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THE PHYSIOLOGICAL EFFECTS OF HIGH CONCENTRATIONS OF CARBON DIOXIDE[1]

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The object of this investigation was a study of the physiological effects of very high concentrations of carbon dioxide on men. By very high concentrations is meant toxic percentages ranging from 5.5 to 12.4 per cent with oxygen varying from 14.4 to 39.7 per cent. The reason for conducting these experiments was the need for more definite and extensive information as to the effects of dangerous concentrations of CO_2 on men in submarines under conditions of enforced submergence following a disaster. While considerable data have accumulated in the literature, the effects of the higher percentages of CO_2 have not been sufficiently determined.

The present study was carried out in conjunction with an investigation of the influence of relatively high oxygen on the noxious effects of high CO_2 in submarines, the results of which appeared in the July, 1930, number of the U. S. Naval Medical Bulletin (1). In those tests, however, very high percentages of CO_2 were not reached, the maximum being only 5.8 per cent.

The Effects of High CO_2 on Animals

It will be understood, unless otherwise stated, that sufficient oxygen was supplied in the various experiments to prevent any deficiency.

Bert (2), in his classic researches in 1878, found that death did not result with small animals in a closed space until CO_2 reached 30 per cent, the oxygen being kept at an ample concentration. Anesthesia was produced at high percentages, the blood pressure being raised and the pulse rate rapid. Life was not endangered by the anesthesia, if under 30 per cent, and recovery was prompt in fresh air.

Friedlander and Herter (3), in 1878–79, reported that rabbits could breath 20 per cent of CO_2 for approximately an hour without any apparent physiological effects except increased cardiac and respiratory activity. Marked depression resulted only after approximately a 24-hour exposure. With 30 per cent of CO_2 signs of toxicity developed rapidly, the animals becoming unconscious with

[1] From the Medical Research Division, Edgewood Arsenal.

a gradual fall of body temperature and finally death. These authors exposed a rabbit to a mixture of 80 per cent CO_2 with 20 per cent O_2, the animal becoming completely narcotized with a rapid drop of body temperature. It lived for one-quarter of an hour in this mixture, and recovered rapidly in pure air.

Benedicenti (4), in 1896, studied the action of high concentrations of CO_2 on mammals, beginning with 10, 12, and 15 per cent. A purely narcotic effect was observed, the respirations being excited only for a short time. With 30 to 35 per cent there was no dyspnea, but narcosis developed in 30 to 45 minutes, with dilation of the pupils and nearly complete abolition of the corneal reflex. The animals survived for a considerable period.

Loewy and Zuntz (5), in 1899, found with animals that the greatest effect on increasing the ventilation of the lungs occurred at 15 per cent CO_2; on exceeding this the breathing volume was reduced by the onset of narcosis. When below 15 per cent CO_2 the breathing volume was increased and diminished in a definite ratio as the CO_2 percentage was raised or lowered in the pulmonary alveoli.

On the other hand, Plavec (6), in 1900, reported that with animals an increasing breathing volume occurred up to 30 per cent of carbon dioxide but began to decrease with the onset of narcosis. With only 5 per cent of CO_2, dyspnea was distinct; with 10 per cent, a marked rise of blood pressure and slowing of the pulse resulted.

Nares (7) showed that rabbits had far greater resistance to CO_2 than dogs, which may explain certain divergent results of earlier workers. He reported that rabbits could survive the inhalation of 80 per cent of CO_2 with 20 per cent of O_2 for a relatively long time, and recovered quickly in normal air. The respirations became greatly deepened in the course of the first minute with the expiratory phase lengthened so that the number of respirations were reduced to half in the first five minutes. An excess of CO_2 induced a marked rise of blood pressure, but it finally dropped nearly to normal under exposure to a still heavier concentration.

Hill and Flack (8), in 1908, studied the circulatory effects of very high concentrations of CO_2 on cats and dogs. The rise of blood pressure was most marked between 10 and 25 per cent. At first the hyperpnea increased with the rising concentration of CO_2 until convulsive breathing resulted; especially marked in percentages from 15 to 30. Above 30 to 35 per cent the depressant and narcotic effects become more and more marked. With very high concentrations the excitatory effect was transitory, being rapidly followed by respiratory depression.

With moderate doses the blood pressure was raised and the vagus and vasomotor centers excited. With higher concentrations the

blood pressure fell owing to the depressant effect upon the heart muscle, the heart easily recovering from this effect by pure air and massage. They concluded that at 10 to 25 per cent of CO_2 the vagus and vasomotor centers were stimulated; above 25 per cent the blood pressure falling and depressant effects ensuing, narcosis finally being established.

Sollman (9) concluded from a review of the literature that as high as 20 per cent of CO_2 is not fatal in an hour to animals, and probably not to man. With 25 to 30 per cent the stimulant phenomena pass into depression with diminished respiration, fall of blood pressure, coma, anesthesia, and gradual death after several hours. There is a loss of reflexes but usually no convulsions.

