OBSERVATIONS DURING APNEA IN CONSCIOUS HUMAN SUBJECTS

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FOR THE past four years, one of the authors (L. R.) has been utilizing controlled respiration throughout the entire course of anesthesia. The technique involves production of apnea with succinylcholine (Anectine®) and maintenance of amnesia and analgesia with a 75 per cent–25 per cent mixture of nitrous oxide and oxygen (1). Although clinical results have been most satisfactory, the following project was undertaken in order to measure and record the physiological changes produced by this technique in the absence of surgery. This paper reports the results of these observations.

METHOD

Volunteer subjects were obtained from a group of inmates in the Federal Penitentiary, Atlanta, Georgia. These men ranged in age from 20 to 32 years. Ten were selected who had no physical defects. Three of these were Negroes, the remaining seven were white. All were of average size and weight. Pre-experiment electrocardiograms, chest films and laboratory work were within normal limits.

The experiment was divided into four phases. All procedures and determinations were carried out in as nearly an identical fashion as possible on each subject.

Phase I.—Each subject received 1/150 gr. of atropine at the beginning of this phase. After proper positioning on the fluoroscopy table, a cardiac catheter (no. 12) was placed in the median antecubital vein of the left arm. An 18 gauge needle was placed in a vein in the right arm. Suitable electroencephalographic leads were placed on the scalp and electrocardiographic leads attached to both arms. A Cournand needle was placed in the right femoral artery and a blood pressure cuff and stethoscope located on the right arm. An elastic recording tambour was placed around the chest at the level of the xiphoid process. A standard Forreger Texas model (rotometer) gas machine

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was used, the soda lime being changed prior to each experiment. A Bennett ventilation meter was placed in the inspiratory side of the circle absorber, just distal to the inspiratory valve. An air-water phase strain-gauge was inserted at the face mask on the inspiratory side of the circuit.

Six electroencephalographic leads and the electrocardiographic leads were attached to appropriate channels of an eight channel Grass electroencephalograph. The recording chest tambour was attached to the eighth channel of the machine. This made possible the simultaneous recording of 6 leads of electroencephalography, one lead of electrocardiography (lead 2), and a tracing of respiratory motion. The

TABLE 1

ARTERIAL BLOOD DETERMINATIONS FOR OXYGEN, CARBON DIOXIDE AND *p*H

Case Number		1	2	3	4	5	6	7	8	9	10
O_2 Capacity*		18.96	18.08	19.18	19.04	20.08	19.51	18.26	18.07	21.70	19.65
Phase I	O_2*	18.65	17.22	17.70	18.54	19.65	19.28	16.43	17.57	21.22	19.25
	CO_2*	46.34	45.09	45.55	47.21	45.96	45.13	43.69	46.16	42.37	41.85
	*p*H	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4
Phase II	O_2*	17.84	16.46	17.10	17.97	19.19	18.94	16.31	17.18	20.37	18.14
	CO_2*	46.55	44.91	45.86	47.77	46.65	44.70	45.82	46.84	44.02	43.97
	*p*H	7.4	7.4	7.4	7.5	7.4	7.4	7.4	7.5	7.4	7.5
Phase III	O_2*	20.32	19.20	21.18	21.23	21.84	21.12	19.85	18.62	21.49	19.83
	CO_2*	45.02	36.14	40.07	41.42	40.61	37.45	38.66	41.51	38.61	35.95
	*p*H	7.6	7.5	7.4	7.7	7.7	7.6	7.5	7.5	7.6	7.5
Phase IVA	O_2*	17.98	18.15	18.23	18.67	19.18	19.75	17.45	17.85	19.06	18.81
	CO_2*	41.12	34.90	41.51	39.37	40.12	33.21	29.32	40.88	29.84	37.91
	*p*H	7.7	7.5	7.4	7.7	7.6	7.6	7.5	7.7	7.7	7.5
Phase IVB	O_2*	18.10	15.20	12.20	10.61	15.05	13.06	13.49	14.45	11.96	13.02
	CO_2*	41.93	35.25	42.42	43.61	37.62	39.55	47.67	49.28	42.18	41.54
	*p*H	7.6	7.5	7.4	7.7	7.6	7.5	7.3	7.5	7.6	7.5

* O_2 and CO_2 in volumes per cent (28.0 C). No correction made for physically dissolved oxygen.

cardiac catheter and the strain-gauge from the gas machine were passed through separate Sanborn manometers, and recordings made on a Sanborn duo-cardiograph. Simultaneous pressure tracings were made from the inspiratory circuit of the gas machine and from the right auricle of the heart. Minute volume of respiration was read directly from the Bennett ventilation meter, and blood pressure was recorded by customary auscultation.

During each phase of the experiment, arterial blood was drawn for oxygen and carbon dioxide content and *p*H. The gas analyses were made by the technique of Van Slyke and Neill as modified by Kety (2). *p*H determinations were done on a Beckman G-2 *p*H meter. Serum

sodium and potassium levels were determined on a flame photometer.

Oxygen content and oxygen capacity values in this presentation are not corrected for the presence of physically dissolved oxygen. Oxygen and carbon dioxide tensions are not reported in this paper due to lack of space, but sufficient data is given to permit the calculation of these if desired (table 1).

Phase II.—After baseline values had been established, the face mask was fitted tightly to the subject, and the subject was instructed to breathe as he wished. The anesthetic bag was removed from the gas machine. Soda lime was in the circuit, so this constituted breathing of room air through the mechanics of the gas machine, without the addition of other gasses. This was continued for a period of ten minutes, during which time a continuous and simultaneous recording of the electroencephalogram, electrocardiogram and respiratory movements was made. Blood samples were drawn for repeat determinations at the end of this phase.

Phase III.—During this phase and for the remainder of the experiment, stimulation with a needle to the skin over the calf of the left leg was carried out at three minute intervals. Each time the skin was stimulated, a consecutive number was called. The subject was instructed to remember the last number heard, and the last number on which the pin-prick was sharp. Each subject was also asked to remember the first number called when he awakened. All subjects were thoroughly instructed regarding this procedure prior to the beginning of phase III.

The anesthetic bag was replaced on the gas machine and filled with pure oxygen. A drip of 0.2 per cent succinylcholine in 5 per cent glucose and distilled water was begun at the rate of 100 drops per minute. This rate of flow was continued until complete muscular paralysis occurred. Respirations were first assisted, then controlled. Throughout the succeeding thirty minutes, muscular paralysis was maintained and manual ventilation carried out with pure oxygen. The pattern of ventilation was that of rapid inspiration with a quick release of the bag. Except when altered for the purpose of measuring its effects on atrial pressure, twice the length of time was allowed for expiration as for inspiration and no pressure was maintained during expiration. Minute volume was calculated every three minutes. Arterial blood for *p*H determination was drawn every five minutes. Simultaneous atrial and bag pressure recordings were made at varying intervals during this time, and under varying conditions of manual respiration. At the end of twenty-five minutes, blood samples were drawn for repeat determinations as in the preceding two phases.

Phase IV-A.—Two hundred milligrams of 2 per cent thiamalyl (Surital®) was injected rapidly into the vein in the right arm. Contents of the bag were emptied and one minute after the injection of thiamalyl, the gas flow was changed to three liters of nitrous oxide and

one liter of oxygen. The succinylcholine drip and manual ventilation were continued. At the end of approximately twenty minutes, blood samples were drawn for repeat determinations.

