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EFFECT OF PHOSPHATE SUPPLEMENTATION ON METABOLIC AND NEUROENDOCRINE RESPONSES TO EXERCISE AND ORAL GLUCOSE LOAD IN OBESE WOMEN DURING WEIGHT REDUCTION

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Thirty six obese women (BMI 29.5 to 44.0 kg m⁻², aged 27 to 45 yrs) participated in the 4-week weight reducing program. All of them have prescribed low fat diet of approx. 4.2 MJ (1000 kcal per day) with high viscous fibre capsules as a basic supplement. In addition 18 women (group 1) received Redusan mineral tablets containing mainly calcium and potassium phosphates while the remaining subjects (group 2) were given Placebo instead of mineral tablets. Before energy restriction and after 4 weeks on the diet, half of the women from each group performed 30 min – bicycle ergometer exercise (30–50 W; HR approx. 110 beats · min⁻¹). The remaining subjects were submitted to oral glucose (75 g) tolerance test (OGTT). Weight loss during energy restriction was not affected by phosphate supplementation (4.6 ± 0.4 and 5.2 ± 0.5 kg in group 1 and 2, respectively). Phosphates caused a significant increase ($p < 0.05$) in the resting metabolic rate (RMR). Net energy cost of work, resting and post-exercise blood glucose, lactate, plasma FFA, adrenalin, cortisol, growth hormone, insulin and testosterone did not differ between the groups receiving phosphates and placebo while respiratory exchange ratio was slightly higher ($p < 0.05$), and the plasma beta-hydroxybutyrate concentration lower ($p < 0.05$) than without phosphate supplementation. Post-exercise plasma noradrenaline was significantly lowered after 4 weeks of energy restriction in group 2 (on Placebo). Neither blood glucose, plasma insulin and noradrenaline responses to oral glucose ingestion nor the glucose induced thermogenesis were significantly affected by phosphate supplementation, whilst blood pressure increases following glucose load were reduced ($p < 0.05$). In conclusion, the present study confirmed a potential usefulness of phosphate supplementation during energy restriction in obese patients due to its effect on resting metabolic rate. The results did not, however, reveal any major alterations in the metabolic and hormonal responses to exercise or to glucose ingestion in comparison with placebo treatment.

Key words: obesity, low energy diet, exercise, oral glucose load, phosphates, metabolic rate, hormones

INTRODUCTION

Hypophosphatemia has been found to cause various metabolic disturbances resulting, among others, in skeletal muscle weakness (1) and glucose intolerance (2). On the other hand, there is an evidence that phosphate

supplementation may enhance work performance by increasing availability of phosphate for energy yielding processes in skeletal muscles, and myocardium as well as by increasing the tissue oxygenation by an elevation of red cell 2,3-diphosphoglycerate (3–6).

It has been reported that the plasma inorganic phosphate concentration is lower in obese than in lean human subjects (7). Moreover, it may decrease further during reduced food consumption.

In our previous study (8) it was found that treatment of overweight women with phosphates during the low energy diet induces a significant increase in the resting metabolic rate and prevents a decrease in the plasma triiodothyronine concentration.

The aim of the present work was to find out whether phosphate supplementation affects the metabolic and hormonal responses to submaximal physical exercise and to oral glucose load in dieting obese women.

MATERIAL AND METHODS

A cohort of 36 obese women was recruited to participate in 4 week weight-reducing program. After careful medical examination they were found to be in good health apart from obesity. The study was approved by the Ethical Committee at the Medical University School in Warsaw, and all subjects gave their informed consent.

Weight reduction program

All the subjects have had prescribed the same low fat, high protein and carbohydrate diet. Their daily allowance of energy intake amounted to 1000 Kcal (4.2 MJ) and they were asked to record all the food stuffs consumed each day. Throughout the study the women led their normal life, majority of them being engaged in the sedentary, professional work. None of them was taking part in any regular sports activity.

The 36 subjects were randomly divided into 2 groups. Group 1 received Redusan Combi (Halsoproducter, AB, Sweden) including gel forming, high viscous fibre capsules (glucomannan, xantan, locus bean guar gum – totally 550 mg per capsule) and mineral tablets containing phosphates (537 mg of calcium phosphate, 107 mg of potassium phosphate, 25 mg of sodium phosphate and trace amounts of chromium, zinc and magnesium salts). The subjects were instructed to take 1–2 Redusan capsules 3 times daily (15–30 min before a meal) and 2 Redusan mineral tablets three times daily (after meals).

The subjects of group 2 received Redusan capsules (as described above) and Placebo (instead of phosphate-containing Redusan mineral tablets).

Throughout the study the women attended the whole-group meetings at the Department every week for control of body mass, check-up of their calorie intake and nutritional instructions.

Protocol of the study

Both groups of the subjects were divided into two sub-groups: a and b. Characteristics of the subjects from the sub-groups is given in *Table 1*.

The patients from the sub-groups 1a and 2a performed exercise test before the treatment, and then after 4 weeks on the diet, while the patients from the sub-groups 1b and 2b were submitted to

oral glucose tolerance test (OGTT). The date of the study beginning was individually adjusted to the subjects' menstrual cycle, so they were always examined during the follicular phase of the cycle. Both the exercise and OGTT tests were performed between 8 and 10 a. m., after an overnight fast. Before the examinations the subjects did not take the Redusan capsules, but they were given 2 mineral or Placebo tablets 30 min before the tests.