The Effects of High CO_2 on Men

Here again it will be understood that the supply of oxygen was ample unless otherwise indicated.

Haldane and Smith (10), in 1892, found on breathing air containing 18.6 per cent CO_2, that profound dyspnea resulted in 1 to 2 minutes, attended by extreme discomfort, throbbing in the head, mental dullness, and cyanosis. When air was rebreathed from a large bag up to the limit of endurance, they had to stop at approximately 10 per cent of CO_2. The distress produced was virtually no different whether O_2 was added or not. If more than 10 per cent was breathed, the effect of the mixture was to produce stupefaction. This effect on animals was already well known even at that time.

Haldane (11) has reported the effects of excess of CO_2 in producing ataxia, stupefaction, and loss of consciousness in connection with the wearing of mine rescue and diving apparatus. The effects were readily produced in the presence of a large excess of O_2, and were therefore entirely independent of the effects of oxygen deficiency. He also stresses the narcotic effect of a large excess of CO_2 in quieting down the respiration, which had led many previous observers to overlook almost entirely the effects of lower percentages in stimulating the breathing.

Hill and Flack (ibid.) reported that when excess of oxygen was rebreathed by a man from a closed space, the CO_2 percentage rose to 10 per cent and slightly over before the breaking point occurred.

Speck (12), in 1892, reported that on inhaling 11.5 per cent CO_2, even the first breath was unpleasant. Disagreeable sensations immediately followed, with dimness of vision quickly developing. On increasing the CO_2 in the inspired air from 0.95 to 11.5 per cent, a nearly fivefold increase in total lung ventilation resulted, the respiratory rate being trebled and the depth nearly doubled. At 7 per cent the CO_2 of the inhaled air equaled that of the exhaled air.

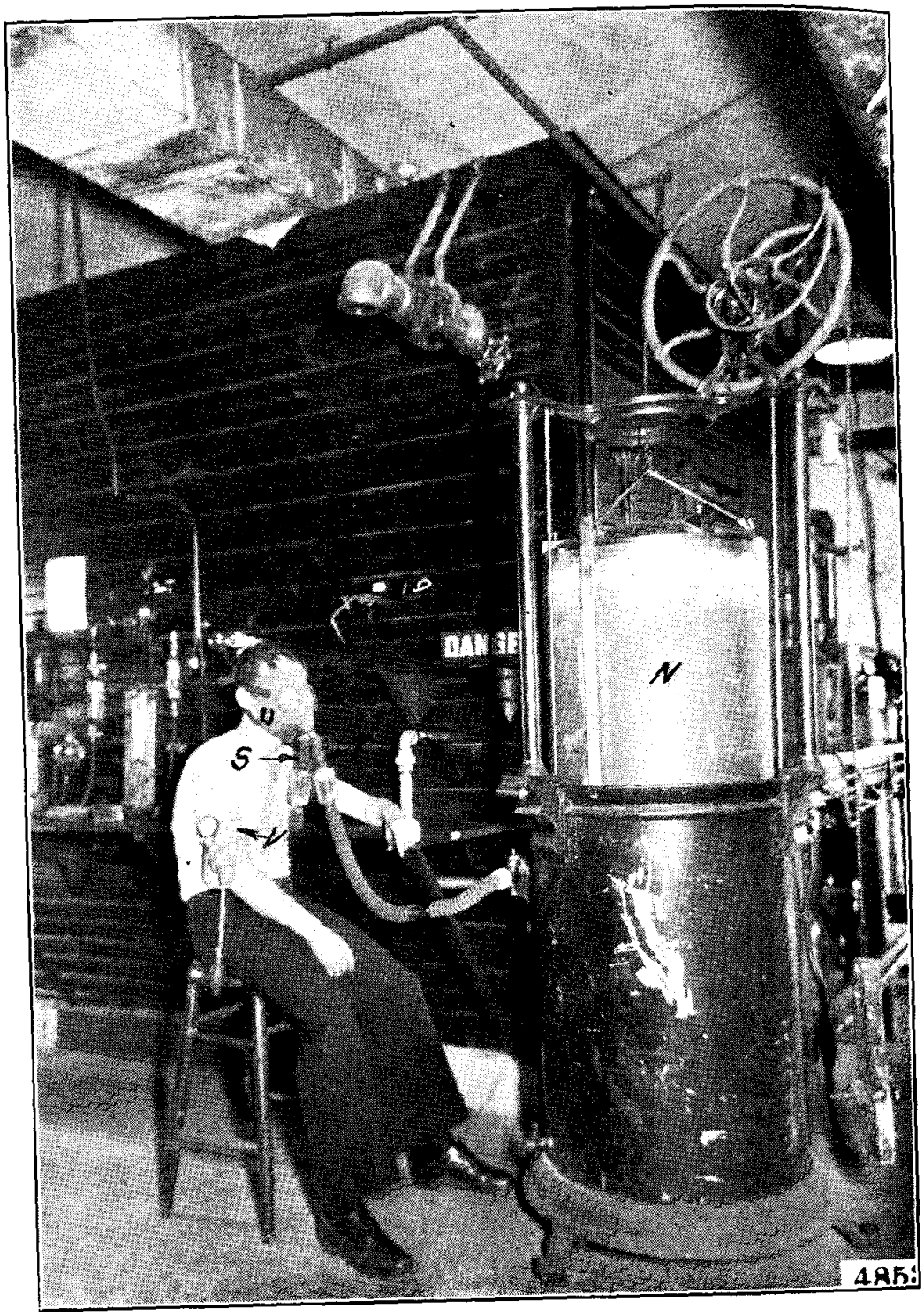
Hill and Flack (8), in 1908, studied the effect of very high percentages of CO_2 on a man. He was entirely unable to even inhale a mixture of 38.2 per cent CO_2 and 9.1 per cent of O_2. He could, however, inhale without spasm of the glottis 15.3 per cent of CO_2 with 14.5 per cent of O_2 for a few seconds, although extremely severe dyspnea resulted. Air containing 20 per cent of CO_2 brought about immediate partial closure of the glottis with a peculiar whooping sound on inspiration.