Phase IV-B.—In this phase hypoxia was deliberately produced. In 7 subjects, the concentration of oxygen was reduced to 10 per cent and the respiratory rate slowed. In 3 subjects, no respiratory activity was carried out. The electroencephalogram was watched for changes indicating hypoxia, and observations were made by three different individuals for the appearance of clinical cyanosis. As soon as definite electroencephalographic changes were established, blood samples were drawn. Oxygen was then administered to the subject. The succinylcholine drip was shut off, and the subject allowed to react.

Electroencephalographic, electrocardiographic and respiratory tracings were continuous from the onset of the experiment until the subject was ready to be moved from the table. The bulk of the data thus produced makes it necessary to present these results using illustrations of a typical case.

Results

Oxygen Saturation (fig. 1).—In phase I, all oxygen saturations fell within normal limits. At the end of phase II (the period of breathing through the mechanics of the gas machine) there was a slight decrease in percent saturation of oxygen in all ten cases. During ventilation with oxygen, the oxygen saturation was above 100 per cent (no correction for physically dissolved oxygen). In phase IV-A, with a mixture of nitrous oxide 75 per cent and oxygen 25 per cent, the oxygen saturations remained within normal range, except in one instance. This finding is believed to have been due to a laboratory error, since no positive electroencephalographic evidence appeared. In phase IV-B, where the oxygen content was purposely decreased, values were below 85 per cent of saturation in all instances but one. This patient inadvertently received two or three breaths of oxygen prior to the blood sampling.

Carbon Dioxide Content (fig. 2).—From the normal carbon dioxide contents in phase I, there was a slight increase in carbon dioxide content at the end of phase II in all cases. Within the first ten minutes of phase III, this value had been reduced to below 40 volumes per cent in all subjects except one. This reduction continued throughout phase IV-A. After fifty minutes of ventilation, the carbon dioxide content of all these individuals had been reduced to below 40 volumes per cent. In three instances it was reduced to below 35 volumes per cent. During phase IV-B (hypoxia), the carbon dioxide content rose in two patients reaching higher than normal values.

The average minute volumes are shown for each phase. During the course of normal manual ventilation, the minute volume did not fall below 10,000 cc. in any instance. Ventilation was purposely reduced during phase IV-B.

Hydrogen Ion Concentration (*fig. 3*).—*p*H readings of arterial blood samples in general paralleled the carbon dioxide content of the blood. A decrease in hydrogen ion concentration appeared in 8 subjects after ten minutes of ventilation and after fifteen minutes in all instances. This shift towards the alkaline side was maintained throughout the period of ventilation except in two individuals. During the short period of hypoxia and lowered minute volume, there was a tendency towards a return to normal in all but one case. In two cases (those left apneic) there was a decided return toward the acidotic range.

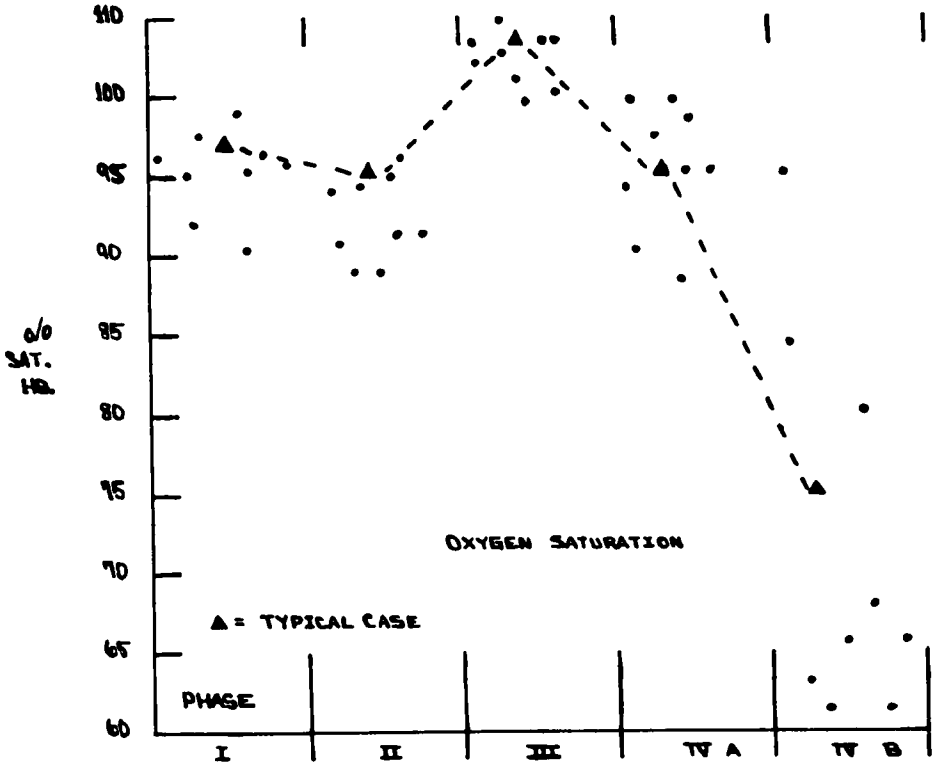

FIG. 1. Oxygen saturation (no correction for physically dissolved oxygen).

Pulse and Blood Pressure.—Ample time was given during phases I and II for the stabilization of the blood pressure and pulse. One minute after the start of the succinylcholine drip, there was an increase in the pulse rate in nine of the ten subjects. This increase varied from ten beats per minute to sixty beats per minute with an average increase of thirty beats per minute. In seven subjects, the pulse returned to its former level within a period of the next five minutes. In two subjects, the pulse remained rapid throughout the course of conscious paralysis. In the 9 subjects who showed an increase in pulse rate, 5 showed a parallel increase in blood pressure. This increase was

marked in only one case in which there was an increase in both the systolic and diastolic pressure of 50 mm. of mercury. All blood pressures returned to normal within three minutes, and remained normal throughout the period of conscious paralysis. Following the injection of thiamalyl, there was an increase in pulse rate in three subjects, lasting less than five minutes. In all subjects there was no further change in pulse rate during the period of sleep. No change in blood pressure was noted following the injection of thiamylal.

