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We measured the physical exercise capabilities of U.S. Army Special Forces soldiers (male) and determined the subsequent ergogenic influence of autologous blood reinfusion. Twelve subjects (Ss) completed maximal exercise treadmill testing in a comfortable (T_a=20°C, T_{dp} = 9°C) environment. Six Ss were later transfused with a 600 ml autologous red blood cell (50% Hct) NaCl glucose-phosphate solution and completed identical maximal exercise tests 3 and 10-days post-transfusion. Pre-transfusion, the 12 Ss had a maximal oxygen uptake ($\dot{V}O_2$ max) of 4.36±0.56 l/min and 55±4 ml/kg/min with a heart rate of 188±10 b/min^{-1}

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and ventilatory equivalent for oxygen of 37±3. For the 6 reinfused Ss, hemoglobin and red cell volume (RCV) increased 10% ($P<0.05$) and 11% ($P<0.05$), respectively, post-transfusion. Reinfusion increased ($P<0.05$) VO_2 max from 4.28±0.22 l/min (54±5 ml/kg/min) to 4.75±0.42 l/min (60±ml/kg/min) and 4.63±0.21 l/min (59±6 ml/kg/min) at 3 and 10 days post-transfusion, respectively. No significant relationship was found between the individual change in RCV and VO_2 max values pre- to post-transfusion. We conclude that Special Forces soldiers have high levels of aerobic fitness that can be further increased by blood reinfusion for at least 10 days. Keywords: Polycythemia

ELITE SPECIAL FORCES: PHYSIOLOGICAL DESCRIPTION AND ERGOGENIC INFLUENCE OF BLOOD REINFUSION

Stephen R. Muza, Ph.D., Michael N. Sawka, Ph.D., Andrew J. Young, Ph.D., Richard C. Dennis, M.D., Richard R. Gonzalez, Ph.D., James W. Martin, M.D., Kent B. Pandolf, Ph.D. and C.R. Valeri, M.D.

US Army Research Institute of Environmental Medicine

Natick, Massachusetts 01760-5007

and

Naval Blood Research Laboratory/Boston University School of Medicine, Boston, Massachusetts 02118

Abbreviated Title: Elite Special Forces

Mailing Address: Dr. Stephen R. Muza

U.S. Army Research Institute of Environmental Medicine

Kansas Street

Natick, MA 01760-5007

617-651-4834

Abstract

We measured the physical exercise capabilities of U.S. Army Special Forces soldiers (male) and determined the subsequent ergogenic influence of autologous blood reinfusion. Twelve subjects (Ss) completed maximal exercise treadmill testing in a comfortable (T_a = 20°C, T_{dp} = 9°C) environment. Six Ss were later transfused with a 600 ml autologous red blood cell (50% Hct) NaCl glucose-phosphate solution and completed identical maximal exercise tests 3 and 10-days post-transfusion. Pre-transfusion, the 12 Ss had a maximal oxygen uptake ($\dot{V}O_2$ max) of 4.36±0.56 l/min and 55±4 ml/kg/min with a heart rate of 188±10 $b \cdot min^{-1}$ and ventilatory equivalent for oxygen of 37±3. For the 6 reinfused Ss, hemoglobin and red cell volume (RCV) increased 10% ($P < 0.05$) and 11% ($P < 0.05$) respectively, post-transfusion. Reinfusion increased ($P < 0.05$) $\dot{V}O_2$ max from 4.28±0.22 l/min (54±5 ml/kg/min) to 4.75±0.42 l/min (60±ml/kg/min) and 4.63±0.21 l/min (59±6 ml/kg/min) at 3 and 10-days post-transfusion, respectively. No significant relationship was found between the individual change in RCV and $\dot{V}O_2$ max values pre- to post-transfusion. We conclude that Special Forces soldiers have high levels of aerobic fitness that can be further increased by blood reinfusion for at least 10 days.

Key words: polycythemia, maximal oxygen uptake, exercise.

INTRODUCTION

Recently, considerable interest has been directed toward quantifying the aerobic fitness of the US military community (3,4,8,17). A substantial data base has accumulated concerning the maximal aerobic power of US Army recruits and cadets, (8,18) as well as soldiers stationed within the continental United States and abroad (17). The primary reason for this interest is the realization that many military missions require a large aerobic exercise component (18). Therefore, soldiers need to be aerobically "fit" for the successful completion of these mission requirements. A military group having many mission requirements for high aerobic "fitness" are Special Forces. These individuals must frequently engage in sustained high intensity operations, such as forced marches with large backpack loads. To our knowledge, data are not available describing the aerobic exercise capabilities of elite Special Forces.