Table 1. Characteristics of patients ($\bar{x} \pm SE$)

Groups	Age (yrs)	Height (cm)	Body mass (kg)	BMI ($\text{kg} \cdot \text{m}^2$)	Body fat* (%)	Waist to hip ratio
1a (n = 9)	39.6 \pm 0.9	164.5 \pm 1.6	91.5 \pm 2.7	33.9 \pm 1.2	41.3 \pm 2.3	0.75 \pm 0.02
1b (n = 9)	37.6 \pm 2.0	164.6 \pm 2.6	89.9 \pm 4.5	33.2 \pm 1.4	42.4 \pm 1.1	0.74 \pm 0.02
2a (n = 9)	39.6 \pm 1.2	161.8 \pm 1.5	86.3 \pm 1.6	32.7 \pm 0.9	43.1 \pm 0.8	0.75 \pm 0.02
2b (n = 9)	38.7 \pm 2.1	163.1 \pm 1.3	90.1 \pm 5.0	33.9 \pm 1.9	45.4 \pm 2.0	0.78 \pm 0.02

* Estimated from the skinfold thickness, according to Durnin and Womersley (20).

The subjects from the sub-groups 1a and 2a performed 30-min bicycle ergometer (Siemens, FRG) exercise at a work load inducing an increase in heart rate to 105–120 beats \cdot min⁻¹. The absolute exercise intensity was within the range of 20–50 W. Identical exercise load was applied for each individual before and after the diet. During exercise ECG was recorded and blood pressure (BP) was measured by auscultation every 5 min.

In blood samples, taken at rest, in the last min of exercise, and then after 30 min of the recovery, concentrations of glucose (BG), lactate (LA), free fatty acids (FFA), β -hydroxybutyric acid (BAOH), insulin (IRI), noradrenaline (NA), adrenalin (A), cortisol, growth hormone (hGH) and testosterone were determined. All blood samples were taken through a catheter inserted to the antecubital vein at least 30 min before the base-line measurements.

Oxygen uptake ($\dot{V}O_2$) and CO₂ output ($\dot{V}CO_2$) were estimated throughout 15 min before exercise, and then every 10 min of its duration. At the 10th, 20th min and at the end of exercise the subjects were asked to estimate their perceived exertion (RPE) using the 15 graded scale of Borg (9).

In the patients from sub-groups 1b and 2b BG, IRI, catecholamine and BP responses to oral glucose load (75 g) were determined. Blood samples were taken through the catheter before glucose ingestion and every 30 min during 2-h of OGTT except those for the plasma NA and A which were taken at 60 and 120 min. In addition, thermal effect of glucose (TEG) was estimated in these sub-groups. For this purpose $\dot{V}O_2$ and $\dot{V}CO_2$ were measured for 15 min before glucose ingestion, and then 5 min measurements were repeated every 15 min throughout OGTT. During the 2h-test the subjects rested in a comfortable sitting position on an armchair in temperature controlled conditions (22–24°C).

Metabolic rate

The resting, exercise and post-glucose metabolic rates were calculated from $\dot{V}O_2$ and $\dot{V}CO_2$ measurements made by means of an open circuit system using the ergooxyscreen (Jaeger, FRG). The data were printed every 30 s and then averaged. The energy cost of work was calculated as

a difference between the exercise (EMR) and resting metabolic rates (RMR), and then the mechanical efficiency (ME) was computed according to the formula:

$$\text{ME (\%)} = \frac{W}{\text{EMR} - \text{RMR}} \times 100$$

where W = exercise load in $\text{kJ} \cdot \text{min}^{-1}$

Thermal effect of glucose (TEG) was calculated as a sum of energy expenditures each 15 min after glucose ingestion minus the base line (RMR) value, and expressed in $\text{kJ} \cdot 2\text{h}^{-1}$.

Blood biochemical analyses

Blood glucose and LA were determined enzymatically using commercial kits (Boehringer Diagnostica Mannheim, FRG). Plasma FFA were measured enzymatically according to Shimazu et al. (10). Determinations of the plasma BAOH were made using the enzymatic method described by Williamson et al. (11). Plasma IRI and hGH levels were determined radioimmunologically using RIA-MJ-63 and RIA-MJ-88 sets (Institute of Atomic Energy, Świerk, Poland), respectively. Plasma A and NA concentrations were measured by the radioenzymatic method of Da Prada and Zurcher (12) using the tests distributed by Chemapol Co. Ltd. (Czechoslovakia). Plasma cortisol and testosterone were determined by radioimmunoassays using antibodies produced at the Institute of Animal Physiology and Nutrition, Polish Academy of Sciences, Jabłonna n. Warsaw (Poland). Blood plasma for determinations of all hormones was frozen immediately after centrifugation and stored at -70°C . To avoid an influence of inter-assay variability plasma samples for each subject, collected during the 4 – week study, were always determined in the same assay.

Blood glucose and IRI responses to oral glucose load were expressed as incremental areas under the curves, calculated by the trapezoid method.

Statistics

The data are presented as means \pm standard error (SE) throughout the text. Significance of differences between groups was determined using a two-way analysis of variance (ANOVA) followed by the Student's t-test.

RESULTS

Changes in body mass

The patients from the subgroups 1a and 1b (on phosphates) lost 4.6 ± 0.4 and 4.7 ± 0.9 kg, respectively, while in those from the subgroups 2a and 2b the body mass decreases were 5.0 ± 0.5 and 5.1 ± 0.7 kg. No significant differences were found either between the subgroups or the main groups.

Responses to physical exercise (Fig. 1)

Heart rate and blood pressure. Both in the subjects from sub-groups 1a and 2a HR during exercise was significantly ($P < 0.05$) lower after 4 weeks on the low energy diet in comparison with the initial values.

