*

Average/Man/Day

Phase	Potassium gm	Sodium gm	Creatinine gm
Control	2.12	2.99	1.62
Starvation			
Day 1	2.10	2.32	1.50
2	1.54	1.84	1.83
3	1.58	1.77	1.42
4	1.77	1.98	1.74
5	1.50	1.95	1.78
6	1.59	1.93	1.77
7	1.56	1.87	1.58
8	1.30	1.78	1.49
9	1.21	1.67	1.94
10	1.12	1.56	0.98
Mean	1.52	1.12	
Rehabilitation			
Day 1	1.44	2.00	1.43
2	2.06	3.33	1.69
3	2.31	4.12	1.56

* Mean of 6 men

TABLE XI
STARVATION STUDY, 1965
Three Estimates of Body Protein Changes (kg)

After 10 Days of Starvation

	Body Density	K + Creatinine Excretion	Potassium-40 Counting
CN	1.30	1.13	1.14
DF	0.78	0.41	1.16
KR	0.69	1.24	1.28
Mc	0.80	0.88	1.00
SN	0.77	0.57	0.81
LN	0.83	1.70	1.25
Mean	0.86	0.99	1.11

TABLE XII
STARVATION STUDY, 1965

Changes in Blood, Plasma, and Red Cell Volumes*

Phase	Blood Volume		Plasma Volume		RBC Volume	
	ml	% decrease from control	ml	% decrease from control	ml	% decrease from control
Control	6266		3844		2422	
Starvation						
Day 5	5399	13.8	3055	20.5	2354	2.8
10	4128	34.1	2300	40.2	1828	24.5
Rehabilitation						
Day 4	4262	32.0	2528	34.2	1734	28.4
40	5438	13.2	3167	17.6	2271	6.2

* Mean of 6 Men

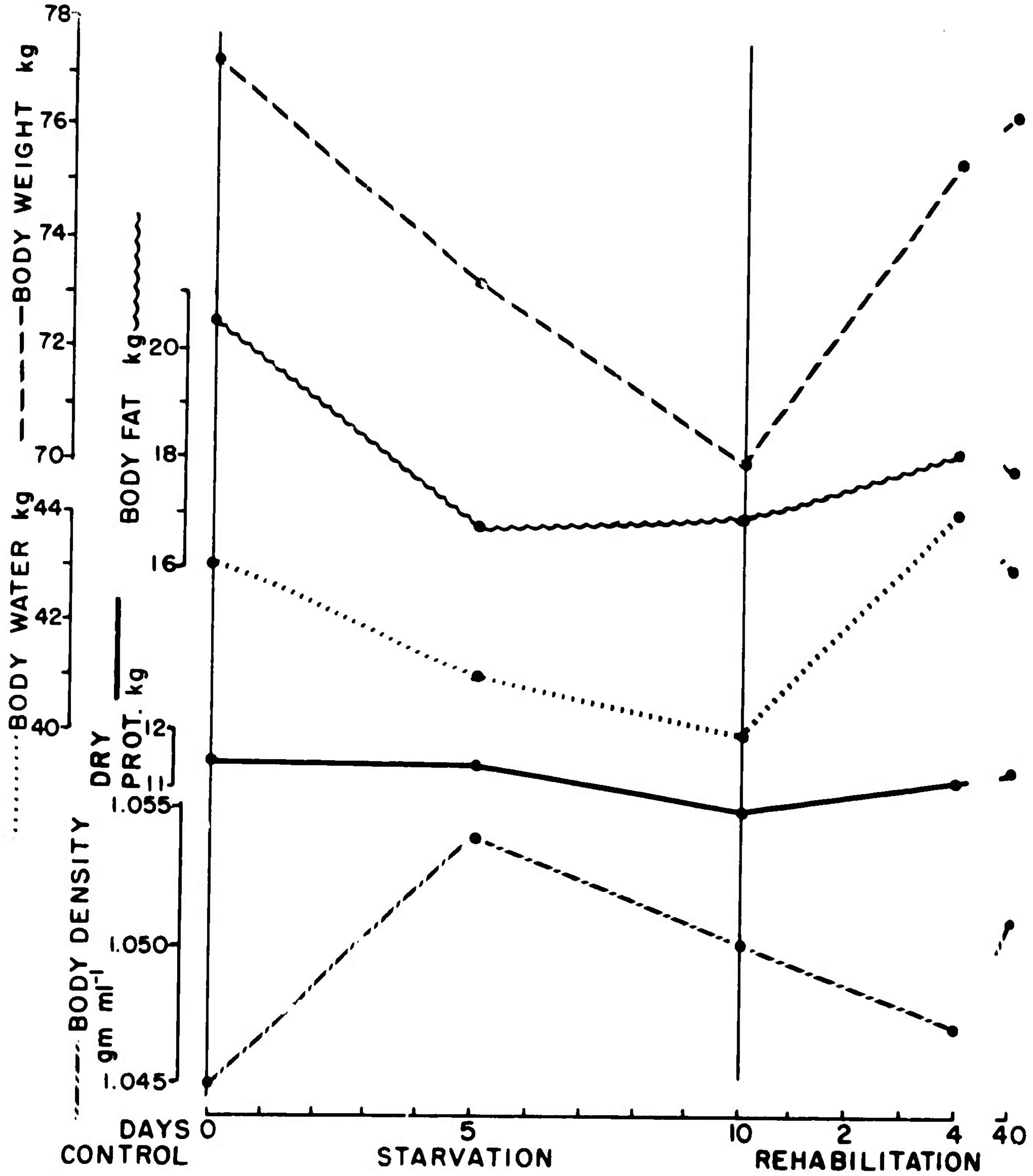

Fig. I CHANGES IN MEAN OBSERVED BODY WEIGHT AND BODY DENSITY; AND ESTIMATED CHANGES IN BODY FAT, WATER, AND DRY PROTEIN DURING STARVATION AND REHABILITATION