Additionally, Special Forces must be prepared to meet a variety of unusual mission requirements. With little notice Special Forces could be assigned a mission requiring great aerobic demands when their immediate physical training was directed toward another component of fitness (ex. strength training). Marked improvements in maximal aerobic power will generally require several weeks of intense training (9), which unfortunately will also be associated with manpower attrition because of orthopedic injuries (1). Therefore, any intervention which can immediately increase maximal aerobic power without manpower attrition has great application to Special Forces. Induced polycythemia has recently been demonstrated to improve an individual's maximal aerobic power and submaximal endurance capacity (6,7). Therefore the use of induced polycythemia as an ergogenic aid may have military application for small groups of Special Forces. But previous studies which have used autologous blood reinfusion, following restoration of normocythemia, to improve their subjects maximal oxygen uptake have generally not employed subject populations or environmental conditions which allow the results to be easily applied to a special military population. Therefore, the present investigation measured the maximal aerobic exercise capabilities of an elite Special Forces detachment and determined the subsequent ergogenic influences of autologous blood reinfusion.

METHODS

Twelve male soldiers from the 10th Special Forces Group (Ft. Devens, MA) participated in this investigation. These subjects were all members of the same team and therefore were exposed to nearly identical training programs during the preceeding six months. The experiments were scheduled so not to interrupt their normal training program. Subjects were informed of the purpose and potential risks of the study, the extent of their involvement, and their right to terminate participation at will. Each signed a statement of informed consent.

During the late fall months, nine subjects had two units of blood removed by phlebotomy. A minimum of six weeks separated the removal of each blood unit. During the subsequent spring months the maximal exercise testing was completed. Initially all subjects were familiarized with the test procedures, had their body fat determined and completed a maximal aerobic power test. Approximately two weeks later, nine subjects received an infusion. During the infusion sessions, the subjects were blindfolded and wore earphones. The blood reinfusion group received approximately 600 ml of a sodium chloride-glucose-phosphate solution containing a ~50% Hct (autologous), whereas the saline infusion group received 600 ml of sodium chloride-glucose-phosphate solution. Both groups then again completed maximal aerobic power tests at approximately

3 days and 10 days post-transfusion. In addition, red cell volume was measured one day before the pre-transfusion and first post-transfusion maximal aerobic power tests. Neither the subjects nor investigators at the US Army Research Institute of Environmental Medicine were knowledgeable as to the identity of the saline and reinfusion groups.

Blood storage, infusion, as well as red cell volume measurements were conducted by the Naval Blood Research Laboratory. The collected blood was separated into its cell and plasma components, and the red cells were frozen with 40% w/v glycerol and stored at - 80°C (15). Red cell volume was measured by the radioactively labelled chromium (^{51}Cr) method (16) and hemoglobin was determined by the cyanmethemoglobin procedure.

The anthropometric measurements and maximal aerobic power tests were conducted at the US Army Research Institute of Environmental Medicine. Body density was determined by hydrostatic weighing (12) as well as by skinfold thickness (5). The percentage of body fat and body surface area were calculated from the appropriate data. Maximal aerobic power was determined by a progressive intensity, continuous effort treadmill test. The warm-up bout consisted of 4-min of walking (1.56 $m \cdot s^{-1}$) at a 4% treadmill grade. The subjects then ran (3.13 $m \cdot s^{-1}$) continuously at an initial grade of 5% with 2-1/2 % increments every 2 minutes. Established criteria were employed for determination of maximal oxygen uptake (13). An automated system (Sensormedics Horizon MMC) was used to serially measure (15 s intervals) oxygen uptake. Heart rates were determined from electrocardiograms obtained from chest electrodes (CM 5 placement) connected to an oscilloscope - cardiotachometer unit (Hewlett-Packard).

For each parameter the group mean ± SD was calculated. A repeated measures analysis of variance was performed followed by Tukey's post hoc procedures when significant ($P < 0.05$) main effects were found between the pre and post-transfusion conditions.