During the hypoxic phase, 2 patients showed an increase of 20 beats in pulse rate, the remaining 8 showed no change. One patient showed

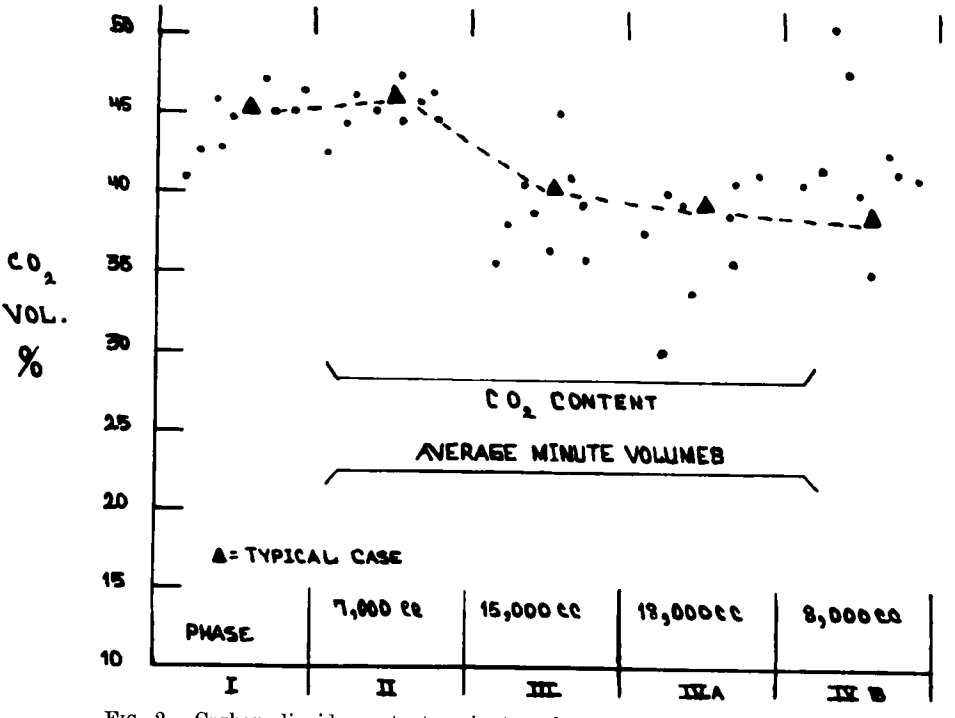

FIG. 2. Carbon dioxide content—minute volume, average for 10 cases.

a 10 mm. of mercury drop in systolic and diastolic blood pressure. The remaining 9 patients showed no change. The sudden change to pure oxygen at the end of the hypoxic phase effected a 10-point lowering of the pulse rate in 3 cases. No change in blood pressure or pulse was seen in the remaining cases.

Sodium and Potassium Levels (table 2).—Throughout the course of this experiment, the sodium and potassium levels remained within normal limits. The apparent variation in values shown in table 2 represents the normal laboratory deviation.

Electrocardiographic Patterns.—The changes in rate have been noted. In one subject, after eight minutes of hypoxia, there was a loss

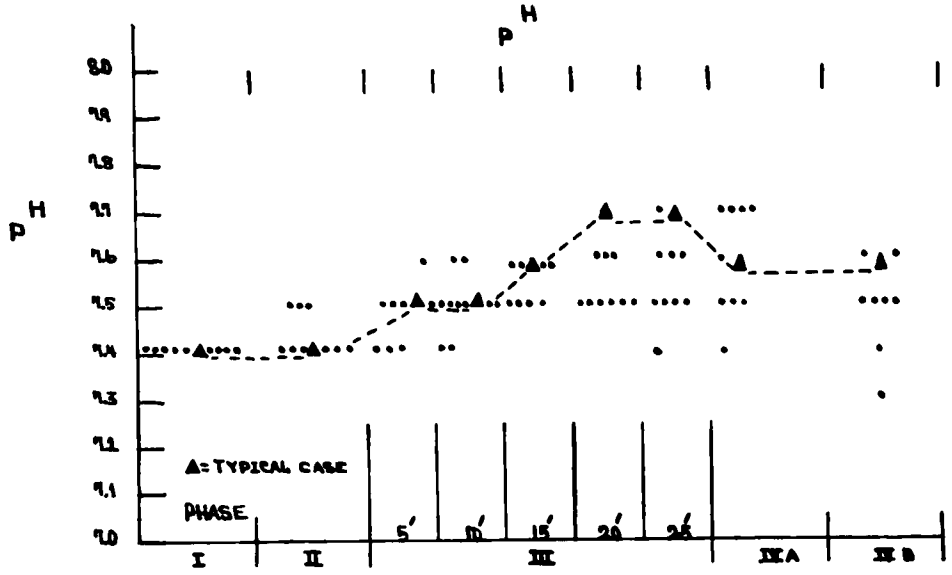

FIG. 3. Hydrogen ion concentration.

of the P wave and an inversion of the T wave. Except for this, there were no other changes in the electrocardiographic pattern throughout the entire course of this work. P-R and QRS intervals remained constant throughout each procedure. Ventricular extrasystoles did occur when attempts were made to enter the right pulmonary artery during cardiac catheterization.

Pain Sensation and Consciousness.—Four subjects were able to recall the number that corresponded to the pin-prick given just prior to the administration of thiamylal. The pin-prick felt sharp to all of these subjects at this time. Six subjects were able to recall the number

TABLE 2

SODIUM AND POTASSIUM VALUES FROM ARTERIAL BLOOD*

	Phase I		Phase II		Phase III		Phase IV-A		Phase IV-B	
	Na	K	Na	K	Na	K	Na	K	Na	K
Case 1	133.8	4.08	125.2	4.10	127.2	4.48	129.8	4.27	—	3.45
Case 2	131.4	3.46	133.4	3.66	—	3.62	122.4	3.43	—	3.19
Case 3	—	3.91	—	3.90	—	4.52	—	4.30	—	4.51
Case 4	—	3.85	—	3.22	—	3.87	—	3.64	—	3.88
Case 5	—	4.23	—	3.56	—	4.62	—	4.23	—	4.47
Case 6	—	4.93	—	3.97	—	4.70	—	4.05	—	4.16
Case 7	130.2	4.21	132.6	4.11	121.6	4.30	—	4.29	124.0	4.16
Case 8	—	4.52	137.8	4.05	125.8	4.52	130.6	4.44	—	4.39
Case 9	132.4	3.77	129.4	3.96	137.2	4.38	158.6	4.47	122.5	4.01
Case 10	131.2	4.05	147.0	3.95	128.0	4.61	125.6	4.48	—	4.68

* All values expressed in mEq.

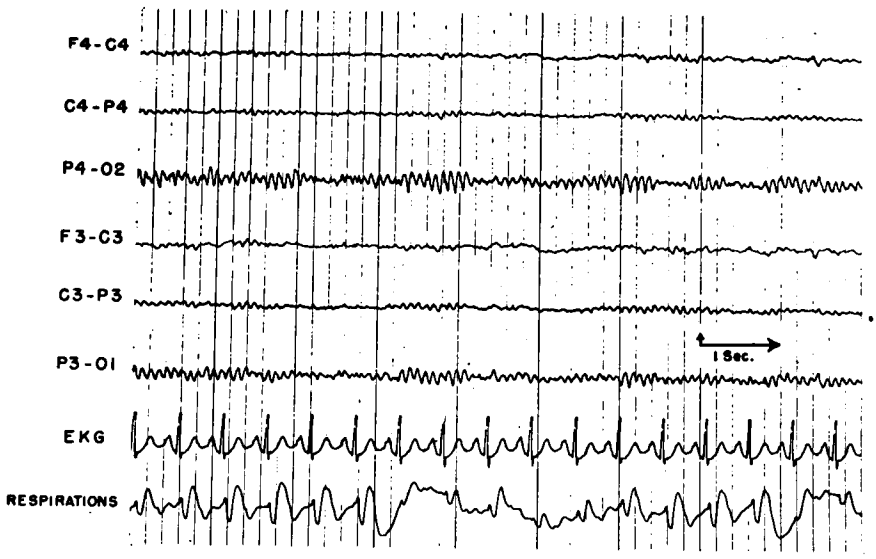

FIG. 4. Phase I: typical recordings. Oxygen—19.65 volumes per cent, carbon dioxide—45.96 volumes per cent, *p*H—7.4. Spontaneous respiration, breathing room air. F-4——C-4 indicate location of electroencephalographic leads.