Haldane, Meakins, and Priestley (13), in 1919, stated that a moderate excess of CO_2, which they regarded as 6 per cent, caused a considerable and persistent increase in the depth and a relatively slight rise in the frequency of respiration. The maximum increase in lung ventilation was produced when excess of CO_2 and deficiency of O_2 were both present.

Davies, Haldane, and Kennaway (14), in 1920, reported the effects of exposing a man in a respiration chamber to CO_2 at percentages of 5.2 to 6.4 per cent for periods of two hours. Immediately after entering the chamber the respirations gradually increased, in a few seconds reaching the maximum depth with a frequency between 22 and 30 and continued so throughout. No marked rise of pulse rate was observed. In one experiment a slight headache developed after eight minutes' exposure in the chamber, lasting throughout. In two other tests no headache occurred in the chamber, but headache of moderate severity with sudden onset and lasting several hours was observed immediately after emerging. There were no other notable after effects from these exposures to CO_2.

Sollman (9), from a review of the literature, pointed out that high CO_2 first produces strong medullary stimulation and in very high concentrations, narcosis, 8½ per cent of CO_2 in man inducing almost immediate dyspnea, rise of blood pressure, and congestion, the situation becoming insupportable in 15 to 20 minutes, but clearing up promptly in fresh air. The medullary centers are first stimulated by excess of CO_2 in the order of respiratory, then vasomotor and then vagus centers to be followed by depression of these centers. An increase of CO_2 up to a certain point causes a marked rise in blood pressure, mainly by stimulation of the vagus center.

Schneider and Truesdell (15), in 1922, determined the normal curves of the circulatory and respiratory responses to a gradual increase of CO_2 in the inspired air. Two groups of experiments were carried out, in one the oxygen being maintained at 30 per cent and in the other the oxygen decreasing as the CO_2 accumulated in the inspired air. The average maximum of CO_2 reached was 7.3 per cent. The pulse rate was accelerated, the final averaging 11.6 and 15.5 in the two groups, respectively, with great variations between indi-



U—FACE PIECE OF GAS MASK.
S—CONNECTION OF GAS MASK TO INTERIOR OF CHAMBER.
T—CONNECTION OF GAS MASK TO SPIROMETER.
N—SPIROMETER.
V—BLOOD PRESSURE APPARATUS.

vidual subjects, and usually first noted at 5 per cent CO_2. The systolic blood pressure began to rise in the majority of subjects at 2 to 4 per cent CO_2, the average final increase being approximately 14.7 millimeters in one group of the tests. The average final increase in diastolic pressure was 7.7 and 12.3 millimeters. The minute volume of breathing rose 31.6 per cent at 1 per cent, and up to 511.9 per cent at 7 per cent in one group of tests; in the other the corresponding figures were 23.9 and 516.9 per cent.

Goldstein and Du Bois (16), in 1927, reported a study of the effect of different concentrations of CO_2 on the human circulation. One subject only was employed in their experiments. He rebreathed from a Douglas bag containing approximately 50 liters of the gas mixture. The maximum initial CO_2 was 3 per cent and the maximum final 9.2 per cent; the observations being made at certain intermediate concentrations. It was found that the increase in systolic blood pressure, while progressive, actually occurred in three definite stages. The duration of each stage could be regulated by changes in the CO_2 concentration of the rebreathed mixture. The systolic pressure, the diastolic pressure, and the heart rate showed a characteristic relationship to the changes in the pulmonary alveolar CO_2 concentration.