RESULTS

Table 1 provides a description of the subject's anthropometrical measurements. The Special Forces soldiers were of fairly large stature averaging 180.5 ± 7.1 cm in height and 79.4 ± 11.4 kg in body weight. Table 2 presents their physiological responses to maximal effort treadmill exercise. All subjects achieved the criteria of a plateauing of oxygen uptake. In addition, the magnitude of the heart rate and ventilatory equivalent of oxygen responses indicate a maximal effort. The mean maximal oxygen uptake was 55.2 ± 4.3 $ml \cdot kg^{-1} \cdot min^{-1}$.

The infusion increased ($P<0.05$) red cell volume by 11% (2.079 to 2.301 ℓ) for the reinfusion groups, and decreased ($P<0.05$) red cell volume by 3% (2.158 to 2.093 ℓ) for the saline group. For the reinfusion group, hemoglobin (Hb) increased by 10% (1.4 $g \cdot dl^{-1}$). Table 3 provides the subjects' physiological response to maximal effort treadmill exercise before and after saline or red cell infusion. For the saline group, heart rate, ventilatory equivalent of oxygen and maximal oxygen uptake were not altered by infusion. For the reinfusion group, maximal oxygen uptake was increased ($P<0.05$) by ~ 11% at 3-days (Post-A) and by ~8% at 10-days (Post-B) post-reinfusion. Figure 1 presents the reinfusion subjects' individual changes in maximal oxygen uptake to the Post-A and Post-B tests. It should be noted that one subject did not improve his maximal aerobic power post-reinfusion. That individual was the 43 year old team sergeant. Figure 2 depicts the individual relationship between the increase in red cell volume and increase in maximal aerobic power for the Post-A test. An insignificant ($P>0.05$, $r=-0.47$) relationship was found between these variables.

DISCUSSION

This report presents anthropometric and aerobic capacity values on a selective segment of the U.S. Army population, a Special Forces (SF) Team. Generally, the Special Forces soldiers were older, taller and of greater body weight and lean body mass than typical soldiers in a combat infantry division (17). These apparent antrhopometric differences may be related to occupational training and job skill requirements. Members of a Special Forces Team are all volunteers and selection to a team is contingent upon the soldier's successful completion of a physically intense occupational training program.

The Special Forces soldiers also tended to have higher levels of aerobic fitness (pre-infusion) than those previously reported for combat infantry soldiers (17). The SF team we studied had spent nearly fifty percent of its training schedule conducting physically intensive field exercises during the five months preceeding the study. In garrison, the SF soldiers participated in an organized physical training program which included approximately 30 km of running, 3 h of calesthenics and weight circuit training and 1 h team sports each week. These SF soldiers had a mean maximal oxygen uptake of 55 $ml \cdot kg^{-1} \cdot min^{-1}$ which corresponds to "high aerobic fitness" (9) for their age and sex. Consequently, the SF occupational and physical training programs appear to provide an effective physical challenge for development and maintenance of high levels of aerobic fitness. However, soldiers who volunteer for SF duty may have high levels of aerobic fitness before entering the SF training program and thus may not be improving their aerobic fitness.

To our knowledge, this SF team is the most aerobically fit U.S. Military unit reported to date (17,18). This observation supports an earlier finding that the physical intensity of military occupations plays a role in the eventual level of aerobic fitness (17). Military units with special operations missions may, by the nature of their duties, attain and maintain a high level of aerobic fitness in some members or attract individuals already having high fitness levels. Support for this is found in a study of British paratroopers between the age of 21-48 yr who had a mean maximal oxygen uptake of 58.5 $ml \cdot kg^{-1} \cdot min^{-1}$ (18).

Several investigators have shown that erythrocyte infusion will increase an individual's maximal oxygen uptake (2,10,11,14). In order to obtain these results the blood handling and infusion procedures of: (a) infusing autologous erythrocytes that represent the product of two blood units; (b) using freeze preservation of erythrocytes; and (c) only reinfusing after the recipient has re-established normocythemia; are needed (6,7). Investigators which used these procedures to improve thier subjects maximal oxygen uptake have generally not employed subject populations (2,10) or environmental conditions (11) which allow the results to be easily generalized to special or elite populations. For example, one study used "international caliber" track athletes (2), another women students (10) and another a hypoxic environment (11). Therefore, research was needed to apply these ergogenic procedures to a military relevent population.

