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Effect of Carbon Dioxide and Other Gases on Electrocardiogram of the Right Ventricle.*

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It has been reported[1,2] that the intravenous injection of carbon dioxide causes the formation of a gas bubble in the right ventricle with a concomitant lowering of the initial ventricular deflection of the electrocardiogram when this is recorded directly from the surface of the right ventricle. Further investigation has shown that this electrical phenomenon occurs not only with carbon dioxide, as was first thought[1,2] but also with the parenteral injection of other gases.

Procedure. Mongrel dogs, averaging 6-12 kilos in weight, were anesthetized with sodium pentobarbital (approx. 35 mg/kilo) by vein. Respirations were maintained through a tracheotomy tube after the chest had been opened with a sternum-splitting incision. In addition to the standard electrocardiographic leads, direct leads were taken by placing a wick electrode without pressure on the heart muscle through a small slit in the pericardium. The various gases were injected through an exposed vein.

The electrocardiograms were taken with a Cambridge Simplitrol, using a fast speed (50 mm/sec.), a thick string casting a 3 mm shadow, and increased intensity of the light source (using a variac transformer). These three improvements made the elements of the QRS complex of the electrocardiogram much easier to read.

Results. As has already been described[1,2] when 50-100 cc of a gas is rapidly injected into the femoral vein of a small dog (6-10 kilos), lying supine, the gas collects in the right ventricle, blocking the pulmonary conus and artery, preventing the passage of blood into the lungs. The right heart dilates; the blood pressure falls. If the gas is carbon dioxide, which is quite soluble, it is readily absorbed by the blood in 15-17 seconds. Circulation through the lungs is resumed as the bubble is reabsorbed and the dog recovers. Other gases or mixtures of gases, such as oxygen, nitrogen, helium and air, are not so readily absorbed, and if the dog's position is not changed, death will occur in 3-5 minutes because of the complete block to the pulmonary circulation. If the gas bubble is not large, the pulmonary circulation may be reestablished by turning the animal into the left lateral position.[3] The gas bubble then floats up from the pulmonary conus to the apex of the right ventricle and allows blood to flow into the pulmonary artery.

As the gas bubble dilates the right ventricle an interesting electrocardiographic change takes place. The initial upward deflection of the electrocardiogram in a direct lead from the right ventricle is lowered or disappears entirely. If only a small amount of gas (10-15 cc) such as carbon dioxide is used, the R wave is merely lowered. With 50 cc or more of carbon dioxide the R wave disappears entirely (Fig. 1). At the same time the P wave increases in amplitude and the ST segment may be slightly raised, with inversion of the T wave. There is no change in the PR interval or in the width of the QRS complex. As the carbon dioxide is absorbed the R wave reappears and the electrocardiogram assumes its control appearance. Repeated injections of CO_2 produce the same sequence of events.

In fatal experiments with the less soluble

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1 Durant, T., Long, J., and Oppenheimer, M. J., *Am. J. Med. Sc.*, 1947, **213**, 633.

2 Durant, T., Long, J., and Oppenheimer, M. J., *Fed. Proc.*, 1947, **6**, 435.

3 Durant, T. M., Long, J., and Oppenheimer, M. J., *Am. Heart J.*, 1947, **33**, 269.

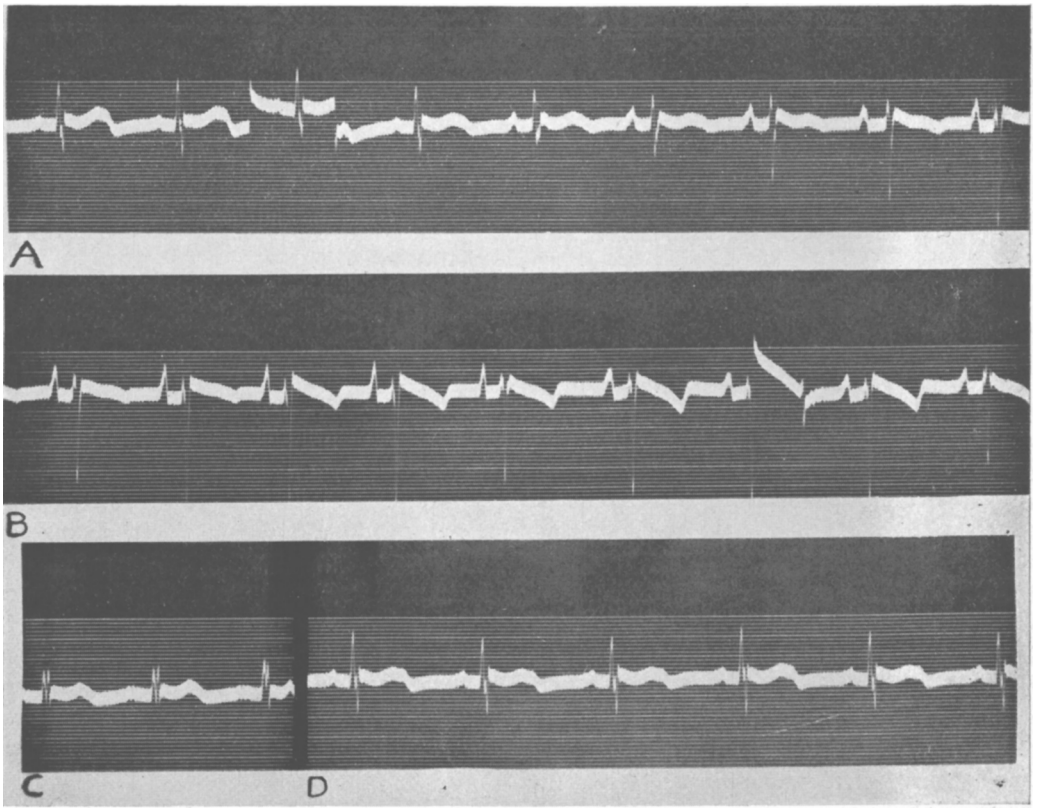

FIG. 1.