Fig. 2 MINERAL EXCRETION, STARVATION STUDY 1965

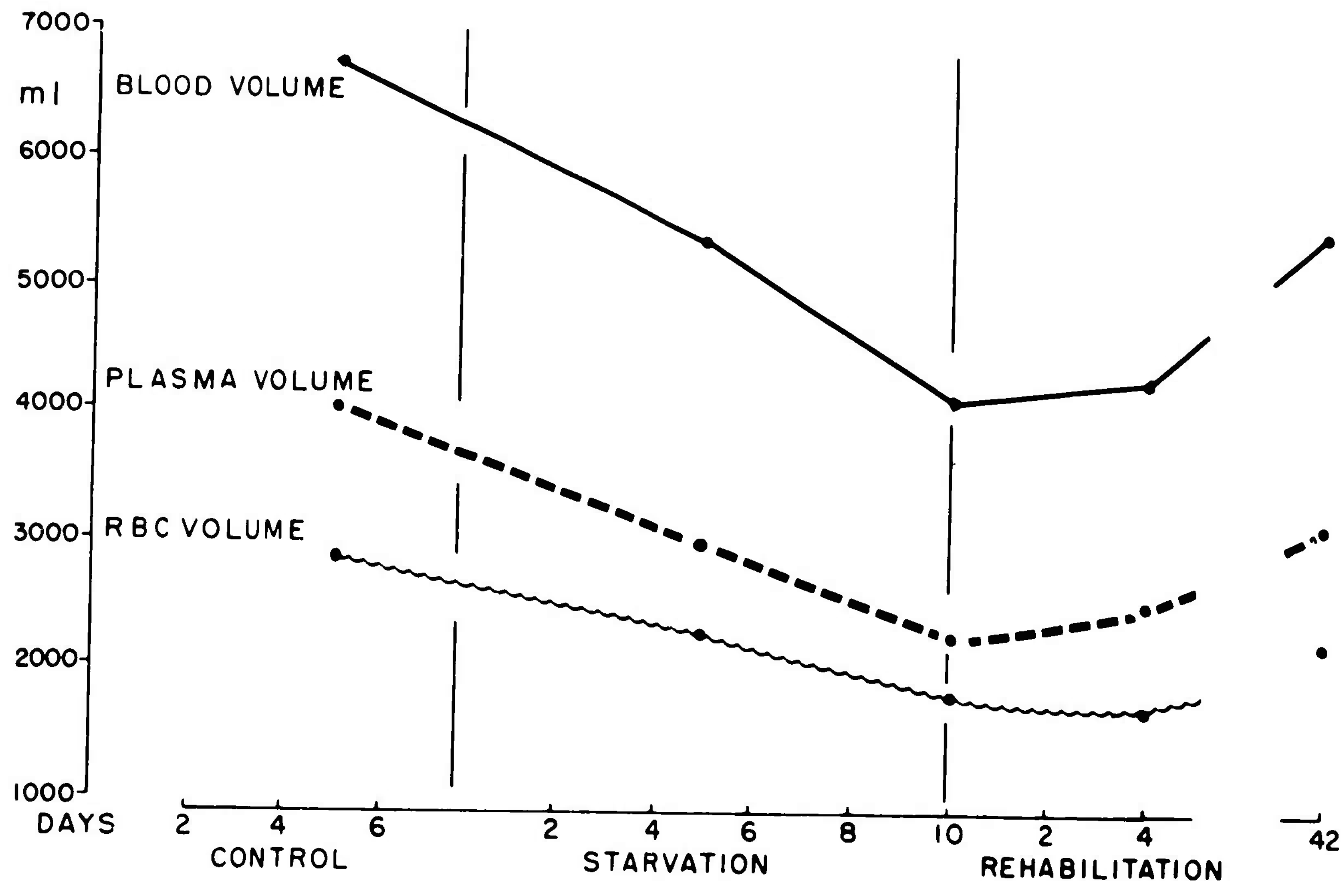

Fig. 3 BLOOD CHANGES, STARVATION STUDY 1965

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Herman L. Johnson — LeRoy O. Matoush

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13. ABSTRACT

Body composition changes were observed in six healthy, adult males 21 to 52 years of age, while fasting for 10 days. Fluid was available ad libitum.

The mean loss in body weight (7.30 kg) was densitometrically partitioned into a 3.6 kg loss of fat and a 3.7 kg loss in the fat free body mass, which included a loss of 0.86 kg of dry protein. The USAMRNL fat predicting nomogram described fat losses adequately; however, urinary potassium and creatinine excretion, or potassium-40 counting, exceeded densitometric estimates of the dry protein compartment by 13% and 22%, respectively.

The triceps and scapula skinfolds demonstrated the greatest decrease (24.1 and 21.6%) while extremity girths decreased from 9.8% to 3.2% with the circumferences of the waist and buttocks diminishing by 5.8%.

Blood, plasma, and red blood cell volumes were significantly lowered during the fast in accordance with the severe hypohydration that was exhibited. No sequelae were noted during and after 40 days of rehabilitation when body weight was virtually restored to control levels. Use of D_2O as a tracer to demonstrate total body water appeared to be inapplicable during the starvation phase of the study.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Body Composition						
Body Fat						
Body Density						
Body Water						
Protein						
Minerals						
Blood Volume						
Anthropometry						
Skinfolds						

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