THE RAPID SHALLOW BREATHING RESULTING FROM PULMONARY CONGESTION AND EDEMA.

By EDWARD D. CHURCHILL, M.D., and OLIVER COPE, M.D.

(From the Surgical Laboratories, Massachusetts General Hospital, Boston.)

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Experimental studies by Dunn (1) demonstrated that multiple embolism of the pulmonary arterioles and capillaries is followed by a temporary inhibition of respiration succeeded by rapid shallow breathing. Dunn attributed this phenomenon to the stimulation of sensory nerve endings in the lungs. This explanation was favored by the fact that the injection of starch produced no alteration in the respiratory rate when both vagi had been previously sectioned.

Attracted to this problem by its bearing upon the occurrence of rapid and shallow respiration in lobar pneumonia, Binger and Moore and their associates (2–6) have carried out a carefully planned series of experiments. Their studies chiefly concern the effects of the embolism of pulmonary arterioles and capillaries produced by the intravenous injection of starch grains under varying conditions. These observations were supplemented by other experimentally induced modifications of the pulmonary circulation. In their conclusion (6) to this instructive series of papers they state: "Since rapid and shallow breathing is not the result of (1) anoxemia, (2) increased pCO_2 and hydrogen ion concentration of the serum, (3) restriction of pulmonary vascular bed by nearly half, (4) increase in resistance to the flow of blood to and from the lungs, (5) the presence of starch grains in the lungs acting as a local irritant, it must be the result of the secondary pathological changes which occur in the pulmonary parenchyma following embolism. The nature of these changes, congestion and edema has been discussed elsewhere. Whether they operate directly on nerve endings or through their influence on lung volume and tissue elasticity is not certain." In their discussion the authors are inclined toward the hypothesis of direct irritation of the vagal nerve endings,

but wisely decline to theorize in the absence of more direct experimental evidence bearing on this point.

During the course of an investigation having quite another bearing, we have made certain observations which appear to demonstrate the occurrence of the usual signs of vagal stimulation in association with the experimental production of pulmonary congestion and edema. As a method completely different from those of Dunn or Binger was being employed, it seems desirable to briefly recount the results of our experiments.

Method.

A Drinker heart preparation (7) was made in a cat anesthetized with intravenous sodium-barbital (5 per cent solution). This procedure when complete leaves the heart exposed in a normally breathing animal, and is easily made by suturing the edges of the pericardium to the margins of an oval window created in the anterior wall of the chest by the removal of the sternum. After the closure of the chest and the resumption of normal respiration, ligatures were placed about the right branch of the pulmonary artery, and the group of right pulmonary veins respectively. The artery is readily reached from within the pericardium in that portion of its course which lies between the ascending aorta and the superior vena cava. The placing of a ligature about the right pulmonary veins is a more delicate procedure, as the thinness of their walls makes the liability to accidental puncture very real.

After both ligatures were in place they were tied so as to completely occlude the vessels, the one around the artery being tied first in order to avoid the effects of venous obstruction. An especially designed glass cannula was then inserted into the right branch of the pulmonary artery, distal to the point of ligation, and secured in place with a second ligature about the vessel. The cannula was connected by transparent rubber tubing to a glass reservoir which could be raised and lowered to effect changes in pressure. A T-tube leading from a point near the cannula was connected with a mercury manometer to record the pressure. The reservoir and tubing up to the cannula were filled with freshly drawn, heparinized blood from another animal, kept at body temperature.

Respiratory movements were recorded by a thread attached to the costal margin, moving a writing lever on the kymograph record. Systemic blood pressure was recorded by a citrated cannula in the right carotid artery. The blood pressure tracing served also to record pulse rate.

In such a preparation, the right lung is isolated from the rest of the circulation of the animal except for the amount of blood that may enter it through the bronchial artery. Ventilation of this lung is maintained by the normal respiratory movements of the animal as the lung is in its normal position in the closed pleural cavity. By changing the height of the reservoir connected to the cannula in the

right branch of the pulmonary artery, it is possible to alter the intravascular pressure in this isolated lung. Such changes may be produced without directly modifying the dynamics of the systemic circulation, or altering the gaseous exchange in the circulating blood. The latter is maintained by the normally functioning left lung and has been shown in other studies (8) to be adequate for the immediate needs of the animal.