Male dog, 8.2 kg 9/16/47. A. Two control complexes and beginning of injection of CO_2 at millivolt signal (3 millivolts). B. Continuation of A with no complexes omitted. End of injection at millivolt signal. C. Between the end of B and the beginning of C 5 minutes have elapsed. D. Between C and D 5 minutes have elapsed. Anesthesia: Pentobarbital sodium, 35 mg/kg. Camera speed 50 mm/sec. Direct lead from right ventricle.

gases the R wave disappears and may not reappear. In addition the ST segment and the T wave changes become gradually more pronounced.[3]

The etiology of the change in the QRS complex is of interest. It is known that interposing an insulating substance such as air in hyperdistended lungs between the heart and the exploring electrode of chest leads will cause a lowering of the voltage of the R wave.[4,5] Katz and co-workers[6] showed that when parts of the heart surface are short-circuited by means of lead or tinfoil or insulated by glass or rubber, that the voltage of the electrocardiogram is decreased. Any such etiology is ruled out in these experiments because the exploring electrode is directly on the heart muscle.

Another possible cause of the electrocardiographic change is the anoxia caused by the interruption of the blood flow through the lungs. Harris and Randall[4] showed that the reduction of the height of the R wave in anoxic dogs with closed chests was associated with the enlargement of the thorax as a result of the hyperpnea and that there was no change in the height of the R wave in direct leads from the heart in dogs with open chests in concentrations of oxygen as low as 7%.

When animals in our laboratory were sub-

4 Harris, A. S., and Randall, W. C., *Am. J. Physiol.*, 1944, **142**, 452.

5 Lapin, A. W., *Am. Heart J.*, 1947, **33**, 747.

6 Katz, L. and Korey, H., *Am. J. Physiol.*, 1935, **111**, 83.

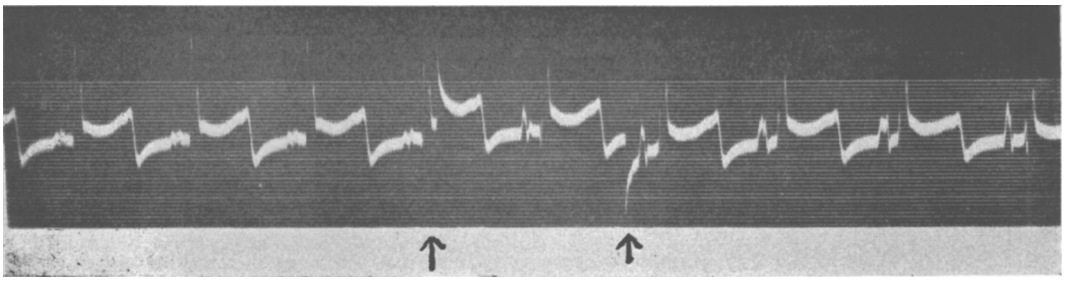

FIG. 2.

Male dog, 8.0 kg 9/30/47. Three control complexes and beginning of mineral oil injection at millivolt signal (3 millivolts). Anesthesia: Pentobarbital sodium, 35 mg/kg. Camera speed, 50 mm/sec. Direct lead from right ventricle. R_1 and R_2 are present in the control complexes. R_1 alone is diminished by the injection of mineral oil. The two arrows indicate the duration of the millivolt signal.

jected to asphyxia by cutting off the artificial respiration, the right heart dilated but there was no lowering of R.

Sudden dilatation of the right ventricle by means of the rapid injection of 100 cc of blood into the jugular vein or by compressing the pulmonary artery was found to be ineffective in changing the amplitude of the R wave.

An important possibility to consider is that the electrocardiographic changes are due to the replacement of blood in the right ventricular cavity by a dielectric. It was found that when mineral oil, a non-conducting liquid, was injected rapidly in sufficient quantities to completely replace the blood in the right ventricle (50 to 100 cc in a 10-kilo dog) the same phenomenon occurred, *i.e.* there was a marked lowering or disappearance of the R wave (Fig. 2). In each case a post-mortem check of the contents of the ventricle was made. In one experiment, wherein only 50 cc of oil was injected in a 12-kilo dog, the R wave was unchanged, and at post-mortem the right ventricle was found to contain some oil mixed with a large amount of blood, hence complete replacement by a dielectric had not occurred.

The injection of carbon dioxide into the left ventricular cavity in several experiments resulted in the production of multiple extrasystoles, making it impossible to evaluate its effect on the R wave in leads from the left ventricle. Moreover, we have been unable to adequately fill the left ventricle with mineral oil so as to study the effects of this dielectric on left ventricular leads. Furthermore, these experiments are complicated by the effects of coronary artery filling by the injected substance.

Conclusion. The rapid intravenous injection of gases or mineral oil in sufficient quantities to replace blood in the right ventricle of dogs will cause the reduction or loss of the initial ventricular deflection of the electrocardiogram in direct leads from the epicardial surface of the right ventricle.