that corresponded to the pin-prick given from three to six minutes prior to the administration of thiamylal. One individual reported diminution of pain thirteen minutes prior to the administration of thiamylal. Six subjects were awake within seven minutes after the re-

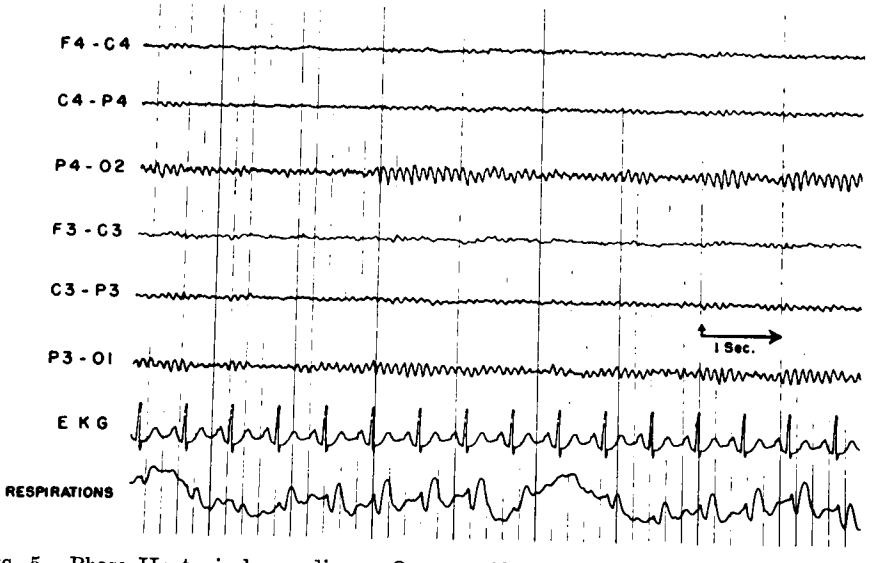

FIG. 5. Phase II: typical recordings. Oxygen—19.19 volumes per cent, carbon dioxide—46.65 volumes per cent, *p*H—7.4 Spontaneous respiration, breathing room air through gas machine. F-4——C-4 indicate location of electroencephalographic leads.

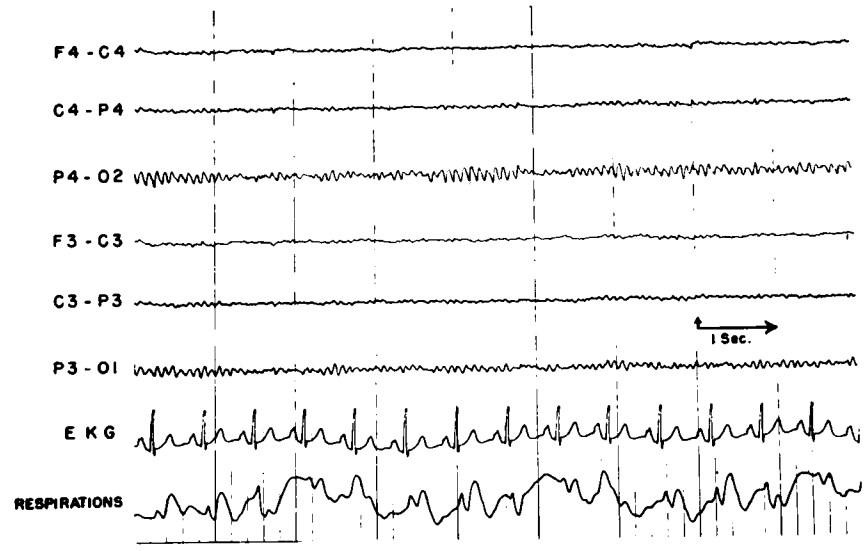

FIG. 6. Phase III: typical recordings. Oxygen—21.84 volumes per cent, carbon dioxide—40.61 volumes per cent, *p*H—7.7. Controlled respiration, with pure oxygen. F-4——C-4 indicate location of electroencephalographic leads.

moval of the face mask and the remaining 4 were awake at ten minutes after the removal of the face mask. All remembered the numbers corresponding to these times. Spontaneous respiration returned in all subjects three minutes after the cessation of the succinylcholine drip.

Eight patients experienced a sore neck for twenty-four hours after the experiment. Two had no soreness at any time. All subjects were

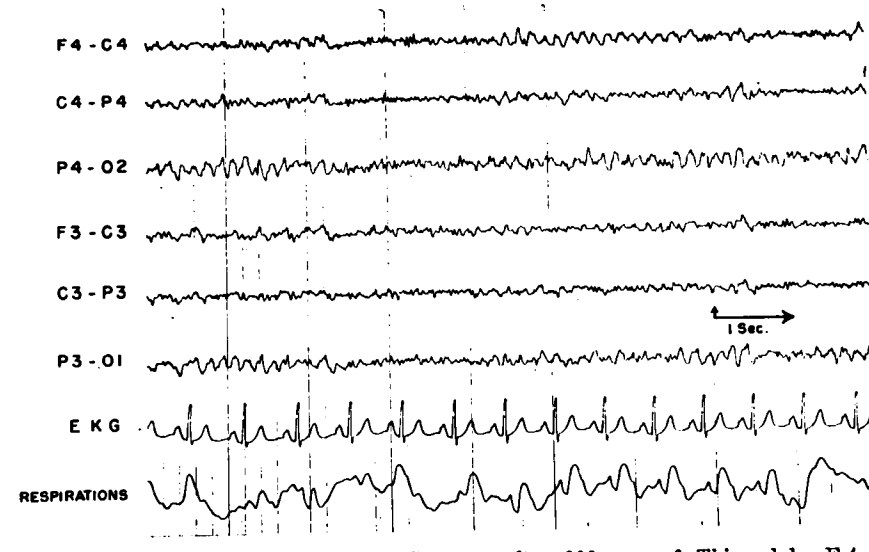

FIG. 7. Phase IV: typical recordings. Changes after 200 mg. of Thiamylal. F-4——C-4 indicate location of electroencephalographic leads.