EXPERIMENTS.

The following experiment illustrates the characteristic changes which have been observed in the respiratory rate and depth and in the systemic blood pressure and pulse rate following a sudden elevation of the intravascular pressure of the isolated right lung. As explained above the complete exclusion of this lung from the circulation of the animal assures that these effects are not due to pressure changes in the heart, variation of blood flow or alteration in the respiratory exchange.

Protocol. Experiment 1. Feb. 24, 1928. Circulatory Isolation of the Right Lung with the Production of Intravascular Pressure Changes.—2:30. Cat (2.7 kilos). Anesthesia induced by chloroform-ether to permit the injection of 19 cc. of sodium-barbital (5 per cent solution) into the saphenous vein. 3:08. Artificial respiration temporarily employed during the period when the chest is open. 3:45. Chest closed and residual air withdrawn from the pleural cavities. Artificial ventilation discontinued. 3:48. Blood pressure cannula inserted into the right carotid artery. 4:05. Ligatures placed about the right branch of the pulmonary artery and the right set of pulmonary veins. 4:20. Ligatures tied. Cannula inserted into the right branch of the pulmonary artery, and connected with a pressure reservoir filled with heparinized cat blood. 4:26. (Kymograph record, Fig. 1.) Reservoir elevated. 4:27. Reservoir lowered. 4:28. Reservoir elevated. 4:29. Reservoir lowered. 4:31. (Kymograph record, Fig. 2.) Reservoir elevated. 4:32. Reservoir lowered. 4:33. Experiment concluded. The heart showed no dilatation or change in appearance during the course of the experiment.

Autopsy.—No air in pleural cavities. The posterior and dependent parts of the lower lobe of the right lung were edematous. The rest of the lung was congested. A very small area of atelectasis was present in the right upper lobe. The left lung was of normal appearance and downy texture.

Sections of the kymograph tracing of this experiment are shown in Figs. 1 and 2. The results of the first elevation of the reservoir connected with the right pulmonary artery are recorded in Fig. 1. The rise in pressure is recorded in the change of level of line *D*, which indicates an elevation from 0 to 42 mm. of mercury. Following a latent period of 6 seconds, the systemic blood pressure (*A*) slowly