Blood reinfusion acutely (3 days post) increased maximal oxygen uptake by 0.473 $l \cdot min^{-1}$. This increase can easily be explained by the 1.4 g 100 ml^{-1} increase in hemoglobin if maximal effort cardiac output approximated 30 $l \cdot min^{-1}$, (1.34 ml $O_2 \cdot g^{-1}$ Hb x 1.4 g $Hb \cdot l^{-1}$ blood = 18.8 ml $O_2 \cdot l^{-1}$ of blood; 18.8 ml $O_2 \cdot l^{-1}$ blood x 30 $l \cdot min^{-1}$ = 564 ml O_2). Interestingly, although there was a similar increase (11%) in red cell volume and maximal oxygen uptake, the individual data

(Figure 2) failed to demonstrate a linear correlation. This lack of relationship cannot be confirmed by previous investigators' data as they did not examine it (6,7); but it may simply reflect our small sample size. Another possibility is that physiological factors besides increased arterial oxygen content; such as blood volume changes, oxidative capacity of skeletal muscle, and myocardial contractility can further modify the ergogenic influence of erythrocyte reinfusion.

In previous studies of the effect of induced erythrocythemia on an individual's maximal oxygen uptake, all subjects were reported to exhibit an increase in aerobic power (2,10,11,14). We observed no increase of maximal oxygen uptake in one of our subjects. This subject was the 43 year old team sergeant. His body composition was near the group average and his pre-infusion maximal oxygen uptake was 53.5 $ml \cdot kg^{-1} \cdot min^{-1}$. The only obvious difference between this subect and the others was his age. Furthermore, the subjects who participated in previous studies which used similar autologuous blood reinfusion protocols ranged in age from 18-25 yr (2,10,11,14). Based on a single observation it would be inappropriate to speculate whether aging may impart a physiological or biochemical limitation on the utilization of an inhanced O_2 delivery. Further studies are needed to determine the effect aging may have on acute increases of maximal aerobic power following blood reinfusion.

Our data indicate that a Special Forces team is of greater stature, lean body mass and aerobic fitness than the general US Army population. Blood reinfusion will acutely increase their maximal aerobic power for a minimum of 10-days after infusion. However, the 43 year old team sergeant did not experience the ergogenic effort despite an increased red cell volume.

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 Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on Use of Volunteers in Research.

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FIGURE LEGENDS

Figure 1. Individual changes in maximal oxygen uptake from the preinfusion (baseline) to the post-infusion A (3 days) and B (10 days) tests.

Figure 2. Individual data for the relationship between the increase in red cell volume and increase in maximal aerobic power for the Post-A test. The broken line represents the line of equality.

Table 1. Anthropometric description of the Special Forces subjects.

	Age (yr)	Height (cm)	Weight (kg)	Surface Area (m^2)	% Fat SF	% Fat UW	LBM
$\bar{X}$	27.3	180.5	79.4	2.00	15.7	15.1	67.2
SD	5.7	7.1	11.4	0.17	4.6	4.0	8.0
RANGE:							
MIN.	22.0	168.0	60.7	1.68	8.0	7.0	53.4
MAX.	43.0	190.0	95.8	2.24	23.0	21.0	79.2
(n=12)							

SF is skinfold, UW is underwater weighing, LBM is lean body mass.

Table 2. Maximal Exercise Responses of Special Forces subjects.

