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The Effect of Induced Metabolic Alkalosis with Sodium Bicarbonate on Racing-Time, Maximal Oxygen Uptake and Anaerobic Lactate Threshold in Competitive Cyclists

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Six high school competitive cyclists were administered with $NaHCO_3$ (sodium bicarbonate ; metabolic alkalosis) and $CaCO_3$ (calcium carbonate ; placebo) and were tested for the effect on maximal oxygen uptake, the exercise time to exhaustion, and anaerobic lactate threshold (AT-HLa) during 1 km and 3 km cycling races and a graded bicycle exercise. The following results were obtained. (1) All the subjects cycled faster by .75 sec under the metabolic alkalosis condition than under placebo condition in 1 km race. However, the difference was not statistically significant. (2) The race time for 3 km cycling race was significantly shorter by at least 3.8 sec under the metabolic alkalosis condition. (3) The maximum oxygen uptake increased by more than 5.5 % (3.5 $ml/kg.min^{-1}$) under the experiment condition. (4) Although there was no statistical significance, the exercise time to exhaustion lasted 23 sec longer under the experiment condition. (5) The AT-HLa did not show difference between the conditions. The experiment condition, however, favored the subjects with the oxygen uptake, $\dot{V}O_2max$, and workload at the anaerobic threshold. It was concluded that the metabolic alkalosis induced by $NaHCO_3$ improves the anaerobic power endurance of cyclists. Further studies are needed to find whether the alkalosis increased the maximal aerobic capacity and anaerobic threshold level.

INTRODUCTION

As early as in the 1930's, researchers have found that artificial acidification speeds up fatigue and accelerates exhaustion, while alkalosis increases blood lactate concentration and improves exercise performance (Denning et al, 1931 ; Dill et al, 1932 ; Brown et al, 1940). The increase of the intracellular and extracellular lactate and the concentration level of H^+ (lactacidosis) is considered to be the major reason for fatigue (Hermansen, 1981 ; Sahlin, 1983 ; 1986). Lactacidosis due to high maximal intensity exercise constricts anaerobic glycolysis and lowers the intracellular pH (Sutton et al, 1981 ; Woodbury and Mills, 1973). If the process of lactacidosis and the lowering of pH can be delayed, the anaerobic glycolysis potential will be improved.

Metabolic alkalosis inducing substances such as $NaHCO_3$ is often administered to achieve that effect by increasing the buffering capacity within the body. It has been hypothesized that thus induced metabolic alkalosis increases momentarily the performance of supramaximal and near maximal intensity exercises with 30 sec to 6 minute duration, where the energy supplied by anaerobic glycolysis is relatively important. Some studies have found that the administration of $NaHCO_3$ or sodium citrate had a positive effect on the mean power output, peak or maximum power output, total output, and time to exhaustion during high intensity exercise of 95% $\dot{V}O_2$ max (Bouissou et al, 1988 ; Costill et al, 1984 ; Denning, 1937 ; Inbar et al, 1983 ; Jones et al, 1977 ; Kowalchuck et al, 1984 ; McKenzie et al, 1986 ; Sutton et al, 1981). Other studies have not supported the hypothesized effect (Brien and McKenzie, 1989 ; Katz et al, 1984 ; Kowalchuck et al, 1989 ; McCartney et al, 1983 ; Margaria et al, 1971 ; Parry-Billings and MacLaren, 1986 ; Poulous et al, 1974 ; Simmons and Hardt, 1973).

The contradictory effects of induced metabolic alkalosis were also reported in the studies of sports performance. Hewitt and Calloway (1936) observed the improvement in the performance of 100 meter and 400 meter swimmers. Goldfinch et al (1988) and Wilkes et al (1983) reported the shortened race time in 800 meter and 400 meter sprints, respectively. In contrast, Johnson and Black (1953) and Kindermann et al (1977) found no improvement in the performance records of 1.5 mile cross country and 400 meter sprint, respectively.

The findings of previous studies on the ergogenic effect of metabolic alkalosis are not conclusive. Most of the previous studies have investigated the effect on the supramaximal exercises with the duration of 30 sec to 2 minutes, and few studies have dealt with the effect on the exercises with longer periods (2 to 6 minutes). The present study examines the effects of administrating $NaHCO_3$ to performance and physiological characteristics during 1 km and 3 km cycling races.