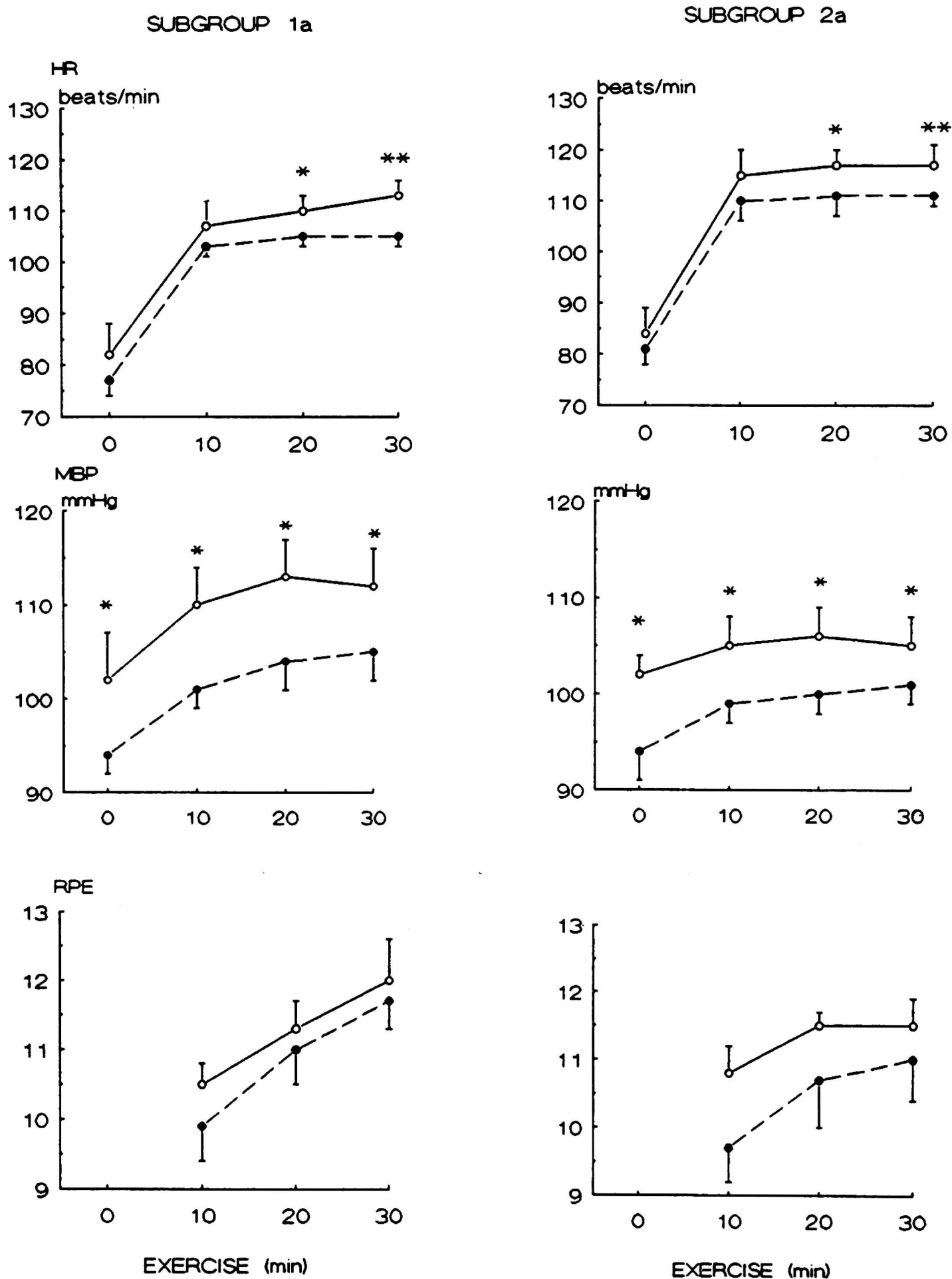


Fig. 1. Heart rate (HR), mean blood pressure (MEP) and perceived exertion (RPE) during 30-min exercise in the subjects before (solid line) and 4 weeks after (broken line) on low energy diet with (subgroup 1a) or without (subgroup 2a) phosphate supplementation. Asterisks indicate significant differences between values obtained before and after the dietary treatment within the subgroups. * $p < 0.05$; ** $p < 0.01$.

Resting and exercise mean blood pressure (MBP) was also significantly lowered by the diet ($P < 0.05$) without any differences between groups. In spite of the decreased HR responses to physical exercise no significant changes were noted in the scores of perceived exertion during the tests performed before and after 4 weeks on the diet.

Oxygen uptake, mechanical efficiency, and respiratory exchange ratio

The resting oxygen uptake (RMR) expressed either in absolute values or calculated per kg of body mass did not decrease in the 4 week-period of the weight reduction. Moreover, phosphate supplementation caused a significant increase in $\dot{V}O_2$ in the sub-group 1a (*Fig. 2*). The exercise $\dot{V}O_2$ was not affected by phosphate treatment.

Exercise oxygen pulse i. e. $\dot{V}O_2$ calculated per 1 heart beat was significantly higher in the sub-group 1a (on phosphates) than in the sub-group 1b ($p < 0.05$). The energy cost of work did not change significantly in either sub-groups as evidenced by similar mechanical efficiency within 4 weeks on the low energy diet (*Fig. 2*).

The respiratory exchange ratio (RER) was elevated in the subjects from the sub-group 1a ($P < 0.05$), and showed a tendency towards a decrease in the sub-group 2a.

Blood metabolites (Table 2)

There were no differences between groups in BG, blood LA and plasma FFA levels. After one month on the low calorie diet the plasma BAOH levels measured before exercise, immediately after exercise cessation and at the 30th min of recovery period were significantly higher in the sub-group 2a than in 1a.

