THE TIME COURSE OF ACID-BASE BALANCE WHILE ON FBM PATROL

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SUMMARY

THE PROBLEM

To determine the effects of elevated atmospheric CO_2 on arterialized and venous pH, P_{CO_2}, and P_{O_2}, and to monitor any changes in plasma electrolytes during chronic operational exposure to CO_2, during an extended FBM submarine patrol.

FINDINGS

No evidence of respiratory acidosis or change in electrolyte concentration was demonstrated during the study. Calcium and phosphate excretion were also found to be within normal limits with the subjects on unrestricted normal diets.

APPLICATIONS

This report is of value to all Submarine Medical Officers and environmental physiologists and all personnel who are concerned with the habitability of closed environments over long time periods.

ADMINISTRATIVE INFORMATION

This investigation was conducted as a part of project MR011. 01-5033, Time Course of Acid-Base Balance While on FBM Patrol. The present report in No. 1 on this project. The manuscript was approved for publication 28 July 1971, and designated as Submarine Medical Research Laboratory Report No. 675.

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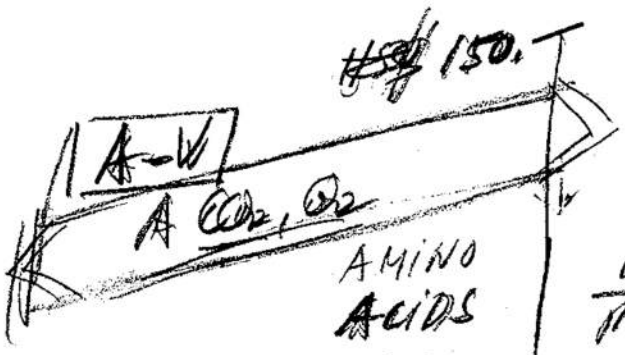
ABSTRACT

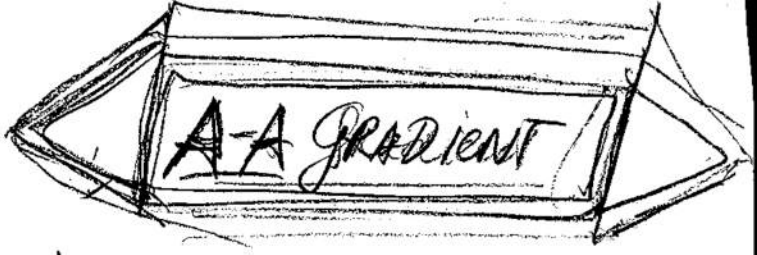
Measurements of arterialized capillary, and venous pH, P_{CO_2}, and P_{O_2} were taken from 15 healthy male subjects during a control period and during days 2, 9, 17, 42 and 56 of a Polaris submarine patrol. Venous plasma concentrations of sodium, chloride, and potassium were determined from frozen samples.

Twenty-four hour urine specimens were collected from four of the men in the study. Daily excretion of sodium, potassium, calcium, and phosphate were determined by analysis of frozen samples. The men were on normal diets with no restrictions or control of calcium intake.

Despite prolonged exposure to elevated levels of CO_2 (.72% to .95% with a mean of .85%), no significant respiratory acidosis was documented. Plasma electrolytes were clinically normal and gave no evidence of acidosis during the study or the post-study recovery period. Urinary excretion of calcium, phosphate, sodium, and potassium were within normal limits.

The direct on-board measurement of blood gas and pH values showed little physiological change at present operational levels of CO_2.





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THE TIME COURSE OF ACID-BASE BALANCE WHILE ON FBM PATROL

INTRODUCTION

The production of compensated respiratory acidosis in man and animals when breathing elevated levels of CO_2 is a well known and has been amply demonstrated. [2,3] The studies reported by Schaefer et al, were performed with CO_2 levels up to 1.5%. [1] These studies point out the need for accurate determination of acid-base changes while breathing lower levels of CO_2. Additionally, previous determinations have used data derived from frozen samples, rather than measurements of pH, P_{CO_2}, and P_{O_2}, made at the time of blood collection. [4,5]

This study was designed to document actual, rather than calculated changes in pH, P_{CO_2}, and P_{O_2} from crew members of an FBM submarine during an operational patrol wherein the CO_2 level normally averages less than 1%. The electrolyte determinations were carried out on frozen samples of the same blood to serve as confirmation of acidosis, if found by the direct methods. Also of interest were the changes in urinary calcium and inorganic phosphate excretion demonstrated in acidosis. Therefore, it was planned to monitor calcium and phosphate excretion. [6]

METHODS

Subjects were fifteen healthy volunteer members of an SSBN submarine crew. Fourteen men were between the ages of 23 and 33 years, and one man was 47 years old. All were in good health, and had no history of pulmonary, renal, or skeletal disease. One man, however, was 11 years post-nephrectomy for correction of a congenital defect. All subjects were exposed to the same operational submarine atmosphere. Oxygen, carbon dioxide and carbon monoxide were measured at four hour intervals in three ship compartments and average values were recorded. On a daily basis, the level of CO_2 varied from .72% to .95%, with a mean of .85%. Oxygen concentration was maintained between 19% and 21%. Carbon monoxide was less than 25 p.p.m. No dietary restrictions or measurements were in effect during the study. Drinking water was distilled and no minerals were added. At no time during the data collection was the submarine environment ventilated with outside air.