METHOD

Subjects

The subjects of the present study were 7 competitive cyclists from Seoul Athletes' High School. On the average, they were 17.3 years old, 171.9 cm tall, weighed 65.7 kg, and had the career experience of 4.7 years (Table 1).

Table 1. Personal Profiles of Subjects. (N = 7)

Subject	Age (yr)	Hight (cm)	Body weight (kg)	Athletic career (yr)
YH	16	173	67.5	3.5
LC	16	172	66.2	3.5
CJ	17	171	62.0	4.5
KY	18	172	68.0	5.5
HH	18	168	61.0	5.5
KJ	18	168	67.0	5.5
SD	18	179	68.5	5.0
Mean	17.3	171.9	65.7	4.7
SD*	0.9	3.4	2.8	0.8

*SD: standard deviation

Procedures

The intermediates for alkalosis used in the study were NaHCO3, and the placebo was $CaCO_3$. The extract powder was used. In order to eliminate possible discomfort due to psychological factors, the powder was inserted in a gelatine capsule and was orally administered along with 400 ml to 500 ml of water (Bouissou et al, 1988). The dosage was prescribed following the same method used in recent studies (Bouissou et al, 1988 ; Parry-Billings and MacLaren, 1986 ; Wilkes et al, 1983). The amount of 0.3 g per 1 kg body weight was given to the subjects 95 to 120 minutes prior to the exercise. The ingestion period was about 10 minutes.

There were three separate sessions for each subject in the experiment ; one session each for an exercise type. There was a two to three day interval between the sessions. Each session consists of two experiments, which were conducted following the same protocol, except for the treatments given ($NaHCO_3$ in one and the placebo in the other). The order between the conditions was determined by a randomized double-blind fashion.

The experimental protocol is shown in Figure 1. The experiment took place in the physiology laboratory of Korea Sport Science Institute. The subjects digested the intermediates during 10 minute period. They then took a rest, sitting on a chair for 80 minutes. After the rest, they did warm-up exercise for 5 minutes on a bicycle ergometer (Monark 846 ; Sweden) with the workload of 15 to 30 W. Upon completing the warm-up, they started a graded exercise on the ergometer until the experimenter stopped them. Starting from 30 W, the workloads were incremented every 2 minutes by 30 W (0.5 kp) at 60 rpm until the subjects reached their maximal workloads. After the exercise, they took a rest on a chair for 20 minutes.

The gas samples were collected and analyzed on the automatic gas analyzer (Ergo-oxyscreen, Erich-Jaeger) every 30 seconds. 30 μl of bloods were sampled during the last 30 seconds of each stage by fingerpricks. The blood lactate level was analyzed with an automatic analyzer (YSI L23).