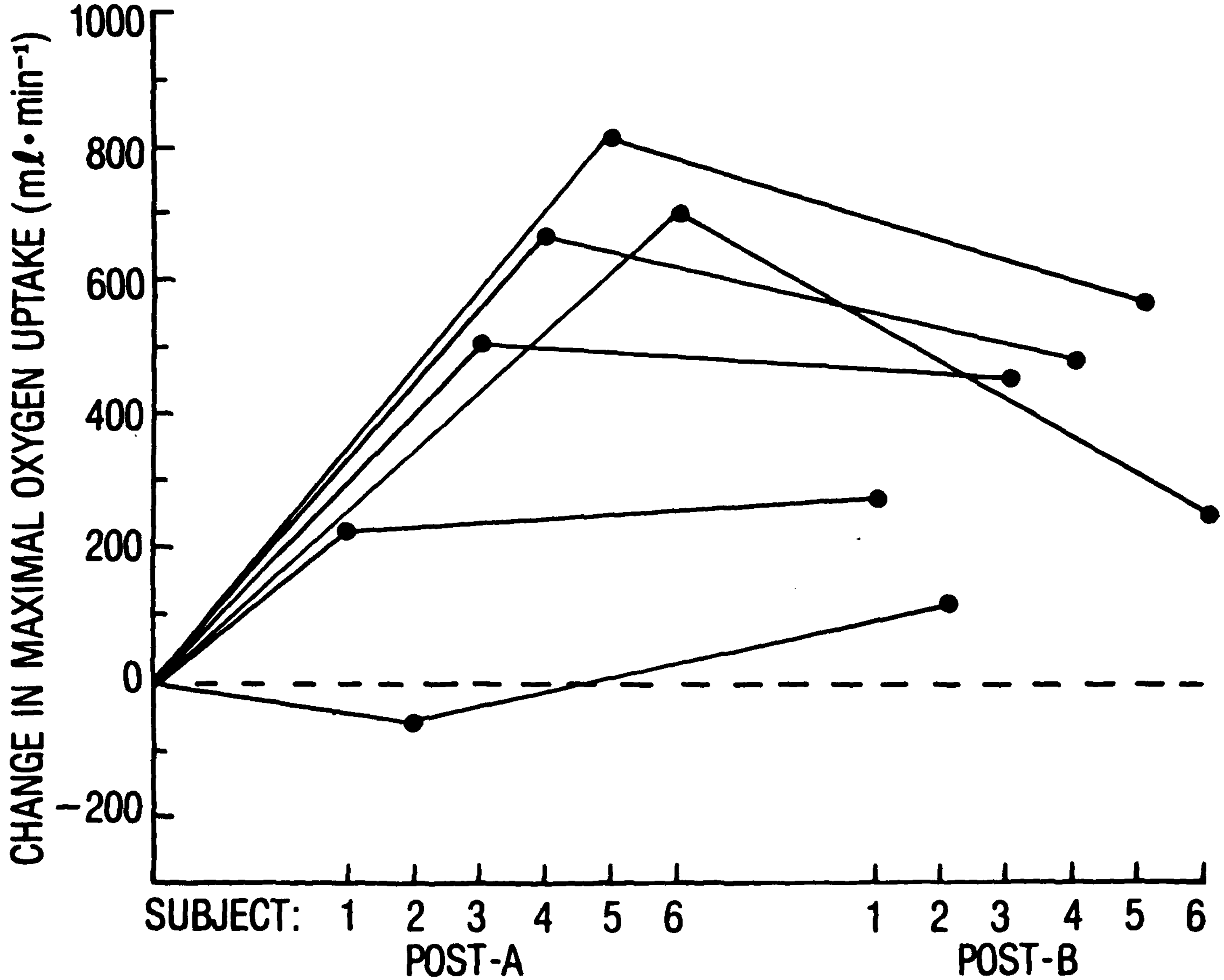
	Heart Rate (b·min^{-1})	$\dot{V}E \cdot \dot{V}O_2$	Maximal Oxygen Uptake (ℓ·min^{-1})	(ml·kg·min^{-1})	(ml·kg^{-1} LBM·min^{-1})
$\bar{X}$	188	37	4.357	55.2	65.0
SD	10	3	0.556	4.3	4.6
RANGE:					
MIN.	168	34	3.475	48.8	54.9
MAX.	199	39	5.551	63.8	71.7
(n=12)					

LBM is lean body mass.

Table 3. Effect of red cell or saline infusion on Special Forces physiological responses to maximal exercise.

	Heart Rate ($b \cdot min^{-1}$)			$\dot{V}E \cdot \dot{V}O_2$			Maximal Oxygen Uptake ($\ell \cdot min^{-1}$)			($ml \cdot kg^{-1} \cdot min^{-1}$)			($ml \cdot kg^{-1}$ LBM $\cdot min^{-1}$)		
	Pre	Post-A	Post-B	Pre	Post-A	Post-B	Pre	Post-A	Post-B	Pre	Post-A	Post-B	Pre	Post-A	Post-B
RED CELL (n=6)															
X̄	190	185	181	37	34	35	4.280	4.753*	4.631*	54	60*	59*	64	72*	70*
SD	7	9	12	2	3	4	0.215	0.426	0.217	5	6	6	6	9	7
SALINE (n=3)															
X̄	197	193	189	35	35	37	4.670	4.714	4.831	56	57	58	67	68	68
SD	2	5	6	5	4	3	1.073	0.837	1.145	4	4	4	3	2	4