Blood hormones (Table 3)

Resting values of plasma NA, A, hGH, IRI and testosterone did not change significantly during the study in either group and there were no differences between the two sub-groups. Plasma cortisol level in both groups significantly decreased after 4 weeks on the low energy diet.

The exercise and post-exercise changes in blood concentrations of A, cortisol, hGH, IRI and testosterone were similar in both sub-groups. The

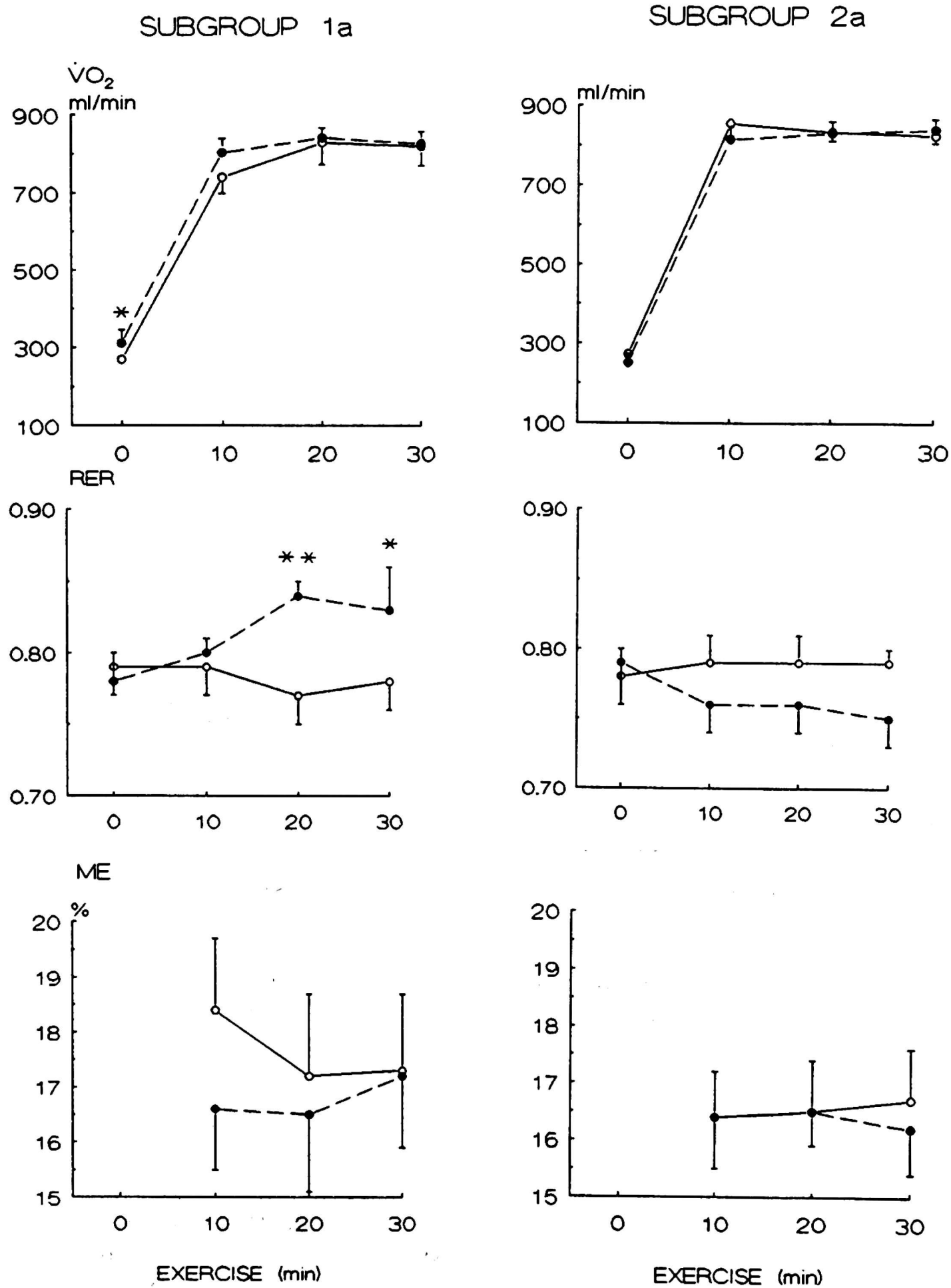


Fig. 2. Oxygen uptake ($\dot{V}O_2$), respiratory exchange ratio (RER) and mechanical efficiency (ME) during 30-min exercise. Description as in Fig. 1.

Table 2. Blood metabolite responses to 30-min exercise (Ex.) followed by 30-min recovery (Rec.) during 4 weeks of the treatment

Variables	Sub-group 1a					
	Initial			4 weeks – on Phosphates		
	Rest	Ex.	Rec.	Rest	Ex.	Rec.
Glucose (mmol · l ⁻¹)	5.2 ±0.21	4.6 ±0.27	5.1 ±0.16	5.0 ±0.11	4.5 ±0.14	4.8 ±0.15
Lactate (mmol · l ⁻¹)	1.02 ±0.04	3.10 ±0.18	1.95 ±0.25	1.02 ±0.03	3.58 ±0.24	2.37 ±0.09
FFA (mmol · l ⁻¹)	0.716 ±0.044	0.803 ±0.064	0.892 ±0.079	0.721 ±0.055	0.741 ±0.054	0.918 ±0.042
β-hydroxybutyrate (mmol · l ⁻¹)	0.177 ±0.014	0.128 ±0.015	0.263 ±0.036	0.131 ±0.014	0.109 ±0.009	0.250 ±0.021
Variables	Sub-group 2a					
	Initial			4 weeks – on PLACEBO		
	Rest	Ex.	Rec.	Rest	Ex.	Rec.
Glucose (mmol · l ⁻¹)	4.8 ±0.17	4.5 ±0.13	4.4 ±0.18	4.9 ±0.10	4.8 ±0.10	4.7 ±0.10
Lactate (mmol · l ⁻¹)	0.98 ±0.04	3.26 ±0.26	2.25 ±0.27	0.99 ±0.04	3.47 ±0.15	2.96 ±0.15
FFA (mmol · l ⁻¹)	0.723 ±0.088	0.807 ±0.105	0.863 ±0.084	0.863 ±0.053	0.832 ±0.053	1.029 ±0.061
β-hydroxybutyrate (mmol · l ⁻¹)	0.247 ±0.030	0.222 ±0.030	0.348 ±0.045	0.267* ±0.070	0.208* ±0.039	0.489** ±0.094