Samples were collected before submerging and during days 2, 9, 17, 30, 42 and 56 of patrol. Recovery samples were obtained 43 days after returning from patrol. Arterialized capillary samples were obtained by digital puncture of siliconized skin after a hand soak of five minutes in water at a temperature of 55°C. All venous samples were collected in heparinized glass vacuum tubes. After measurements of pH, P_{CO_2} and P_{O_2} were completed, venous samples were immediately centrifuged at 4000 RPM. The plasma was stored at -15° C in capped syringes. The measurements of pH, P_{CO_2} and P_{O_2} were made with an Instrumentation Laboratory Model 113-SL Ultra Micro

pH Blood Gas Analyzer. Blood bicarbonate values were calculated using a standard Nomogram. Plasma sodium, potassium, and chloride, as well as urinary sodium, potassium, calcium, and phosphate were determined using standard clinical laboratory methods. The recovery values of the pH, P_{CO_2} and P_{O_2} were measured on a different instrument of the same model as the instrument used in the on-board measurements. All measurements were corrected for temperature and atmospheric pressure variations.

The urinary excretion of sodium, potassium, and phosphate was monitored by collecting 24-hour urine specimens from four of the men. No control data was collected due to operational limitations. Recovery data was collected and might have been influenced by post patrol dietary changes.

RESULTS

Table I summarizes the changes in acid-base balance measured during the study. Statistical analysis consisted of a computerized T-test. No definite pattern of respiratory acidosis was demonstrated. The pH values remained essentially constant during the study, while recovery values were elevated significantly when compared with control values. The P_{CO_2} values showed a similar pattern with a significant depression in arterialized values during day 17. During the study, all pH and P_{CO_2} values remained within normal limits for healthy males. Blood bicarbonate levels showed significant depression on day 17 in both arterialized and venous sample values. Venous bicarbonate values were significantly depressed on days 42 and 56.

Table II demonstrates essentially constant values of plasma electrolyte concentrations. This would be the expected result if no acidosis were found. Plasma water was also within normal limits.

The excretion of calcium and phosphate tabulated in Table III shows only normal dietary variations and all values fall within accepted normal limits. Accurate statistical analysis was not possible because control data was lacking. It must be noted, however, that due to sample storage space limitations, only four of the fifteen men were monitored for urinary electrolytes and calcium phosphate excretion. Urinary sodium and potassium also were within normal limits.

DISCUSSION

During the period of this study, current operational levels of CO_2 failed to produce a pattern of respiratory acidosis. Instrumentation was reliable, with only an occasional CO_2 membrane failure. This may account for a reduction in the P_{CO_2} and bicarbonate data available from several days, especially day 17. The statistical significance determined for day 17 is therefore suspect due to low N values.

In general, venous samples were technically easier to handle and analyze than the arterialized samples and gave more consistent results. The collection

Table I. Arterialized and Venus Blood Levels of pH, P_{CO_2}, P_{O_2}, $(HC03)^-$

		Control	Day 2	Day 9	Day 17	Day 30	Day 42	Day 56	Rec
(Art)	X	7.459	7.433	7.450	7.458	7.457	7.442	7.421	7.429
	Sem	.010	.007	.006	.010	.005	.006	.007	.006
pH	N	15	14	15	13	15	14	14 *	15 *
(Ven)	X	7.415	7.415	7.403	7.409	7.421	7.418	7.390	7.381
	Sem	.011	.006	.010	.014	.008	.006	.005	.007
pH	N	15	14	15	13	15	14	14	15 *
(Art)	X	36.8	37.4	37.6	32.1	37.3	34.8	37.6	41.3
P_{CO_2}	Sem	.8	1.0	1.4	1.7	1.2	1.0	1.4	.7
mm/Hg	N	14	14	10	7 *	9	8	8	15 *
(Ven)	X	46.4	46.8	46.6	42.9	44.2	42.0	44.3	57.9
P_{CO_2}	Sem	1.3	.9	1.6	1.3	1.2	1.6	1.2	1.6
mm/Hg	N	13	13	14	10	9	11	8	15
(Art)	X	87.6	85.6	86.2	97.7	90.8	103.9	103.3	86.1
P_{O_2}	Sem	2.0	1.8	2.5	2.6	2.2	4.3	3.1	1.9
mm/Hg	N	15	14	15	13 *	15	14 *	14 *	15
(Ven)	X	35.9	36.9	30.1	33.3	33.7	40.4	42.0	40.0
P_{O_2}	Sem	2.7	2.1	2.3	3.8	2.4	3.5	4.0	1.9
mm/Hg	N	14	14	15	13	15	13	13	15
(Art)	X	25.8	24.8	25.8	21.7	25.6	23.5	24.6	26.9
$(HC03)^-$	Sem	.7	.7	.8	.9	1.2	.9	.7	.5
meq/L	N	14	14	10	7 *	10	8	8	15
(Ven)	X	29.8	30.0	28.8	26.5	28.6	26.9	26.5	30.3
$(HC03)^-$	Sem	.9	.7	1.1	.8	1.0	.9	.6	.7
meq/L	N	13	13	12	10 *	10	10 *	8 *	15