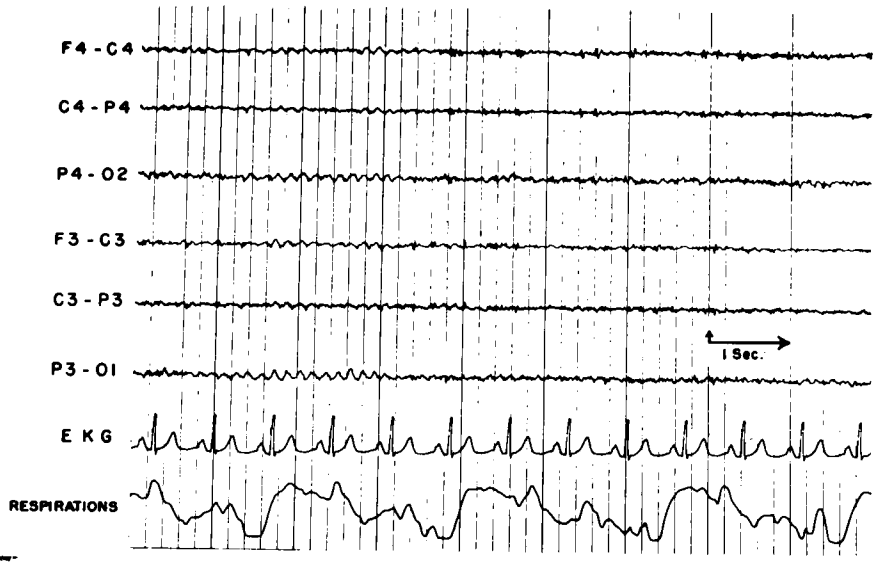

FIG. 8. Phase IV-A: typical recordings. Oxygen—19.18 volumes per cent, carbon dioxide —40.12 volumes per cent, *p*H—7.6. Controlled respiration, 75 per cent nitrous oxide—25 per cent oxygen. F-4——C-4 indicate location of electroencephalographic leads.

aware of fasciculations, but only one experienced pain during this muscular activity. This individual had a cramp in his right calf for five minutes after the start of succinylcholine. All subjects were conscious and could remember clearly the details of this period of paralysis.

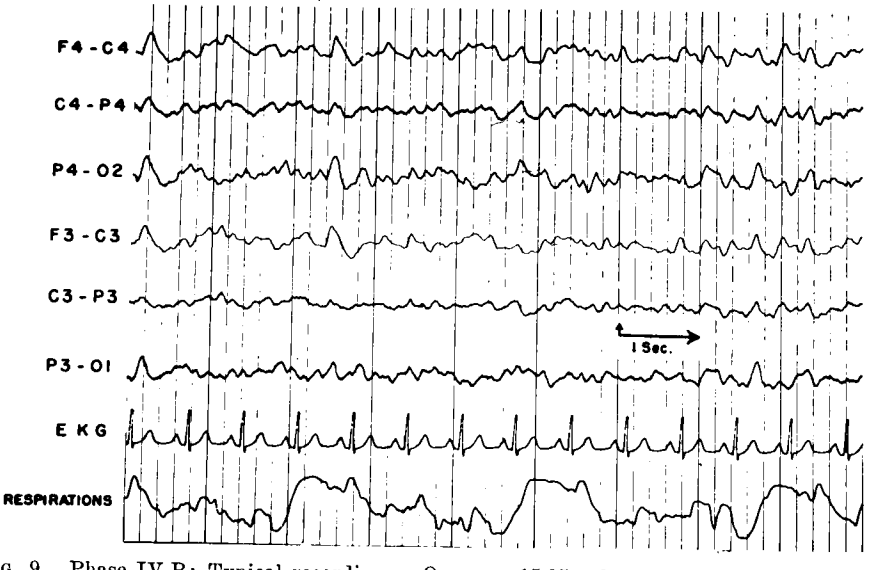

FIG. 9. Phase IV-B: Typical recordings. Oxygen—15.05 volumes per cent, carbon dioxide —37.62 volumes per cent, *p*H—7.6. Hypoxia, four minutes after reducing oxygen content. F-4——C-4 indicate location of electroencephalographic leads.

Since no endotracheal tube was used, the stomachs of 5 of these individuals were inflated. Two experienced a sense of fullness and a desire to belch. The remaining 3 experienced extreme nausea, and a desire to vomit. These 3 individuals began to sweat rather profusely with the onset of nausea. This sweating was noted by the observers, and the patient later reported that it occurred at almost the exact instant when the sensation of nausea first appeared.

Three of the subjects were troubled by nausea for twenty-four hours after the experiment. The remaining 7 had no sequelae.

Electroencephalographic Patterns.—Figure 4 shows the normal pattern seen in all 10 subjects during phase I of this experiment. This consists of a well modulated 10-per-second alpha wave intermixed with minimal 25-per-second beta waves. As shown in figures 5 and 6, there

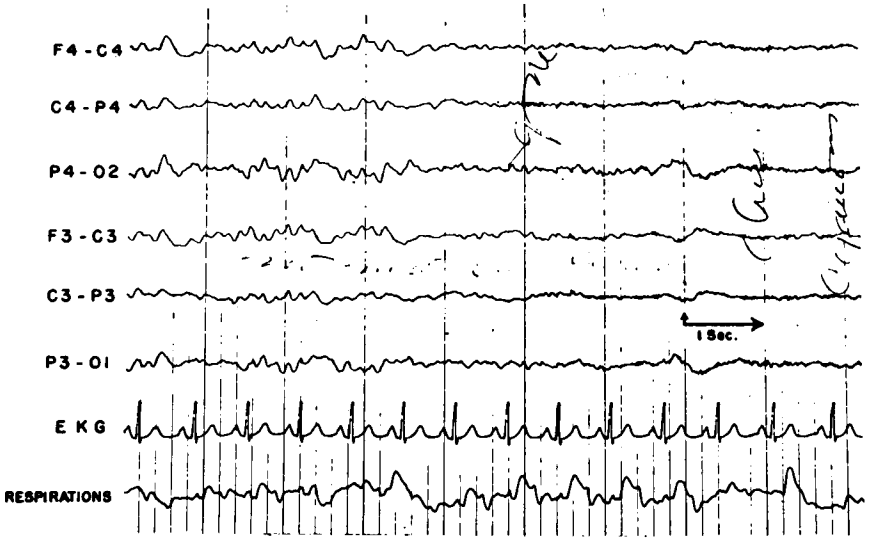

FIG. 10. Typical recordings: return to normal five seconds after oxygen. F-4——C-4 indicate location of electroencephalographic leads.

was no change in this pattern throughout phase II and throughout the period of conscious apnea. The obliteration of the alpha rhythm, by speaking to the patient or by passively opening the patient's eyes, occurred consistently until after the thiamylal was administered.

Figure 7 shows the pattern achieved by the injection of thiamylal in all 10 cases. These changes began at the end of thirty seconds after the completion of the injection and lasted over a period of three minutes. The changes constitute an increased amplitude in the 20- to 22-per-second beta waves followed by low and medium voltage, bilateral 5- to 7-per-second waves in all head regions, and later by bilaterally synchronous 2- to 4-per-second waves intermixed with medium and high amplitude. Figure 8 shows the baseline pattern that was reached

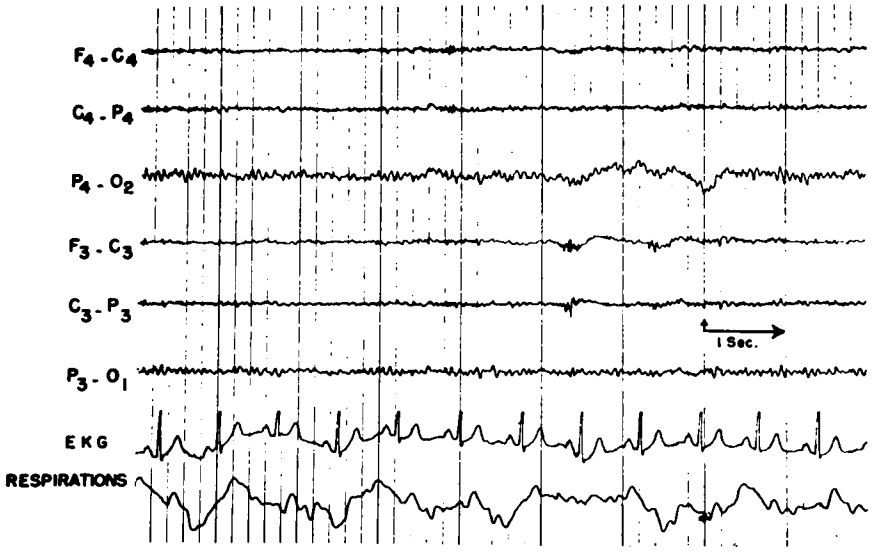

FIG. 11. Typical recordings: waking pattern after 10 minutes.