EXPERIMENTAL

Procedures

Seven male subjects were used, all of submarine personnel, the ages varying from 19 to 30.

The gas mixtures were set up in a respiration chamber which has been described in a previous article by the writer (1). The analyses for CO_2 and O_2 were made with the Henderson-Orsatt gas analysis apparatus. Carbon dioxide was supplied to the chamber from a cylinder, being passed successively through a wet meter and a flometer; oxygen by the same technique when relatively high concentrations were desired; nitrogen similarly as a diluent when low percentages of oxygen were desired in conjunction with high CO_2.

The subjects breathed the air mixtures by the method illustrated in the accompanying photograph.

A gas mask of the standard Navy type was adjusted to the subject. The mask was connected to rubber inspiratory and expiratory valves contained in glass bulbs with glass connecting pieces as shown in the photograph. The inspiratory valve was connected by corrugated hose to a steel tube piercing the wall of the respiration chamber; the expiratory valve to a balanced spirometer of 150 liters capacity. The subjects, therefore, inhaled from the chamber and exhaled into the spirometer. Peripheral resistance to breathing was virtually elimi-

nated as the connecting tubing of the assembly was approximately 1 inch in inside diameter.

The arterial blood pressures were read by the auscultatory method, using a Tycos aneroid instrument which had been checked against a mercury apparatus. The blood pressures were read twice at definite intervals during the period of exposure varying from one-half to five minutes depending on the length of the experiment. The maximum reading only is recorded in the tables. The blood pressure was also read five minutes after the end of the test.

The pulse rate was counted at the radial artery and the respiratory rate by observation of the average number of oscillations of the spirometer per minute during the reading of the minute-volume of expiration.

The minute-volume of expiration was determined from the final reading of the spirometer, the subject exhaling into the instrument during the entire experimental period except for the intervals required to empty it in order to start a second reading. The total minute-expiration volume was then computed by dividing the total volume by the number of minutes as recorded by the stop watch.

Normals for pulse rate and blood pressure were read in each test immediately prior to the experiment. The normal minute-expiration volume was not determined at the time for the reason that adequate normal data had already been collected in connection with previous tests (1), being based on the averages of three to five tests; each being taken at intervals of not less than 24 hours.

Discussion of the Data

The concentrations of CO_2 were so excessive as to be intolerable within a comparatively short time. It will be noted, however, that the periods of exposure to the same concentration showed considerable variation. This was largely due to individual differences in tolerance toward the mixtures of gas breathed. The periods of exposure recorded do not represent the maximum record of endurance under the conditions but they do indicate the time interval beyond which serious symptoms were threatened.

It will be noted that there are seven groups of tests presented in Table I arranged in the order of ascending percentages of CO_2, i. e., from 5.5 to 12.4 per cent, inclusive. The test at 5.5 per cent CO_2 was carried out for purposes of comparison, this percentage not being considered as in the high category.

Certain of the table headings require brief comment. The "Minute-Expiration Volume Rise per cent" indicates the percentage increase in liters per minute as compared with the average reading when breathing atmospheric air. Under "Pulse Rate" the reading taken just prior to the test is recorded under "B"; that taken at

approximately the midpoint of the test under "D." Under "Blood Pressure," "B" indicates the reading just before, "D" the maximum systolic during, and "A" that taken five minutes subsequent to the test. The "Systolic Rise per cent" and "Diastolic Rise per cent" record the percentage increase over the normals taken just prior to the experiments.

A summary of the physiological data is assembled in Table II. It will be noted that the maximum and minimum data with the average for all subjects are recorded under the respective table headings.

TABLE I

Subject	Duration, minutes	Respiratory rate	Pulse rate		Minute expiration volume liters per minute	Minute expiration volume rise, per cent	Blood pressure			Systolic rise, per cent	Diastolic rise, per cent
			B	D			B	D	A		
CO_2: 5.5 per cent; O_2: 14.5 per cent											
B	5	16	100	103	30	173					
H	5	12	80	90	23	109					
K	5	27	74	86	43	291					
CO_2: 5.9 per cent; O_2: 40.6 per cent											
B	5	16			26	136					
H	5	16			32	200					
I	5	27			27	125					
J	5	14			37	185					
K	5	19			33	200					
L	5	27			46	320					
S	5	29			29	123					
CO_2: 6.0 per cent; O_2: 21.1 per cent											
B	20½	18	77	82	29	164	108	118	108	9	0
							82	82	78		
H	22	13	77	84	26	136	116	120	112	3	11
							70	78	70		
K	21	28	85	96	45	309	122	140	118	15	12
							82	92	84		
CO_2: 7.5 per cent; O_2: 16.0 per cent											
B	5	21	90	102	43	291	102	132		29	14
							72	82			
H	6	16	77	86	28	154	108	142	106	31	34
							64	86	66		
I	3½	25	70	80	36	200	108	128	103	18	24
							66	82	63		
J	3¼	18	70	80	54	315	110	142	112	29	15
							80	92	72		
K	4½	22	80	96	39	254	119	142		19	17
							72	84			
S	5	30	73	76	32	137	113	132	108	17	19
							67	80	72		