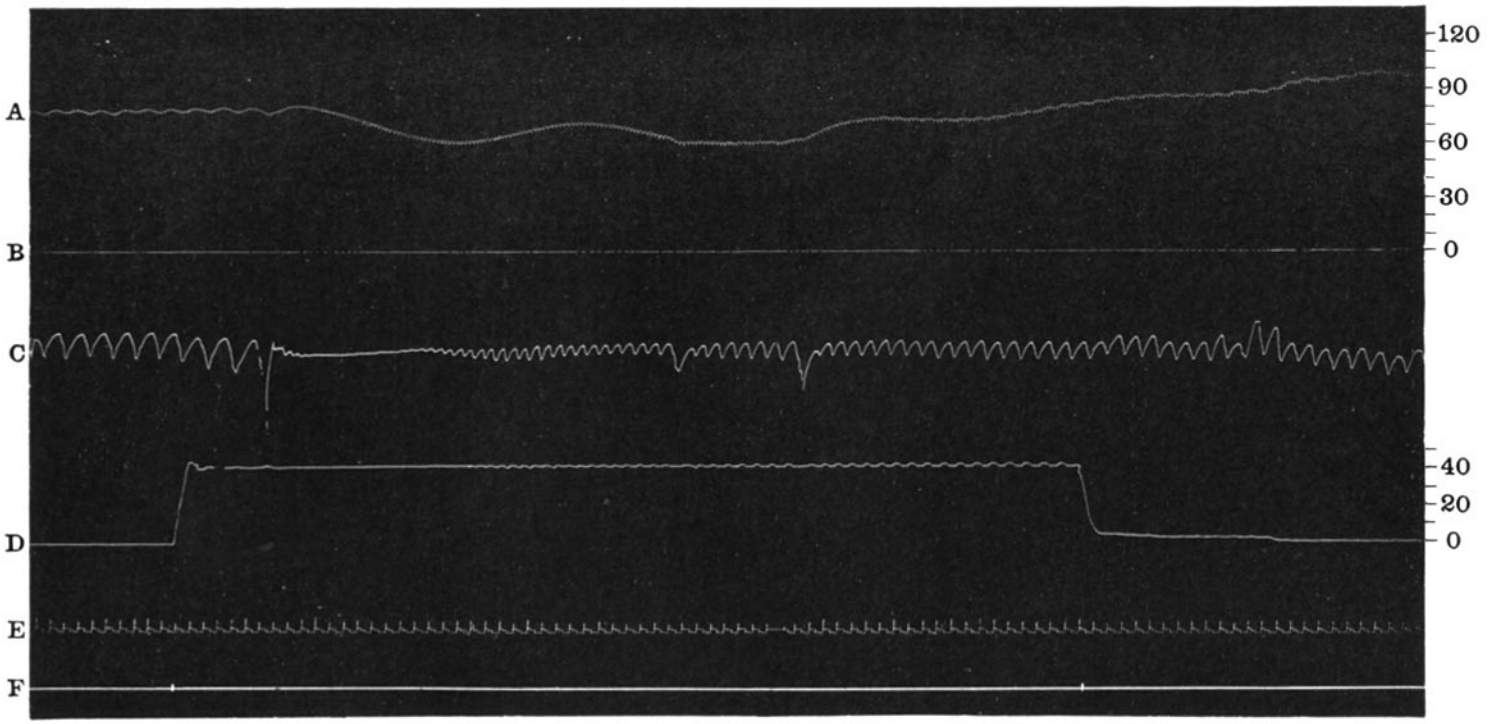

FIG. 1. Section of kymograph tracing from Experiment 1. *A*, systemic blood pressure in mm. of mercury recorded from right carotid artery. *B*, blood pressure base line. *C*, respiratory excursion of costal margin; down stroke of lever on inspiration. *D*, pressure in right branch of the pulmonary artery measured in mm. of mercury. *E*, time in 1 second intervals. *F*, signal marker indicating points when reservoir attached to the cannula in the right branch of the pulmonary artery was raised and lowered. The elevation of intravascular pressure in the isolated lung is followed by an apneic pause of respiratory excursions, succeeded by rapid shallow breathing. There is a simultaneous fall in blood pressure with slowing of the heart rate.

drops from 78 mm. of mercury to 60 mm. The pulse rate diminishes from 240 per minute to 204 per minute. The tracing of the respiratory excursions shows marked changes; a period of apnea lasting 8 seconds is followed by rapid and shallow respirations, the rate increasing from 47.5 to 75 per minute. These effects tended to disappear even before the reduction of pressure, although at the