Values significantly different from group 1 – *p<0.05; **p<0.01.

plasma NA concentration achieved during exercise in the sub-group 2a was significantly lowered after 4 weeks on Placebo, while in the sub-group 1a there was a tendency towards elevated NA values.

Oral glucose tolerance test

Blood glucose

In group 1b the fasting BG level was significantly lowered after 4 weeks on phosphate treatment (P<0.05). The maximal post-glucose BG achieved at 30th or 60th min of OGTT showed a tendency towards a decrease after 4 weeks on the diet but the differences were not statistically significant. Similar tendency was also observed when the responses of BG to glucose load were

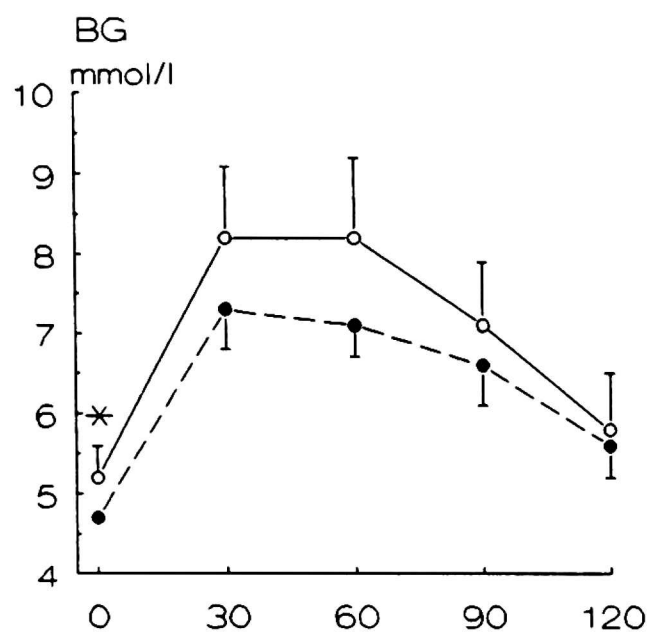
Table 3. Blood hormone responses to 30-min exercise (Ex.) followed by 30-min recovery (Rec.) during 4 weeks of the treatment

Variables	Sub-group 1a					
	Initial			4 weeks on Phosphates		
	Rest	Ex.	Rec.	Rest	Ex.	Rec.
Noradrenaline (pmol · ml ⁻¹)	1.58 ±0.18	2.05 ±0.13	1.70 ±0.19	1.99 ±0.16	2.77 ±0.34	2.16 ±0.24
Adrenalin (pmol · ml ⁻¹)	0.14 ±0.02	0.32 ±0.05	0.18 ±0.03	0.16 ±0.02	0.36 ±0.08	0.26 ±0.06
Cortisol (µmol · l ⁻¹)	0.191 ±0.023	0.266 ±0.051	0.218 ±0.027	0.136 ⁺ ±0.014	0.163 ±0.019	0.188 ⁺ ±0.031
Growth Hormone (ng · ml ⁻¹)	3.0 ±0.9	6.9 ±1.3	5.7 ±1.5	3.1 ±0.5	8.6 ±2.6	5.6 ±1.7
Insulin (µU · ml ⁻¹)	22.8 ±2.5	22.2 ±2.4	22.1 ±2.1	16.6 ±1.6	15.9 ±1.9	16.2 ±1.9
Testosterone (nmol · ml ⁻¹)	4.20 ±0.87	4.72 ±1.04	4.80 ±1.00	4.37 ±0.66	4.68 ±0.73	5.20 ±0.88
Variables	Sub-group 2a					
	Initial			4 weeks on PLACEBO		
	Rest	Ex.	Rec.	Rest	Ex.	Rec.
Noradrenaline (pmol · ml ⁻¹)	1.86 ±0.22	2.88 ±0.35	1.97 ±0.21	1.65 ±0.37	2.05 ⁺ ±0.40	1.62 ±0.57
Adrenalin (pmol · ml ⁻¹)	0.24 ±0.07	0.45 ±0.09	0.27 ±0.07	0.22 ±0.06	0.38 ±0.12	0.28 ±0.09
Cortisol (µmol · l ⁻¹)	0.226 ±0.025	0.301 ±0.036	0.246 ±0.036	0.162 ⁺ ±0.025	0.225 ±0.035	0.194 ±0.041
Growth Hormone (ng · ml ⁻¹)	2.5 ±0.6	5.6 ±1.1	1.5 ±0.6	2.5 ±0.6	6.4 ±3.0	2.6 ±0.6
Insulin (µU · ml ⁻¹)	17.1 ±3.1	13.2 ±1.5	18.4 ±3.2	14.7 ±2.3	12.7 ±1.8	13.7 ±2.1
Testosterone (nmol · ml ⁻¹)	5.89 ±0.93	6.69 ±1.28	6.2 ±1.2	5.03 ±0.80	5.48 ±0.66	5.89 ±0.94

Values significantly different from the initials within the groups ⁺p<0.05.

expressed as the incremental area under the curve (*Table 4*). In group 2b (on Placebo) the fasting BG concentration as well as the maximal post-glucose BG and the areas under BG curves remained unchanged throughout the whole period of the study (*Table 4, Fig. 3*).