TABLE I—Continued

CO_2: 8.8 per cent; O_2: 38.7 per cent

Subject	Duration, minutes	Respiratory rate	Pulse rate B	Pulse rate D	Minute expiration volume liters per minute	Minute expiration volume rise, per cent	Blood pressure B	Blood pressure D	Blood pressure A	Systolic rise, per cent	Diastolic rise, per cent
H	10	17	71	78	33	200	110	144	98	31	11
							74	84	63		
I	8	27	76	102	34	183	112	128	103	14	8
							74	80	66		
J	7	18	70	85	42	223	115	142	115	23	12
							82	98	82		
K	7	24	85	94	44	300	104	128	98	23	12
							68	76	76		
L	9	24	72	81	37	236	102	122	106	19	20
							68	82	72		
CO_2: 10.4 per cent; O_2: 14.4 per cent											
B	½	22	78	102	39	254	108	142	108	31	30
							72	94	68		
H	2¼	19	75	87	36	227	112	160	110	34	41
							60	104	67		
I	2	35	74	95	51	300	114	144	122	26	37
							54	74	60		
J	1½	20	77	90	66	407	120	172	120	43	35
							78	105	82		
K	1	19	74	119	39	254	122	168	118	38	36
							72	98	74		
L	1 3/10	20	76	83	35	218	108	138	110	28	44
							66	95	72		
S	2	33	72	81	53	293	118	156	120	32	45
							66	96	68		
CO_2: 12.4 per cent; O_2: 39.7 per cent											
B	1	18	70	92	30	172	112	200	-------	78	30
							72	94	-------		
H	2	18	79	103	23	109	113	137	-------	21	12
							69	77	-------		
I	1	19	74	84	19	58	109	134	-------	23	57
							51	80	-------		
J	¾	17	83	94	35	170	116	203	-------	75	29
							76	98	-------		
K	1	21	92	98	32	190	100	197	-------	97	18
							67	79	-------		
L	1	22	74	81	38	245	112	173	-------	54	24
							70	87	-------		
S	1	27	76	88	31	129	109	148	-------	36	21
							70	85	-------		

TABLE II.—*Summary of physiological data*

Number subjects	CO_2 per cent	O_2 per cent	Respiratory rate rise		Pulse rate rise		Minute expiration volume rise, per cent		Systolic rise, per cent		Diastolic rise, per cent	
			Average		*Average*		*Average*		*Average*		*Average*	
3	5.5	14.5	[1]		3–12	8	109–291	191	-------		-------	
7	5.9	40.6	[1]		-------		123–320	184	-------		-------	
3	6.0	21.1	0–12	4	5–11	7	136–309	203	3–15	9	0–12	7
6	7.5	16.0	0–14	6	3–16	10	137–315	225	17–31	24	14–34	20
5	8.8	38.7	1–11	4	7–26	13	183–300	228	14–31	22	8–20	13
7	10.4	14.4	3–19	8	7–45	19	218–407	279	26–43	33	30–45	38
7	12.4	39.7	1–11	4	7–24	13	58–245	153	21–97	55	12–57	27

[1] Variable.

OBJECTIVE SYMPTOMS

(*a*) *Respiratory rate.*—The normal respiratory rates were not actually determined, but an average figure of 16 per minute for comparison was assumed.

With CO_2 at 5.5, 5.9, and 6 per cent, with corresponding oxygen at 14.5, 40.6, and 21.1 per cent, there was a tendency to a slight rise in the majority of the subjects, although an apparent actual slowing occurred in certain instances. With CO_2 at 7.5 per cent the effect varied from 0 to plus 14 with an average rise of 6. At the still higher figure of 8.8 per cent of CO_2, the increase varied from 1 to 11, averaging at 4; while at 10.4 per cent the average was 8. At 12.4 per cent of CO_2 the rate appeared to be somewhat slower, the rise ranging from 1 to 11 with an average of 4. The conclusion is drawn that at concentrations of CO_2 varying from 5.5 to 12.4 per cent there is a tendency to an increase in the respiratory rate, but it is comparatively slight.

(*b*) *Pulse rate.*—At 5.5 per cent of CO_2 there was a rise of pulse rate from 3 to 12 with an average of 8. The average increases at 6, 7.5, 8.8, and 10.4 per cent were 7, 10, 13, and 19, respectively. In general, the rise in pulse rate, while variable, was moderate with a tendency to increasing acceleration up to and including 10.4 per cent of CO_2. The pulse rate increase at 12.4 per cent CO_2 varied from 7 to 24 with an average of 13, there being no tendency to a rise above the trend of the data at 10.4 per cent CO_2. Individual differences in the rise for all groups were marked.