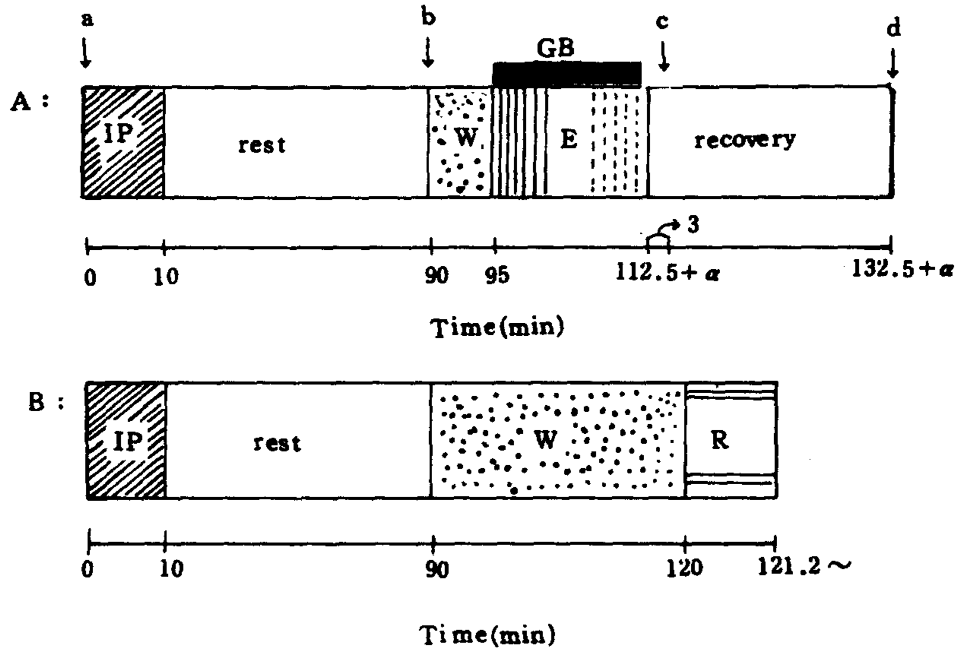

Figure 1. Schematic illustration of the study's protocol.

; A=a progressive exercise test, B=race(1000m & 3,000m)

IP ; ingestion period

W ; warm-up

R ; race

E ; progressive bicycle exercise

GB ; respiratory gas and blood samples

a∼b ↓ ; blood samples

Analysis of Data

The AT-LA was determined by plotting the HLa (blood lactate concentration) level on a coordinate of workloads and exercise time along the experimental stage and finding the second increase point. The differences in the measured values between the experimental and placebo conditions were examined by a dependent t-test. The significance level was .05.

RESULT

Previous studies which used $NaHCO_3$ to induce alkalosis reported some of its side effects such as acute gastrointestinal distress, vomiting, diarrhea, stomachache, and headache. Out of six subjects, one complained about diarrhea after the experiment.

Table 2 shows the record of 1 km and 3 km cycling races for the experimental and placebo conditions. In 1 km race, the average race time under the experimental condition was 1 minute and 20.43 sec, and under the placebo condition, it was 1 minute and 21.18 sec. The experimental group cycled faster by .75 sec, but the difference was not statistically significant. In 3 km race, the subjects cycled faster under the experimental condition by 3.88 sec, which was statistically significant.

Table 2. Records of 1 km and 3 km Cycling Races of the Subjects.

Subject	1Km(min : s)			3Km(min :s)		
	placebo	alkalosis	t	placebo	alkalosis	t
1	1:22.15	1:21.25		4:16.16	4:15.41	
2	1:21.78	1:19.14		4:17.82	4:12.78	
3	1:22.48	1:22.38		4:25.93	4:18.16	
4	1:20.54	1:20.36		4:33.33	4:27.38	
5	1:21.44	1:21.05		4:23.43	4:24.86	
6	1:18.67	1:18.38		4:30.44	4:25.24	
Mean	1:21.18	1:20.43	1.90	4:24.52	4:20.64	2.73*
SD	1:40	1:46		6.79	5.99	

* P < .05 : Alkalosis significantly faster than placebo in 3,000m time

Table 3 shows the maximal aerobic capacity under two conditions. The $\dot{V}O_2$ max during graded bicycle exercise was larger for all subjects under the experimental condition by 3.51 ml/kg.min^{-1}. The difference was small, but consistent enough to reach the significance level. The time to exhaustion was prolonged by 23 sec under the experimental condition, but the difference was not significant.

Table 3. Results of Maximal Aerobic Capacity under Two Conditions. (Mean ± SD)

$\dot{V}O_2$ max/kg(ml/kg · min $^{-1}$)	63.86±3.60	67.37±5.99	2.55*
time to exhaustion(min : s)	19 : 00.43±46.23	19 : 23.54±1 : 07.78	1.22

* $p < .05$: Alkalosis significantly higher than placebo in maximal oxygen uptake.

Table 4. shows the anaerobic threshold determined by the onset point of the rapid increase in the blood lactate concentration. The lactate concentration level at the anaerobic threshold was 4.27 mM under the experimental condition, and was 3.79 mM with placebo. The difference was not significant.