SUBGROUP 1b



SUBGROUP 2b

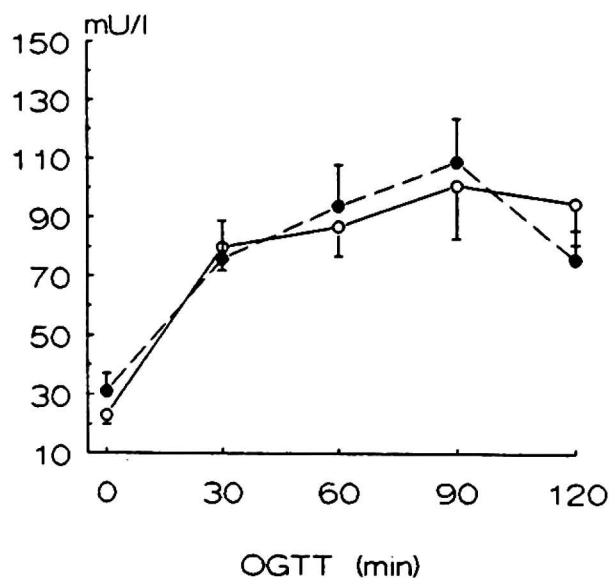
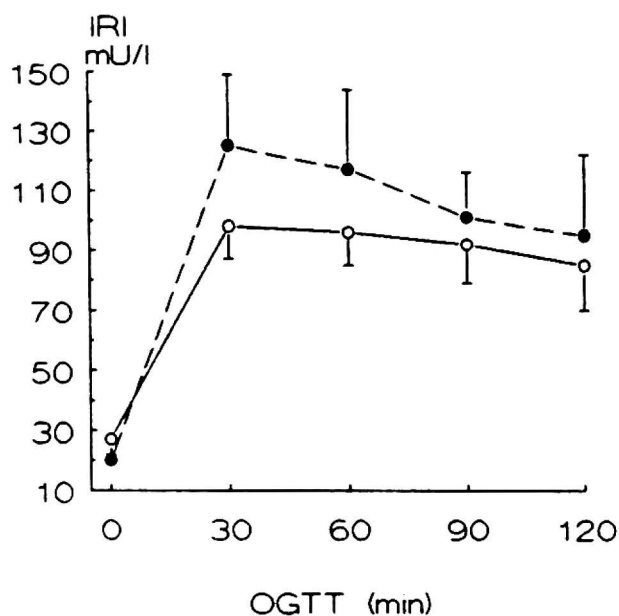
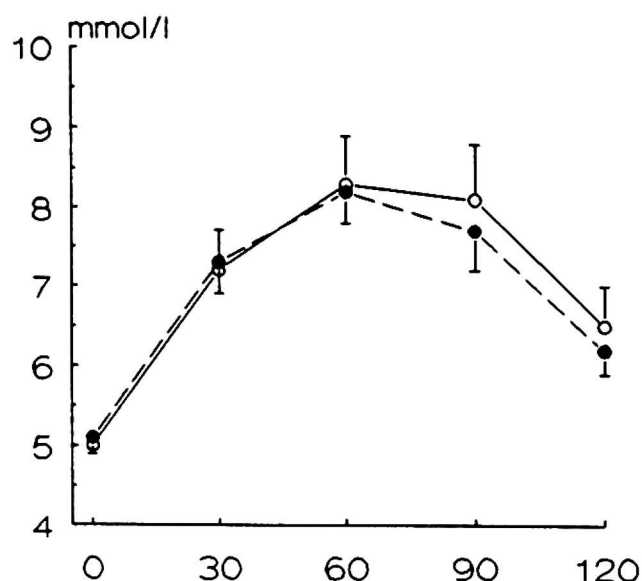


Fig. 3. Blood glucose (BG) and insulin (IRI) responses to glucose load (OGTT) in subjects before (solid line) and after 4 weeks (broken line) on low energy diet with (subgroup 1b) or without (subgroup 2b) phosphate supplementation. * $p < 0.05$.

Plasma IRI

The fasting plasma IRI concentrations did not change significantly during the study in either group. In the sub-group 1b the maximal post-glucose IRI showed a strong tendency towards higher levels in comparison with the initial values, whilst in the sub-group 2b no changes in the insulin response to glucose was found. Thermal effect of glucose varied greatly among subjects. No significant differences between groups were found after 4 weeks on the diet (Table 4).

Table 4. Oral glucose tolerance test — summarized data

Responses to glucose load	Sub-group 1b		Sub-group 2b	
	Initial	4 weeks on Phosphates	Initial	4 weeks on PLACEBO
Blood glucose				
Maximal post-glucose level (mmol·l ⁻¹)	9.3 ± 0.9	7.8 ± 0.4	8.8 ± 0.6	8.4 ± 0.4
Incremental area under the curve (mmol·l ⁻¹ ·min)	252.2 ± 52	218.8 ± 29.3	282.5 ± 44.8	255.9 ± 27.8
Plasma insulin				
Maximal post-glucose level (μU·ml ⁻¹)	114.9 ± 11.9	146.3 ± 28.5	117.1 ± 16.2	128.4 ± 19.5
Incremental area under the curve (μU·ml ⁻¹ ·min·10 ³)	7.04 ± 0.81	8.99 ± 1.66	6.53 ± 0.95	6.66 ± 0.92
Thermal effect of glucose (kJ·2h ⁻¹)	73.4 ± 24.8	58.5 ± 16.1	55.9 ± 13.3	60.2 ± 12.7