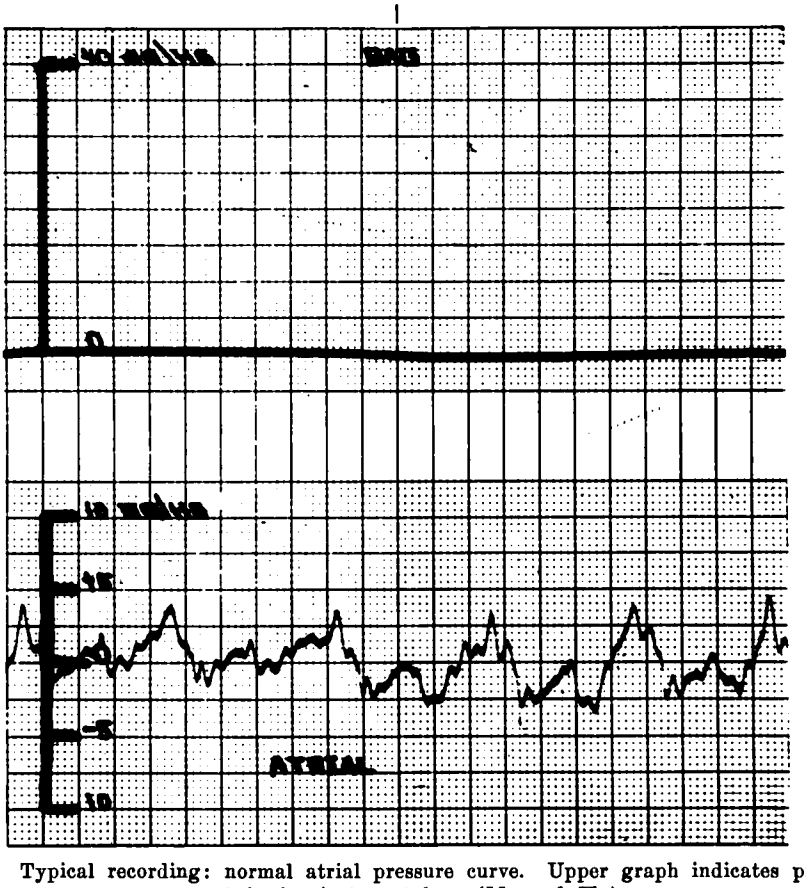

FIG. 12. Typical recording: normal atrial pressure curve. Upper graph indicates pressure present in inspiratory tube. (Mm. of Hg).

within the first five to seven minutes after the beginning of nitrous oxide. This consists predominantly of high voltage, 25-per-second beta waves with some 12- to 15-per-second alpha wave activity. Spindles appear from time to time.

Figure 9 shows the changes resulting from the development of hypoxia. Hypoxic changes manifested themselves in all cases within one hundred seconds of the reduction of oxygen content. The appearance of cyanosis occurred in 8 subjects, sixty seconds after a noticeable change in the electroencephalogram. In 2, the changes in the electro-

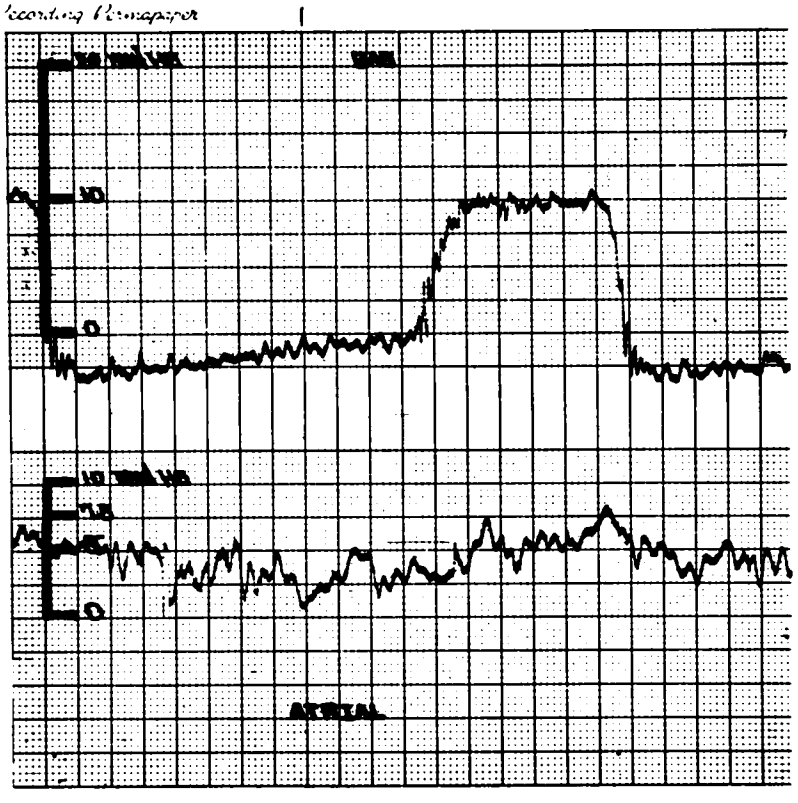

FIG. 13. Typical recording: customary ventilation pattern and atrial response. Upper graph indicates pressure present in inspiratory tube. (Mm. of Hg).

encephalogram and the appearance of cyanosis were concomitant. In no case did cyanosis appear prior to the change in the electroencephalogram. Hypoxic changes manifested themselves by the appearance of bilateral slowing with 6- to 7-per-second activity in all head regions. As hypoxia progressed, there was continuous medium voltage, 5- to 7-per-second activity decreasing slowly in amplitude and diminishing in frequency until the record shows high voltage, 1½- to 3-per-second activity. All of the changes throughout this experiment

were bilaterally synchronous and maximal in the parieto-occipital region. Figure 10 shows the point five seconds after the administration of oxygen at which the electroencephalograph returned to its prehypoxic level. This change occurred consistently at five to thirty seconds following the administration of pure oxygen, after which the electroencephalogram progressed to its pre-experiment level as seen in figure 11.