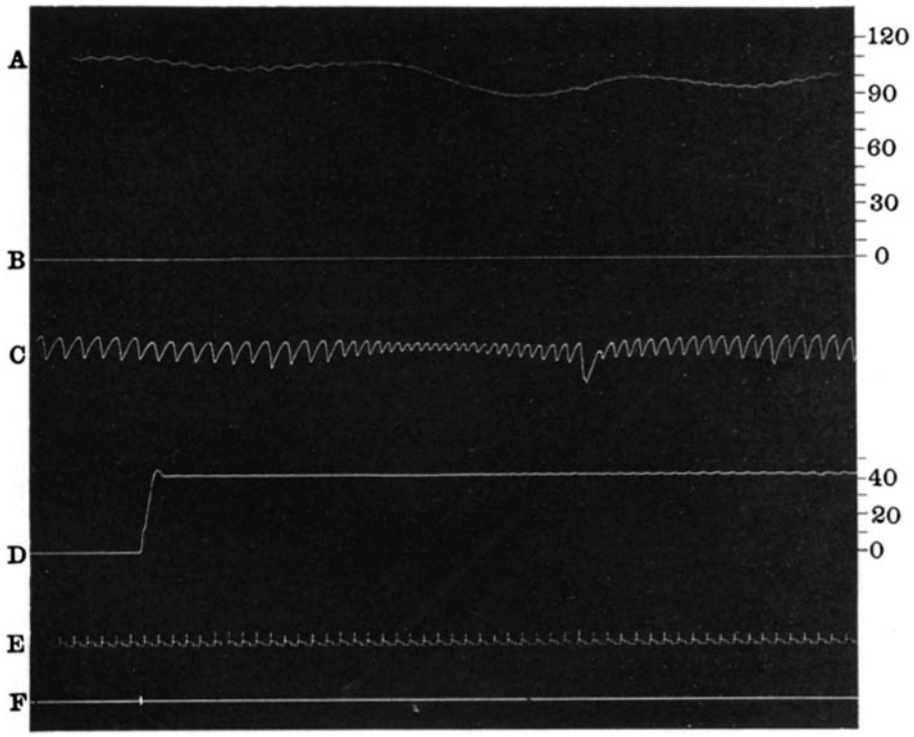

FIG. 2. Section of kymograph tracing from Experiment 1. Tracings as in Fig. 1. The elevation of pressure in the right branch of the pulmonary artery is followed by the institution of rapid shallow breathing without a period of apnea. The fall in blood pressure and slowing of heart rate is as in Fig. 1.

start of the second elevation, the respiratory rate was still increased over its previous value.

In the second experimentally produced rise in pressure, the tracing of which is not shown, similar changes took place. The pressure in the right pulmonary artery was raised from 0 to 38 mm. of mercury. Following a latent period of 7 seconds, the heart rate decreased from 240 to 228 per minute. The systemic blood pressure fell from 82 mm. of mercury to 77. The respiratory rhythm showed

no apneic pause, but the rate was increased from 45 to 80 per minute and the excursions became very shallow.

The third period is shown in Fig. 2. A rise in pressure of 42 mm. of mercury in the right pulmonary artery was followed by a latent period of 13 seconds. The systemic blood pressure dropped from 110 to 90 mm. of mercury, with a coincident slowing of cardiac rate from 252 to 228 contractions per minute. The respiratory rate increased from 45 to 90 per minute and became very shallow. As before, there was a tendency for the respiration to return to its original rate and depth before the pressure was reduced.

This experiment has been repeated fifteen times on six different cats with perfectly consistent results, *viz.*, a slowing of cardiac rate, a fall in systemic blood pressure and the institution of rapid shallow breathing, at times preceded by an apneic pause. It is unusual to be able to repeat the procedure in an individual animal with the same degree of success as was done in the experiment just described. Even here, the return to initial conditions between the changes in pressure was not complete. This is not surprising, as the congestive changes in the lung are presumably of a nature to produce a prolonged effect and not to permit of recovery during the period of the experiment.

DISCUSSION AND SUMMARY.

These experiments record the effects of the experimental production of pulmonary congestion and edema in a lung completely isolated from the general circulation, but with an intact nerve supply. The resulting changes are: a slowing of the heart rate, a fall in systemic blood pressure and a temporary inhibition of respiration succeeded by rapid shallow breathing. The pulse rate and blood pressure show a rapid and spontaneous return to initial conditions. The respirations show a partial but not a complete return to their former rate and depth. The effects on respiration are similar to those described by Dunn and Binger and Moore which follow multiple embolism of the pulmonary circuit with starch granules. The alterations in the pulse rate and blood pressure are characteristic of the effects of vagal stimulation. A chemical effect on the respiratory center is excluded by the nature of the preparation.

These results, therefore, add further evidence to support the hypothesis that the rapid shallow breathing attending congestion and edema of the lungs is due to the stimulation of nerve endings in the lungs.

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