(*c*) *Minute-expiration volume.*—The average increases at 5.5, 5.9, and 6 per cent CO_2 were 191, 184, and 203 per cent, respectively, the expiration volume being practically doubled at 6 per cent CO_2. There were wide individual variations, i. e., 136 to 309 per cent at 6 per cent, 109 to 291 per cent at 5.5 per cent, and 123 to 320 per cent at 5.9 per cent.

The average respective increases at 7.5, 8.8, and 10.4 per cent CO_2 were 225, 228, and 279 per cent. The corresponding data at 5.5, 5.9, and 6 per cent were 191, 184, and 203 per cent. The trend was for this value to rise with an increasing CO_2, but even from 6 to 10.4 per cent the actual average increase was only 37.4 per cent. The difference between 8.8 and 10.4 per cent CO_2 was negligible, i. e., less than 10 per cent. Apparently the lung ventilation was not materially increased above 7.5 per cent. The average was practically tripled at 6 per cent and only raised 24 per cent above that figure at 10.4 per cent CO_2.

At 12.4 per cent CO_2 there was a definite fall in the expiration value; the percentage increase above normal varying from 58 to 235

per cent with an average of only 153 per cent. It will be noted that the data are even distinctly lower than at 5.5 per cent. In other words, the actual ventilation of the lungs decreased strikingly when CO_2 rose above 10.4 per cent. This was in all probability a direct toxic effect of the high CO_2 concentration.

(*d*) *Blood pressure: Systolic.*—The blood pressure was not taken in the tests at 5.5 and 5.9 per cent CO_2. At 6 per cent the percentage rise varied from 3 to 15 per cent, with an average of 9 per cent. At 7.5, 8.8, and 10.4 per cent the respective average increases were 24, 22, and 33 per cent. The range of individual variations was considerable—i. e., from 17 to 31 at 7.5 per cent, 14 to 31 at 8.8 per cent, but at 12.4 per cent there resulted a very marked rise, ranging from 21 to 97 per cent and averaging at 55 per cent.

The maximum systolic readings at 12.4 per cent were 203, 200, 197, and 173 for four subjects. On the other hand, the respective maximum readings for the three remaining subjects were only 148, 134, and 137. These contrasting data bring out the wide range of response in blood pressure obtaining between different subjects. Marked individual fluctuations were also observed at lower concentrations of CO_2.

(*e*) *Blood pressure: Diastolic.*—There was a rise of diastolic blood pressure in all groups of tests in which this response was observed. At 6 per cent CO_2 the increase varied from 0 to 12 per cent and averaged 7 per cent. The rise was much greater at 7.5 per cent CO_2, varying from 14 to 34 per cent and averaging 20 per cent. The increase was somewhat less at 8.8 per cent CO_2, averaging only 13 per cent, but showed a marked rise of 38 per cent at 10.4 per cent CO_2. Up to this point the diastolic tended roughly to increase with the systolic blood pressure. At 12.4 per cent CO_2, however, the average diastolic rise was lowered to 27 per cent, as against a decided average increase of the systolic pressure of 55 per cent.

The maximum reading of the diastolic pressure for all tests was 105 at 10.4 per cent CO_2 and the minimum in that group was 74. The maximum figure at 12.4 per cent CO_2 was 98, the minimum 77. The corresponding results at 8.8 per cent CO_2 were 98 and 76. Individual variations therefore were conspicuous.

The data for both systolic and diastolic blood pressure had fallen to practically normal at all concentrations of CO_2 when taken five minutes after the end of the period of exposure.

Subjective Symptoms

Periods of exposure.—The period at 6 per cent CO_2 varied from 20½ to 22 minutes, which could have been extended. Although considerable discomfort resulted toward the end, the situation was not intolerable. At 7.5 per cent CO_2 the period ranged from 3½ to 6

minutes. The symptoms were more urgent, but here again the limit of endurance was not reached. For this reason the periods of exposure at 8.8 per cent CO_2 were lengthened to a point much nearer the intolerable limit. Naturally with human subjects it was essential to be on guard against dangerous symptoms. At 10.4 per cent CO_2 the maximum period was 2¼ and at 12.4 per cent CO_2, 2 minutes. It was not considered advisable to exceed these limits with such very high concentrations, in view of the effect on the morale of the subjects.

The subjective symptoms observed during exposure were as follows: Panting and dyspnea almost immediate, the respiratory efforts resembling the effect of tremendous physical exertion with the sensation that inspiration was beginning before expiration was completed: dizziness, feeling of fullness in the head, sensation of flushing and actual sweating of the face; drowsiness tending to actual stupor, sense of impending collapse, irritation of the throat, and a slight choking sensation.