Atrial Pressures.—Figure 12 shows the typical pressures measured in the right atrium during the first two phases of the experiment with

FIG. 14. Typical recording: continued pressure during expiration. Upper graph indicates pressure present in inspiratory tube. (Mm. of Hg).

no pressure in the gas machine. Figure 13 shows the effect of normal bag manipulation on the atrial curve. Bag pressure in this instance was 10 mm. of mercury and the atrial pressure rose to vary from plus two to plus seven with a mean atrial pressure of five. Atrial pressure tended to lower during the expiratory phase and to increase during the inspiratory phase. In figure 14 is seen the effect of increasing the expiratory pressure to a point where the baseline does not return to zero. In this instance there is, in addition to an increase in mean atrial pressure, a decrease in the limits of the atrial pressure curve.

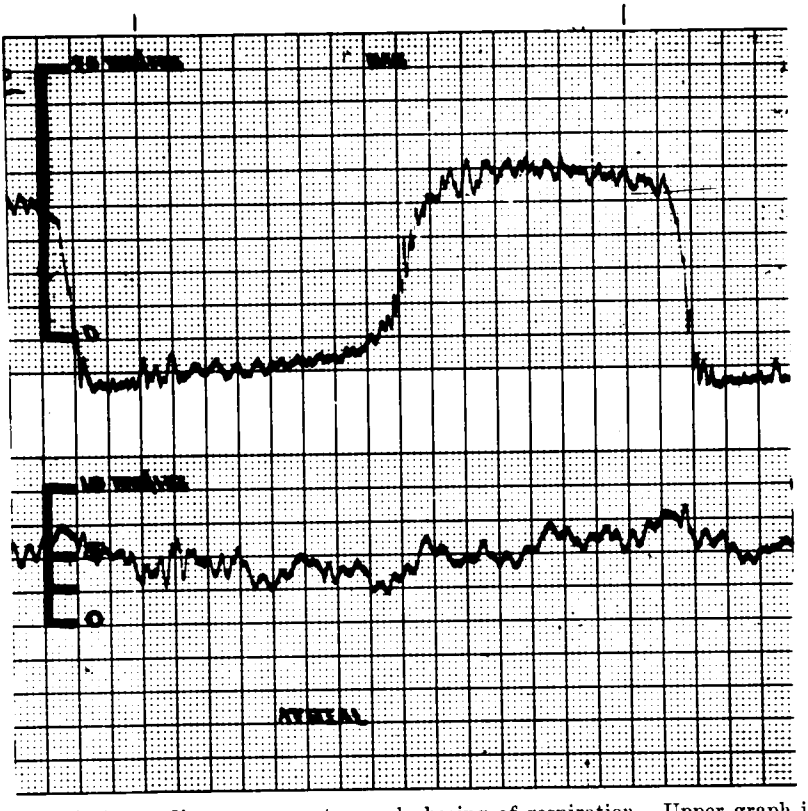

FIG. 15. Typical recording: response to equal phasing of respiration. Upper graph indicates pressure present in inspiratory tube. (Mm. of Hg).

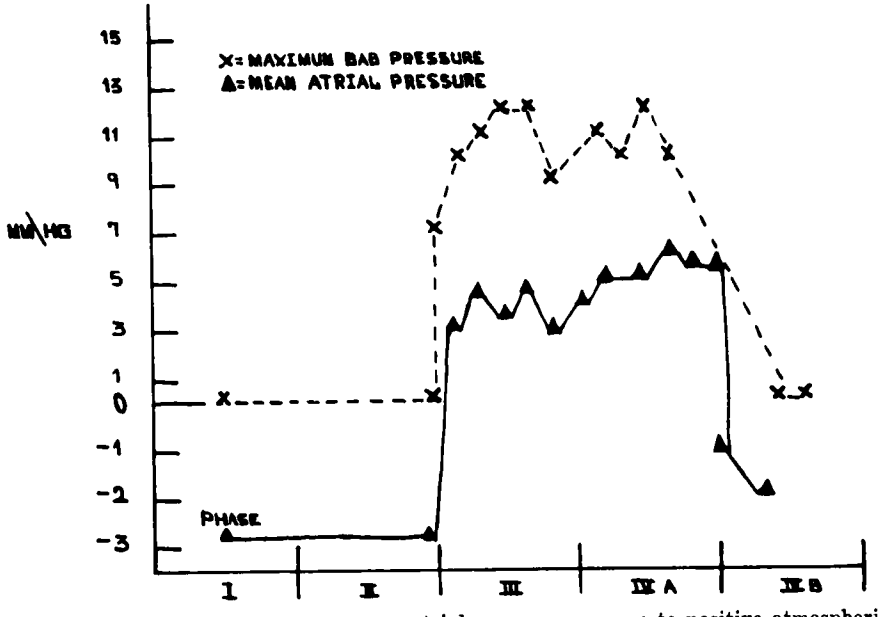

FIG. 16. Typical atrial pressure curve: atrial pressure response to positive atmospheric pressure. Upper graph indicates pressure present in inspiratory tube.

In figure 15 is shown the effects of exaggerated bag pressure with equal phasing of respiration and the subsequent marked increase in the mean atrial pressure. The over-all effects of these pressures are summarized in figure 16 which shows the relationship of the mean atrial pressure to the maximum bag pressure during the last two phases of this experiment. Following cessation of controlled ventilation, atrial pressures fell rapidly to normal, returning to their negative phasing within three minutes after the cessation of bag breathing. Figure 17 shows

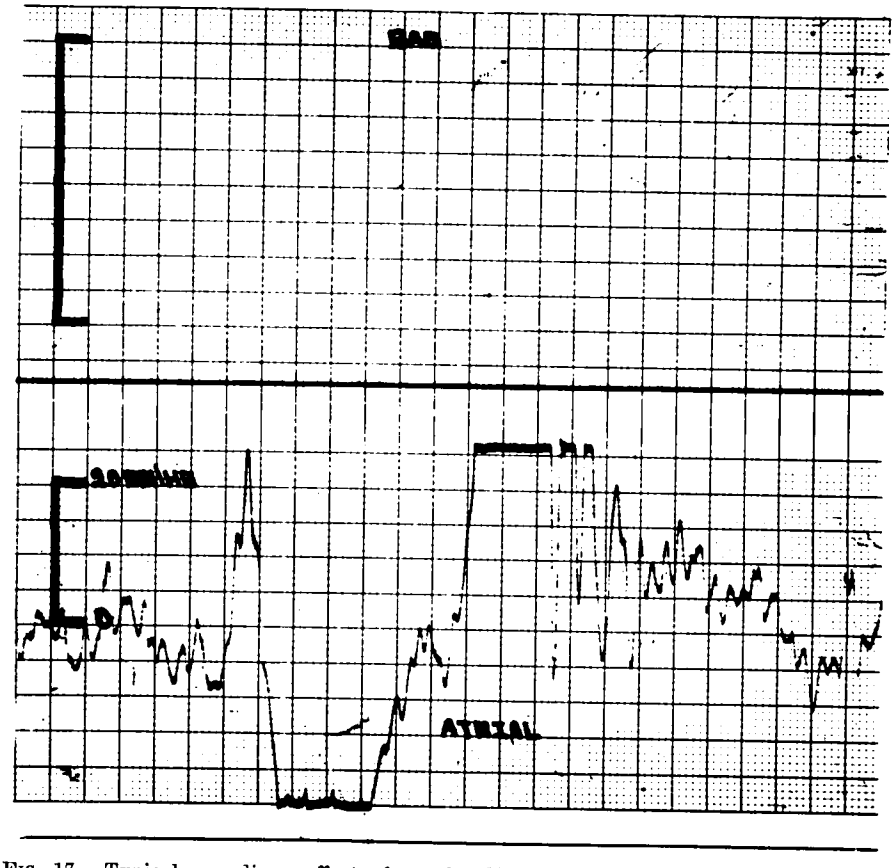

FIG. 17. Typical recording: effect of cough. Upper graph indicates pressure present in inspiratory tube. (Mm. of Hg).

the effect of a cough on atrial pressure. This effect is biphasic, the atrial pressure going markedly towards the negative side during the inspiration just preceding the cough, and then increasing to well beyond the limits of pressure measurement during the Valsalva maneuver of closing the glottis.