Table 4. Anaerobic Threshold Levels under Experiment Conditions. (Mean ± SD)

variable	AT-HLa (mM)	AT_{LA} · $\dot{V}O_2$/kg (ml/kg · min $^{-1}$)	AT_{LA} · %$\dot{V}O_2$ max (%$\dot{V}O_2$max)	AT_{LA} · Workload (Watt)
placebo	3.79 0.76	49.7 3.20	77.9 4.9	218.6 14.6
alkalosis	4.27 0.66	54.0 3.27	80.4 4.2	235.7 20.7
t	1.55	6.09***	2.55*	2.83*

* $p < .05$, *** $p < .001$; Alkalosis significantly higher than placebo in AT-$\dot{V}O_2$/kg · %$\dot{V}O_2$ max · Workload

All the other values at the anaerobic threshold were significantly different between two conditions. The oxygen uptake (AT_{LA} $\dot{V}O_2$/kg) increased under the experimental condition ($p < .001$). AT_{LA}%

$\dot{V}O_2$ max under the placebo condition was 77.9 %, which was lower by 2.5 % than under the experimental condition. The workload at the anaerobic threshold increased by 17 W, showing that it was also favored by the experimental condition.

DISCUSSION

Researchers interested in the balance between acid and alkali in human body have examined the effect of metabolic alkalosis induced by sodium bicarbonate with healthy adults or highly trained athletes (Bouissou et al, 1988 ; Brien and McKenzie, 1989 ; Chun, 1988 ; Jones et al, 1977 ; Sutton et al, 1981 ; Wilkes et al, 1983). The studies administered 0.15 to 0.40 g of $NaHCO_3$ per kg body weight to subjects either in a gelatine capsule or with 250 ml to 550 ml low sugar drinks. Most of the studies reported apparent metabolic alkalosis after 60 to 150 minutes.

When calcium carbonate was administered to the subjects, there was no significant changes in pH, base excess, and standard HCO_3^-, indicating that $CaCO_3$ does not affect the balance between acid and alkali (Bouissou et al, 1988 ; Goldfinch et al, 1988 ; Wilkes et al, 1983).

The present study administered $NaHCO_3$ to induce metabolic alkalosis and $CaCO_3$ as a placebo 95 minutes prior to graded exercise and 120 minutes prior to cycling sprints.

The race times for 1 km cycling sprint did not differ significantly between two conditions. Under the experimental condition, all six subjects shortened the race time by 0.1 to 2.64 sec with the average of .75 sec, although the difference did not reach the significance level of the present study. During 0.75 sec in 1 km sprints, the subjects can go 12 meters. In an 1 km race, 12 meters can make a great difference. The present result is in accordance with previous findings that performance records at 400 meter running event (Goldfinch et al, 1988) and at 100 meter swimming (Hewitt and Calloway, 1936) improved when the athletes were treated with $NaHCO_3$.

The effect of $NaHCO_3$ in the present study is more apparent in 3 km cycling race. 5 out of 6 subjects cycled faster under the experimental condition by 3.88 sec. In 3 km race, the subjects can go about 40 meters during 3.88 sec. These results indicate that metabolic alkalosis induced by $NaHCO_3$ had an ergogenic effect on the performance of well trained cyclists.

There are studies which have not found the positive effect of $NaHCO_3$ (Johnson and Black, 1953 ; Margaria, 1971). There are some differences in the treatment the subjects received and the type of sports investigated between those studies and the present study. First, a difference can be found in the dosage of the intermediate. As was pointed out in Goldfinch et al (1988) and Wilkes et al (1983), small amount of $NaHCO_3$ is not enough to induce metabolic alkalosis. For example, Margaria (1971) prescribed only 4 % of the present dosage. Second, the effect of induced metabolic alkalosis concerns anaerobic capacity rather than aerobic one. Therefore, there will be little effect of metabolic alkalosis on the performance of sports which depend on aerobic capacity. It explains partly why Johnson and Black (1953) did not support the effect of $NaHCO_3$ on 2.4 km cross-country running event.

The findings of the present study also point to a possibility that metabolic alkalosis induced by $NaHCO_3$ affects maximal intensity exercises with durations of 2 to 6 minutes more than supramaximal exercises with durations of 30 sec to 2 minutes. The present findings support the suggestion that the effect of bicarbonate loading on short term anaerobic power is questionable since it does not have significant effect on the exercise with 30 sec duration but on the exercise with 2 to 5 minute duration (Parry-Billings and MacLaren, 1986). In fact, only in the last trial of repeated exercises with 1 minute duration or in the exercises with 95 % $\dot{V}O_2 max$ which lasted over 4 minutes were observed the effects of $NaHCO_3$ (Costill et al, 1984 ; Jones et al, 1977 ; McKenzie et al, 1986 ; Sutton et al, 1986 ; Wijnen et al, 1984), but not in the exercises with durations of 30 sec to 2 minutes (Brien and McKenzie, 1989 ; Katz et al, 1984 ; McCartney et al, 1983).