Plasma catecholamines

The resting values of NA concentrations were similar in both sub-groups b at the beginning of the study. During the food restriction in the sub-group 1b only a tendency towards reduced plasma NA concentration was noted, whilst in the sub-group 2b significantly lowered values of NA were found after 4 weeks on the diet ($P < 0.05$). After glucose ingestion there was a significant ($P < 0.001$) increase in the plasma NA with the maximum values obtained after 60 or 120 min of the test. In the sub-group 1b the maximal post-glucose NA levels were 2.81 ± 0.25 and 2.80 ± 0.28 , pmol·ml⁻¹ at the beginning of the program and after 4 weeks, respectively. In group 2b the respective values were 2.54 ± 0.56 and 2.34 ± 0.55 pmol·ml⁻¹ ($p > 0.05$, Fig. 4).

The initial fasting plasma A concentrations were similar in both sub-groups and glucose ingestion did not influence the hormone level in either group.

Mean blood pressure measured before glucose ingestion did not differ between groups and it did not change significantly during the study. During the initial examination glucose load caused a significant increase in MBP in both groups. This response was markedly reduced only in the group 1b treated 4 weeks with phosphates (Fig. 4).

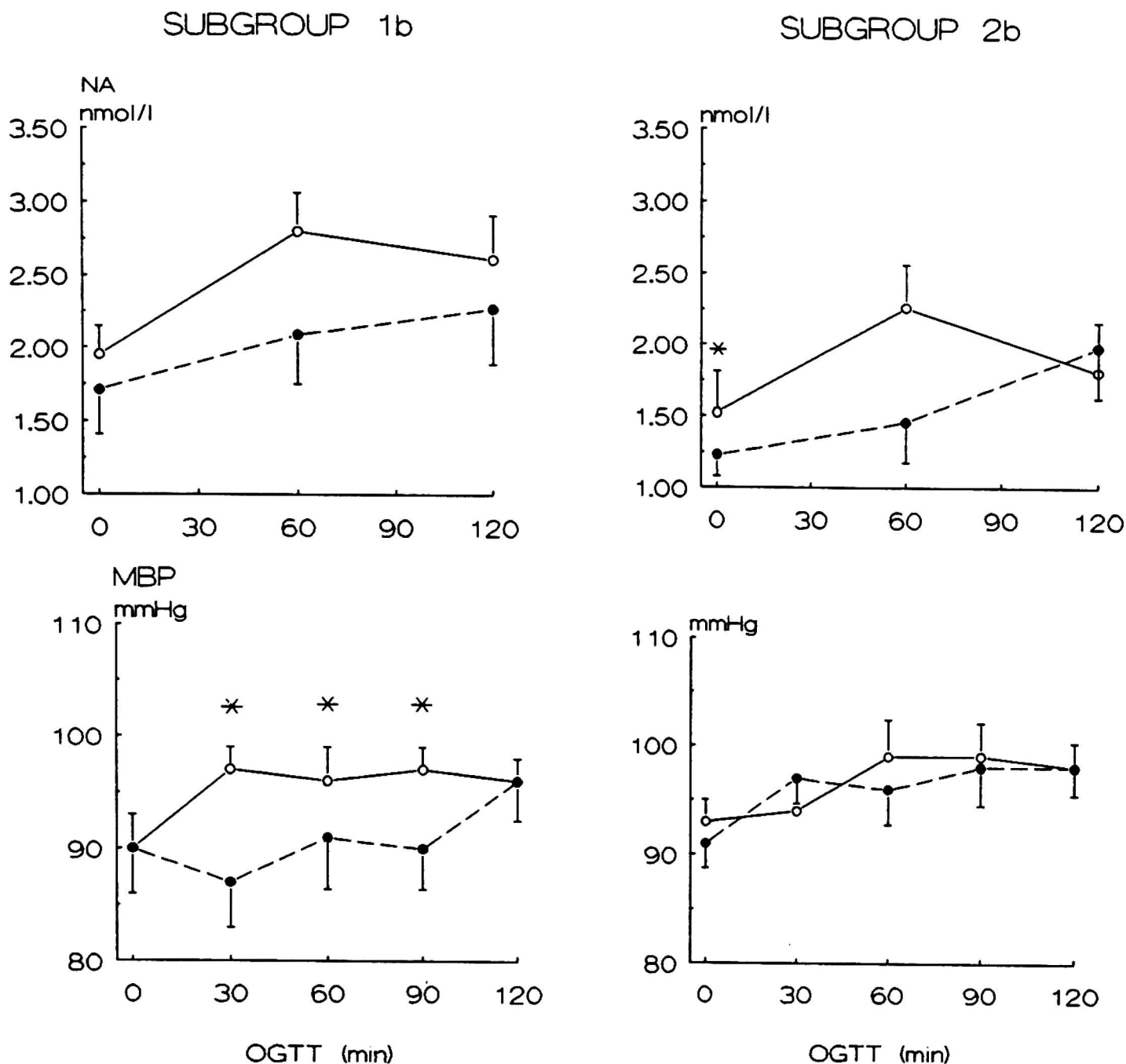


Fig. 4. Plasma noradrenaline (NA) and mean blood pressure responses to glucose load (OGTT) in the subjects before (solid line) and after 4 weeks (broken line) on low energy diet with (subgroup 1b) or without (subgroup 2b) phosphate supplementation. * $p < 0.05$.