The atrial pressure curves for all 10 cases were essentially the same as that shown in figure 16. In two cases, the value for mean atrial pres-

sure exceeded that of the bag pressure by 1.5 mm. of mercury throughout the entire course of controlled ventilation. The pattern of the curve in these two cases was identical with the other cases except for the reversal of pressure values.

No difference occurred in the character or magnitude of this atrial pressure response as a result of the change in the breathing mixture. Hypoxia had no discernible effect.

Discussion

Oxygen, Carbon Dioxide, and pH.—The arterial blood values for oxygen, carbon dioxide and *p*H followed our clinical impression, gained from a series of 12,000 cases, that oxygenation is adequate. Carbon dioxide removal is excellent, and to such a degree as to maintain a normal *p*H as long as proper ventilation is carried out. It is felt that with the minute volumes provided as in this experiment, these same values can be obtained in any patient (3).

The slight decrease in oxygen and increase in carbon dioxide after ten minutes of spontaneous respiration through the mechanics of a gas machine confirms previous work that has been done regarding the effects of dead space and resistance (4).

Atrial Pressures.—The problem of increased pressure within the mediastinum has been worked out by several investigators. The increase in atrial pressures in this experiment coincided with that reported by others. In the absence of any marked change in blood pressure or pulse, one must assume that atrial filling continues at a satisfactory rate probably as a result of the increase in pressure differential between the extrathoracic veins and the mediastinal vessels (5). It has been pointed out by other investigators that atrial filling can proceed at a normal volume in spite of these higher pressures (3). Another investigator has pointed out the necessity of peripheral accommodation in order to maintain adequate venous return (6). In this instance, the level of anesthesia is so light that peripheral reflexes can be maintained intact and thus compensate for this change in atrial pressure.

This work again confirms the fact that atrial pressures are increased least when the ratio of inspiration to expiration is 1:2 (3). This allows more time for filling of the atrium when there is the least pressure within the pleural cavity. The extreme swing in pressures during the mechanism of coughing again emphasizes the abrupt changes that can take place in the hemodynamics of the circulation (7).

Blood Pressure and Pulse.—The only significant changes in blood pressure and pulse rate occurred immediately following the administration of succinylcholine. These changes could be the effect of the drug itself (9). They could also be the result of the onset of fibrillatory twitchings and the anxiety produced by these and progressive paralysis. Probably both factors play a part, the primary one being

the apprehension produced by an abnormal state. The fact that in all instances, blood pressure returned to normal within five minutes and that in eight out of ten instances the pulse returned to normal, lends support to the latter as the main causative factor.

The absence of other changes in these phenomena indicates the ability of the normal circulatory system to compensate for minor changes in pressure relationships.

Consciousness and Pain.—It was thought at the outset of this experiment that a lowering of carbon dioxide content of the blood might lead to the production of some degree of analgesia or unconsciousness. In this series of 10 individuals, 6 fail to recall the period for from three to six minutes just preceding the injection of thiamylal. In spite of the fact that the carbon dioxide content in these individuals had been lowered by five to ten volumes per cent at this time, it is considered that this period of unconsciousness represents a retrograde amnesia as a result of thiamylal, and not the effect of a lowered carbon dioxide content. This view was strengthened by the absence of electroencephalographic changes until after the injection of thiamylal had taken place, although amnesia does not necessarily produce electroencephalographic change (8). The one case who felt a diminution in pin-prick cannot be considered significant.

Nausea and Sweating.—It is interesting that the 3 individuals who broke out into a profuse sweat shortly after the beginning of controlled ventilation were the individuals who experienced extreme nausea with an inflated stomach. This phenomena has been observed at times during the course of clinical anesthesia, where sweating has not lent itself to any of the usual explanations. It may be postulated that the level of anesthesia is light enough to allow a distended stomach to produce sweating through a reflex mechanism, even though the patient is not awake enough to experience nausea.

Another interesting feature, though of questionable significance, is the fact that the only 3 individuals who experienced postexperimental nausea in this series were those individuals in whom the carbon dioxide content was allowed to rise during the hypoxic phase of the experiment. Although a small series, this incidence of nausea in these individuals would indicate that carbon dioxide accumulation plus hypoxia may be the cause of some postoperative nausea and vomiting.

Electroencephalographic Patterns.—Electroencephalographic monitoring of the depth of anesthesia has occupied a prominent place in recent work. The absence of electroencephalographic changes during a period of hyperventilation in the early phases of this work indicate that there is no change in consciousness resulting from a lowering of the carbon dioxide content of arterial blood. The changes occurring after the injection of thiamylal represent the deepest plane of anesthesia reached during this technique, since during the administration of nitrous oxide the patient is in a very light level of anesthesia.

This technique lends itself well to the monitoring of brain wave activity for the appearance of hypoxia. The electroencephalographic changes produced during anesthesia with other agents are generally of such low frequency (the usual slow and burst variety) that the appearance of the signs of hypoxia can readily be confused with deeper anesthesia. Since the electroencephalographic patterns with this technique are of a high frequency variety, the appearance of hypoxia becomes evident with the occurrence of slower brain wave activity, which can be recognized and cannot be attributed to increasing depth of anesthesia.

The fact that electroencephalographic signs of moderate hypoxia occur prior to any significant change in electrocardiogram and blood pressure makes possible a more accurate monitor for hypoxia than has been presented before. The electroencephalogram patterns presented in the preceding illustrations can be considered typical for the changes which take place during this technique of anesthesia.

Summary

This paper reports the results of an experiment to measure certain physiological changes occurring in conscious subjects during apnea and compares these changes in the same subjects during anesthesia. Ten human volunteers were paralyzed with succinylcholine, ventilated with pure oxygen, then with nitrous oxide, 75 per cent, and oxygen, 25 per cent, and finally rendered mildly hypoxic by reduction in the concentration of oxygen. During each of the phases, electroencephalographic, electrocardiographic, and respiratory tracings were run simultaneously, arterial and blood determinations were made of the values for oxygen, carbon dioxide, *p*H, sodium and potassium. Minute volume of respiration and subjective response to pain were recorded. Simultaneous pressures were measured within the right atrium and the anesthesia circuit.

Results obtained in this experiment showed adequate oxygenation and removal of carbon dioxide when adequate ventilation of the type described was maintained. There was no change in consciousness during the period of hyperventilation with oxygen alone. There were no changes in the values for sodium and potassium. Electroencephalographic findings were commensurate with those expected for the type of anesthetic being administered, and no electrocardiographic changes occurred.

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