*Statistically significant at the 5% level.
Sem — Standard Error of the mean.

Table II. Plasma Electrolytes and H_2O (Mean Values) N = 15

	Control	Day 2	Day 9	Day 17	Day 30	Day 42	Day 56	Rec	Expected Normal
Sodium Meq/L	139.3	141.3	138.7	139.0	137.4	139.1	138.6	139.1	136 - 145
Chloride Meq/L	101.1	101.5	101.9	101.6	101.3	101.4	101.2	99.8	100 - 106
Potassium Meq/L	3.9	3.9	3.7	3.4	3.8	3.8	3.7	4.4	3.5 - 5.0
H_2O%	91.3	90.6	91.2	91.5	91.2	91.0	91.1	91.1	90 - 92

Table III. Twenty-Four Hour Urine Excretion

		Day 2	Day 9	Day 17	Day 30	Day 42	Day 56	Rec	Expected Normal
Sodium Meq/24 hr.	$\bar{X}$	166.5	183.7	174.5	184.0	156.5	234.5	218.0	
	Sem	10.2	10.9	33.3	55.5	25.5	63.2	75.3	130 - 260
	N	4	3	4	3	4	4	4	
Potassium Meq/24 hr	$\bar{X}$	67.3	81.8	78.9	97.9	69.4	82.8	103.9	
	Sem	16.4	26.8	12.8	21.6	15.3	26.4	59.3	25 - 100
	N	4	3	4	3	4	4	4	
Calcium Mg/24 hr.	$\bar{X}$	285.0	146.5	166.0	248.0	151.0	193.3	190.0	
	Sem	60.0	51.7	51.0	82.6	43.7	67.8	13.1	141 - 364
	N	4	3	4	3	4	4	4	
Phosphate Mg/24 hr. (inorganic)	$\bar{X}$	1426.0	1537.0	1247.0	1457.0	1595.0	1784.0	2590.0	
	Sem	479.0	576.0	486.0	628.0	785.0	747.0	981.0	900 - 1300
	N	4	3	4	3	4	4	4	

of blood from fingertip puncture occasionally resulted in air contamination of capillary tubes during measurement. Using ultramicro equipment, air may cause oxygen levels to be abnormally high, and may explain why arterialized samples had slightly higher oxygen tensions on several days. The use of ear lobe puncture for arterialized samples may be adviseable in future work.

All recovery samples were performed on a different instrument and by a different technician than were the onboard values. This may have introduced some small constant error in pH, P_{CO_2} and P_{O_2} data. Slight changes in calibration and individual technique are to be expected.

Plasma electrolyte concentrations remained constant and no chloride changes were seen that were compatible with acidosis. Since only mild changes were demonstrated at 1.5% CO_2 levels, submarines could be operating with a concentration of CO_2 which fails to produce respiratory acidosis. There are several other factors which must be investigated under low levels of atmospheric CO_2. These factors include: (a) individual response to various concentrations of carbon dioxide, and (b) the effect of circadian biological cycles on the overall acid-base changes.

In the past, several attempts have been made to classify men into categories of "responders" and "non-responders" when exposed to elevated levels of CO_2.[7] An initial attempt at separating our volunteers into groups according to CO_2 tolerance has been started at this Laboratory. At the present time, a method for definitive evaluation of each individual is not yet available.

It is well known that cyclic biological functions can cause changes in calcium metabolism and may affect acid-base balance as well. Blood samples were drawn during the work cycle of the individual volunteer. It was not possible to collect samples on a fixed, pre-determined time schedule due to rotation of watches and other operational commitments.

It is concluded that the results of this study would seem to substantiate the adequacy of present standards of atmosphere control. No significant physiological changes were demonstrated under the operational levels of CO_2 maintained on this particular submarine. Calcium and phosphate excretions were determined to be within normal limits with variation due to diet. Accurate dietary control is possible, but difficult to enforce on an operational submarine.

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