DISCUSSION

Metabolic and hormonal responses to exercise

The present study confirmed our previous data showing that phosphate supplementation during energy restriction increases the resting metabolic rate (8). However, the exercise oxygen uptake as well as the calculated mechanical efficiency (ME) remained unchanged. It should be emphasized, however, that the term mechanical efficiency, has been used in this paper, as the ratio of the total energy expenditure minus RMR to the external work load. Thus, it does

not reflect the true muscle mechanical efficiency. The generally low values of this ratio found in this study in obese women are most probably caused by relatively high cost of their leg mass movement and the excessive postural activity due to the lack of training (13).

Similarly to the results reported by Kreider et al. (6) in our study the exercise respiratory exchange ratio (RER) tended to increase after phosphate treatment. According to Kreider et al. (6) the increase in RER may reflect the stimulatory influence of phosphates on the regulatory glycolytic enzymes, since in their experiments the RER elevation was accompanied by enhanced blood lactate levels. In our study, however, this was not the case.

Among other blood metabolites measured a difference between groups was noted only in the plasma beta-hydroxybutyrate level, which showed a tendency towards lower values in the subjects supplemented with phosphates than in those on Placebo. It is unknown whether this difference results from lower ketone bodies production or their greater utilization in the former group.

Hormonal responses to exercise

Phosphate supplementation did not influence the plasma catecholamine, growth hormone, insulin, testosterone and cortisol concentrations either at rest or after exercise. It should be noted that a tendency towards lowered plasma noradrenaline (NA) concentrations after 4 weeks of energy restriction, occurred only in group 2 (on Placebo) although it has been assumed (14, 15) that food restriction could inhibit activity of the sympathetic nervous system. The present results might suggest that phosphate supplementation during the short period of food restriction could prevent the inhibition of the sympathetic activation, however, scattering of NA values and lack of significant differences between groups do not allow to draw any clear cut conclusions.

Circulatory responses to exercise

Phosphate loading did not influence the circulatory responses to exercise. However, in both groups HR and mean blood pressure measured during exercise were significantly lowered by the applied dietary restrictions. Since this effect was not connected with any decrement of energy expenditure it indicates some improvement in the mechanisms of circulatory control with weight reduction similar to that induced by training.

It should be noted that the circulatory responses to exercise differed from those observed after a very low calorie diet (400 Kcal per day) when a decrease in blood pressure was associated with accelerated heart rate (16). Despite the above alterations in HR the subjective degree of strain, estimated using Borg's

scale (9), was similar before and after the program. It may be due to the relatively low work intensity, since it was shown that the afferent signals from low work loads may be more difficult to discern (17).

Metabolic and hormonal responses to oral glucose load

According to the criteria of the National Diabetes Data Groups (18) the patients participating in this study had normal glucose tolerance except three subjects from the sub-group 1b whose maximal blood glucose level during OGTT exceeded $10 \text{ mmol} \cdot \text{l}^{-1}$ in the first examination. However, the plasma insulin responses to oral glucose were exaggerated in the majority of subjects indicating a diminished whole body insulin sensitivity. During 4 weeks of weight reduction program blood glucose responses to glucose ingestion tended to be lowered in the sub-group 1b while in the sub-group 2b they remained unchanged. In neither groups the plasma insulin levels were reduced during energy restriction period, moreover, in the sub-group 1b even increases in the plasma insulin responses were found. Thus, some improvement of glucose tolerance in this group seems to be rather attributed to the enhanced insulin secretion than to the increased insulin sensitivity. This is an unexpected finding, since most of the studies concerning the metabolic effects of weight reduction suggested an improvement in insulin sensitivity.

De Fronzo et al. (2) demonstrated that hypophosphatemia results in glucose intolerance and tissue insulin resistance. So, it might have been expected that phosphate supplementation would positively influence glucose utilization. However, our data did not support this assumption.

Already at the beginning of the study the thermogenic effect of glucose showed large interindividual variability and we were unable to show any significant correlations between the post-glucose thermogenesis and body mass, percentage of fat, blood glucose, plasma insulin or noradrenaline concentrations. None of these factors alone could explain the variability in thermic effect of glucose in obese women participating in the present study. During energy restriction in sub-group 1b there was only a tendency towards a decrease of glucose-induced thermogenesis, while in the sub-group 2b no change in TEG was noted. The present data did not confirm the findings of Jaedig and Henningsen (19) demonstrating an enhancement in the post-prandial thermogenesis by phosphate supplementation in obese women. The possible reason of the above discrepancy may be the fact that the study of Jaedig and Henningsen (19) was performed in nondieting patients, while in the present work phosphates were given during energy restriction.

It is of interest that blood pressure increases in response to glucose ingestion were considerably diminished after 4 weeks on the low energy diet with phosphate supplementation, although the plasma NA levels following

glucose load did not change significantly. At the same time in the group on Placebo the post-glucose blood pressure was similar to that before the treatment and the plasma NA levels showed a more pronounced tendency to decrease than in the group with phosphate supplementation. It seems, therefore, that the changes in blood pressure response to glucose are related to some other factors than the sympathetic activity.

In summarizing: The present study showed that in obese women being on a diet of approx. 4.2 MJ (1000 kcal) daily, phosphate supplementation increases resting metabolic rate but it does not influence net energy cost of physical exercise or glucose-induced thermogenesis. Phosphate treatment appeared to cause only minor changes in the metabolic and hormonal responses to exercise manifesting themselves in a slight elevation of respiratory exchange ratio, lower plasma beta-hydroxybutyrate levels and a tendency towards higher plasma noradrenaline concentration. No influence of the phosphate supplementation on blood glucose, plasma insulin and noradrenaline levels following oral glucose ingestion was ascertained, whilst blood pressure in response to glucose load was lowered by phosphate treatment.

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