On removing the mask, the face was distinctly cyanosed in certain cases and the expression dazed. The condition tended to be semi-stuporous for a fraction of a minute afterwards. Two of the subjects who were Hospital Corps men described the stuporous sensation during the test as similar to the incipient effect of a general anesthetic. They felt that they would have lost consciousness within a few minutes if the time of the tests with the two highest concentrations of CO_2 had been extended. Subject J actually collapsed at 12.4 per cent of CO_2, but regained complete consciousness in approximately one-half minute after removing the mask, with no subsequent symptoms except a slight headache. It was not considered advisable to continue the tests at 10.4 and 12.4 per cent beyond a minute or two on account of the danger of collapse. None of the subjects experienced nausea or throbbing of the temples at any time. It is not believed that any of the subjects could have withstood 10 per cent of CO_2 for longer than 10 minutes without complete stupefaction.

The subsequent symptoms were comparatively mild. Headache, although not present in all, was the most pronounced, but not beyond 30 minutes. Drowsiness, or a dazed condition, continued for a few minutes in certain subjects, but general weakness was not complained of.

There were marked individual variations in the number and severity of the subjective symptoms between different subjects under similar conditions. Thus headache resulted in some, but not in other subjects; dyspnea varied in severity; depression and drowsiness were more marked with certain individuals; the degree of dizziness varied. One subject would report that the limit of endurance had been nearly

reached; another that he could have held on under the conditions for several minutes longer. Subject H was remarkably resistant in contrast to the other subjects and was outstanding in this respect in all tests. The degree of dyspnea and depression, particularly, were strikingly less.

The influence of oxygen.—The concentration of oxygen was varied considerably in certain of the tests. The question arises whether this factor had any definitive influence in ameliorating the objective or subjective symptoms induced by the large excess of CO_2. It will be noted in Table II that two tests were carried out at practically 6 per cent CO_2 with the oxygen 21.1 per cent in one and 40.6 per cent in the other. The minute-expiration volume and the subjective symptoms showed no marked differences in the two tests.

Another comparison was afforded between CO_2 at 7.5 per cent with 16 per cent O_2 and at 8.8 per cent with 38.7 per cent O_2. The objective signs were distinctly greater at 8.8 per cent CO_2 and the subjective symptoms more intense, despite the association with high oxygen. Still another comparison was brought out between CO_2 at 10.4 per cent with 14.4 per cent O_2 and at 12.4 per cent with 39.7 O_2. There was a large increase in the subjective effects and in the systolic blood pressure at 12.4 per cent CO_2, although associated with high oxygen. The trend of these data indicated that high oxygen as compared with normal or moderate low oxygen did not minimize the physiological effects of excessive concentrations of CO_2.

Summary

1. The subjective and objective effects of toxic concentrations of CO_2 on men were studied; the percentages varying from 5.5 to 12.4 per cent with oxygen ranging from 14.4 to 39.7 per cent.

2. The concentrations of CO_2 were so excessive as to be tolerated for only a comparatively short time. The periods of exposure did not represent the extreme limit of endurance but a stage was reached beyond which serious symptoms were impending. The maximum period of exposure was 22 minutes at 6 per cent and the minimum one-half minute at 10.4 per cent CO_2.

3. The respiratory rate per minute showed a tendency to a slight increase above normal, the average rise being only 8 at 10.4 per cent CO_2. The average increase at 12.4 per cent CO_2 was negligible, reaching only 4.

4. The pulse rate per minute was accelerated in moderate degree, the average rise varying from 7 at 6 per cent CO_2 to 19 at 10.4 per cent. It was 13 at 12.4 per cent.

5. The systolic blood pressure always increased and rose with ascending CO_2 concentration. The maximum increase at 6 per cent

CO_2 was 18 millimeters, the minimum 4 millimeters; the corresponding data at 10.4 per cent were 52 and 30 millimeters; at 12.4 per cent, 97 and 24 millimeters. The average percentage rise was 55 per cent at 12.4 per cent CO_2, 33 per cent at 10.4 per cent, and 24 per cent at 7.5 per cent CO_2.

6. The diastolic blood pressure showed in general a trend similar to that of the systolic pressure. The maximum increase at 6 per cent CO_2 was 10 millimeters, the minimum 0 per cent; the corresponding data at 10.4 per cent were 34 and 20 millimeters; at 12.4 per cent, 29 and 8 millimeters, being less than at 10.4 per cent. The average percentage rise was 27 at 12.4 per cent CO_2, 38 at 10.4 per cent, and 20 at 7.5 per cent.