A possible explanation concerning the physiological mechanisms involved in the improved physical performance due to induced metabolic alkalosis may be put forward. Bicarbonate loading increases the extracellular HCO_3 reserve, which accelerates the discharge of [H^+] and [La^-] from muscle cells due to increased gradient between intra and extra cellular pH's (Hirche et al, 1972 ; Mainwood and Worsley-Brown, 1975). As a result, the duration for intracellular pH to reach the critical inhibitory level is prolonged, that is, the process of acidosis is delayed (Jones et al, 1977 ; Sutton et al, 1981), and thus, fatigue is delayed and anaerobic energy production is increased (Hermansen, 1981 ; Sahlin, 1983 ; 1986). The increased anaerobic capacity contribute to improve performance in exercise (Goldfinch et al, 1988 ; Wilkes et al, 1983).

During graded exercise, $\dot{V}O_2$ max per kg body weight increased significantly by 5.5 % (3.51 $ml/kg.min^{-1}$) under the experimental condition. The finding is in contrast to those of Kowalchuck et al (1984), who found that $NaHCO_3$ resulted in non- significant increase of 2.6 % (1.3 $ml/kg.min^{-1}$). The two studies also differ in the time to exhaustion. Kowalchuck and the colleagues (1984) found no difference between the $NaHCO_3$ and placebo groups, while the present study found that the experimental condition delayed the time by 23.14 sec, although the value was not statistically significant.

The increase in the maximal oxygen uptake by the induced metabolic alkalosis can be attributed partly to the delayed time to exhaustion under the experimental condition in the present study. Kowalchuck et al (1984) suggested an intimate relationship between the time to exhaustion and the maximal oxygen uptake level by showing that acidosis induced by NH_4Cl (ammonium chloride) shortened the time to exhaustion and accordingly, the $\dot{V}O_2$ max was significantly lower than placebo or alkalosis conditions.

Another reason for the inconsistency between the present findings and those of Kowalchuck et al (1984) can be found in the different workloads used in the graded exercises and the subjects. Kowalchuck and the colleagues intensified the workloads by 16.7 W by the minute from the initial state of 16.7 W (100 kpm/min) with non-athlete adults, while in the present study, the workloads were intensified by 30 W every 2 minutes from the initial state of 30 W with well trained athletes.

The second increase point which determines the anaerobic threshold was found at a point higher by 0.58 mM under the experimental condition, although the value was not significant. The AT_{LA} VO_2 max and AT_{LA}%$\dot{V}O_2$ max increased significantly under the experimental condition. The workload level at the anaerobic threshold (AT_{LA}workload) was also higher under the experimental condition. The present findings are in contrast with those of Kowalchuck et al (1984) who found the lower values for these measure than the placebo condition (although they were not statistically significant).

The reasons can be found in the above mentioned differences in the graded workload and the subjects on the one hand, and more importantly in the differences of criteria for the anaerobic threshold level on the other. In the present study, the HLa levels were plotted in relations to the workloads and the duration of exercise and the anaerobic threshold was determined by finding the second rapid increase point of the HLa (Cho, 1989), whereas Kowalchuck and the colleagues (1984) considered the AT_{LA} level to be 1 mM from the rest level. As mentioned earlier, the metabolic alkalosis accelerates the discharge of [La] from muscle cells, the HLa after bicarbonate loading is higher throughout the test period than under the placebo condition (Bouissou et al, 1988 ; Brien and McKenzie, 1989 ; Chun, 1988 ; Jones et al, 1977 ; Kowalchuck et al, 1989 ; Parry-Billings and MacLaren, 1986 ; Sutton et al, 1981). Accordingly, when the AT_{LA} level under the alkalosis condition is determined based on its rest level, such AT_{LA} level becomes lower than the placebo level, resulting in idiosyncratic measures of the anaerobic parameters.

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