Post-A and Post-B refer to tests of 3-days and 10-days post-infusion.
*$P < 0.05$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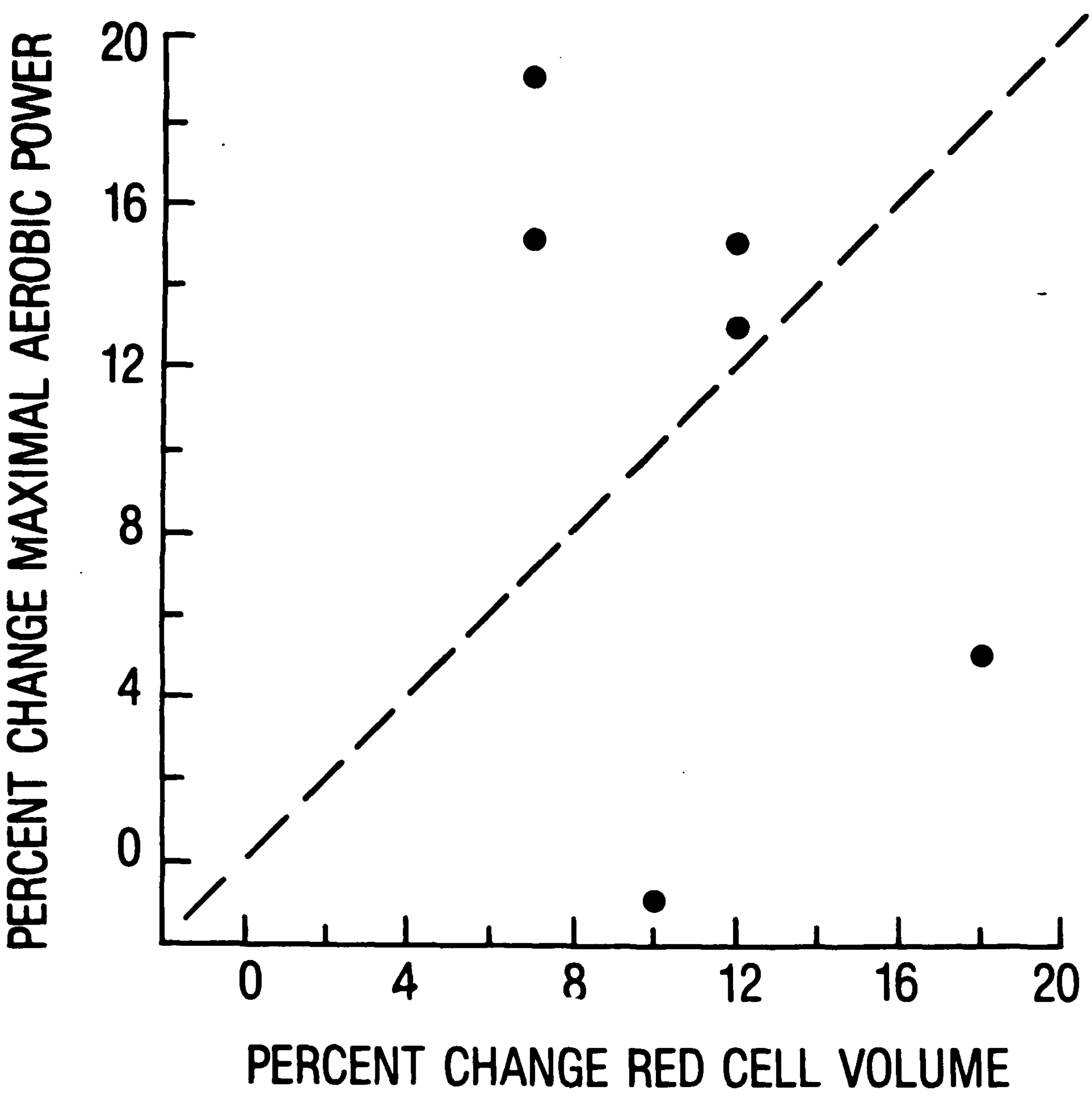

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