7. The average minute-expiration volume per minute increased as follows: 203 per cent at 6 per cent CO_2, 225 per cent at 7.5 per cent, 228 per cent at 8.8 per cent, 279 per cent at 10.4 per cent, and only 153 per cent at 12.4 per cent CO_2. The last-named result is of particular interest as it indicates a fall in the lung ventilation at this concentration of CO_2 whereas there was a rising increase up to and including 10.4 per cent CO_2. There were wide individual differences between subjects as was observed in the other physiological responses.

8. The subjective symptoms were as follows: Marked dyspnea resembling the effect of extreme physical exertion; dizziness; flushing and sweating of the face; feeling of stupefaction and an apprehension of impending collapse. The after effects were practically limited to moderately severe headache but not persisting beyond 30 minutes. There was marked individual variation in the severity of the symptoms, certain subjects showing much less intolerance to high concentrations of CO_2 than others. It is not believed that any of the subjects could have withstood 10 per cent CO_2 for longer than 10 minutes without losing consciousness.

9. There was no evidence that high oxygen alleviated the toxic effects of the excessively high concentrations of CO_2 employed in these experiments.

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SOME THOUGHTS FOR THE FUTURE[1]

By K. C. MELHORN, Captain, Medical Corps, United States Navy

MR. PRESIDENT, FELLOW MEMBERS OF THE SOCIETY, AND THEIR GUESTS:

In this, the last time that I shall have the privilege of appearing on the program of the society, I will ask your indulgence for a few moments in talking frankly regarding the future of your public-health service as I see it. If I say some things that are unpleasant or perhaps disagreeable, they are mentioned only because they should be and because we are not a group of "yes men" always saying nice things to please. God help you all if this society ever permits its meetings to degenerate into such a state of affairs that members hesitate to frankly and fully voice their opinions.

How true the saying: "Where there is no vision the people perish." If there ever was a time when broad vision is required in Haiti's public health service it is now—daily and hourly—in every unit where the comfort and good will of people are properly considered. Executives and their staffs who lack imagination can not appreciate mental attitudes. In no phase of public-health work can we afford to be complacent. The policy of a powerful organization is definitely concerned with the winning and holding of the confidence of the people and, before that can be done, it must sell itself to the public. People must be made to feel that on coming into our hospitals and meeting members of the staff that they are coming into the professional homes of our doctors and nurses.

As stated in a recent publication: "Hospitality in a hospital should begin at the front door. The courtesy and the cordiality one receives with his first greetings after admission, and during his stay in the hospital are the things that sell the hospital to him and through him to the community. A hospital in bad repute that has a reputation for being cold, unsympathetic, rude, soon loses the confidence of its patients and this will contribute in no small degree to their discomfort as well as retard their recovery. A disgruntled physician or nurse will react adversely on a patient and can easily influence his prejudice against the hospital. These matters are not in any wise inconsistent with good organization, good order, or discipline. As a

[1] Delivered at the fourth annual congress of the Haitian Medical Society, Port au Prince, Haiti, June 5, 1930.

matter of fact, satisfied patients make for good order and progress, because their praise invariably increases the morale of the hospital personnel and good morale is one of the most vital reasons for the success of any business."

All health matters must depend in their final disposition on the will of the people, and this in turn must be the result of a developed intelligence which will sweep aside ignorance and selfishness. Health is purchasable, as so often stated, but not so much in terms of dollars and cents as in the contributions of individual loyalty to the standards proclaimed by our authorities.

You are seeking permanent, not temporary, foundations for the health of Haiti and must seek them candidly and fearlessly. As always, the right will prove to be expedient.

What shall you do, then, to push this great campaign for health to its righteous conclusion? You must clear away with a thorough hand all impediments to success and you must make every adjustment of law that will facilitate the full and free use of your whole capacity and force as a fighting unit.

Two tremendous obstacles stand in your way. They are the weak support of your courts and your lack of social-service work. Regarding the first, we have discussed it on several occasions and shall not renew it here. With respect to the second, how many have ever stopped to think how little has been attempted in Haiti in the field of social service? How feeble has been the response to the call, "Who is my neighbor?" Do you know that in this city of 80,000 people there are but four ladies who, without financial return of any kind, are engaged in real social-service activities, who are doing a magnificent work in a quiet way, who are finding out what are the handicaps to health in their city, where the disease-ridden sections are, and what the practical solution is? When Haiti can enlist 1,000 more such women in the cause of public health you need have no fear for the future. When the group consciousness that has manifested itself so strikingly in Haiti during the past year will direct its attentions to the needs of the public-health service and will actually participate by organized effort in practical welfare work the result of your battle for health will no longer be in doubt.

To succeed, organized effort in the future must be directed not only to the continued support of hospitals, clinics, and sanitation units but the program of medical examination of school children, oral hygiene, and public-health nursing must be firmly established as the supporting framework of the whole structure. If traveling clinics, health centers, and public-health education measures are not developed as strong reserves for your front-line units of hospitals, dispensaries, and rural clinics, you will not succeed. In other words, without these