flask. In this way, the fertilization membranes of 98–100% of the eggs can be removed.

Reference

1. JUST, E. E. *Basic methods for experiments on eggs of marine animals.* Philadelphia: 1939.

Electrophrenic Respiration

S. J. SARNOFF, E. HARDENBERGH, and J. L. WHITTENBERGER

Department of Physiology, Harvard School of Public Health

A new type of artificial respiration has been developed which uses electrical stimulation of one or both phrenic nerves. Current is supplied by a Grass stimulator set to deliver 40 impulses/sec, each impulse having a duration of 2 millisec. The current is fed through a rotating potentiometer which describes an arc, the length of which can be set by an adjustable lever. This lever is driven at a rate that can be adjusted by a friction clutch arrangement. In this way, the voltage delivered to the stimulating electrode is rhythmically raised and lowered at that rate per minute at which it is desired to maintain respiration. The increase in voltage is gradual and results in a smooth diaphragmatic contraction that produces effective inspiration. The reverse permits effective expiration by the passive relaxation of the diaphragm.

Within satisfactorily flexible limits, an increase in peak voltage applied to the nerve results in an increased force of diaphragmatic contraction and an increased tidal and minute volume. A linear relationship has been shown to exist between peak voltage applied and the minute volume accomplished, making easy the adjustment of the effective depth of respiration.

Electrophrenic respiration has been studied in the rabbit, cat, dog, monkey, and man. From the obtained data the following observations have been made:

(1) A smooth diaphragmatic contraction, closely resembling that seen during spontaneous respiration, follows the application of a gradually increasing voltage applied to the phrenic nerve.

(2) The ventilation accomplished by stimulating the phrenic nerve is, within satisfactory limits, directly proportional to the peak voltage applied.

(3) The spontaneous minute volume, arterial blood oxygen and carbon dioxide tensions of the experimental animal and man can be duplicated by the use of electrophrenic respiration with the submaximal stimulation of one phrenic nerve in the absence of spontaneous respiratory activity.

(4) Maximal stimulation of one phrenic nerve can produce overventilation and alkalosis. Bilateral maximal phrenic nerve stimulation produces a further decrease in arterial blood carbon dioxide tension and may triple the animal's spontaneous minute volume. These facts indicate the reverse of the method.

(5) An adequate minute volume and normal arterial blood oxygen and carbon dioxide tensions have been maintained in the cat for as long as 22 hrs in the absence of spontaneous respiratory activity by electrophrenic respiration.

(6) The experimental animal under anesthesia and unanesthetized man promptly relinquish control of respiration when adequate electrophrenic respiration starts.

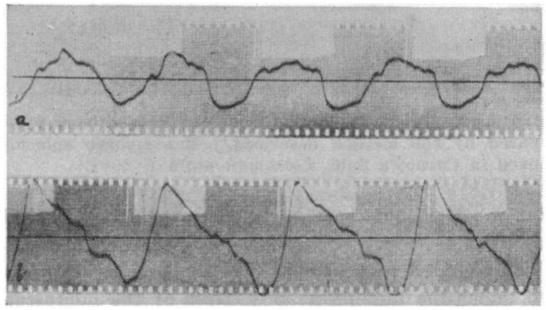

FIG. 1. Pneumotachogram of 33-year-old female. The area within the curve under the base line is directly proportional to the amount of inspired air. The area above the base line represents expiration.

Fig. 1 shows the pneumotachographic tracing obtained from a 33-year-old woman (a) during spontaneous respiration and (b) during electrophrenic respiration. The apparatus used was that described by Silverman (*4*) and by Silverman and Whittenberger (*5*). It can be seen that with a rate slightly slower than the patient's spontaneous rate, electrophrenic respiration produced a larger tidal and minute volume than that produced by spontaneous respiration.

In the same patient, studies of arterial blood oxygenation with the Millikan oximeter (*1*) revealed that arterial saturation could be increased over spontaneous levels by means of electrophrenic respiration.

Since the preparation of this manuscript, an opportunity arose for using this method of artificial respiration on a 5-year-old boy with complete respiratory paralysis following rupture of a cerebral aneurysm. As the only means of artificial respiration, it was capable of sustaining life for 52 hrs. Additional data are in press concerning the blood gas tensions and minute volumes achieved with this technique (*2*), its use in man (*6*), and the mechanism of suppression of spontaneous respiratory activity during electrophrenic respiration (*3*).

References

1. MILLIKAN, G. A. *Rev. sci. Instr.*, 1942, **13**, 434.
2. SARNOFF, S. J., HARDENBERGH, E., and WHITTENBERGER, J. L. *Amer. J. Physiol.*, in press.
3. SARNOFF, S. J., WHITTENBERGER, J. L., and HARDENBERGH, E. *Amer. J. Physiol.*, in press.
4. SILVERMAN, L. *J. ind. Hyg. Toxicol.*, 1946, **28**, 183.
5. SILVERMAN, L., and WHITTENBERGER, J. L. In ***Methods in medical research***, in press.
6. WHITTENBERGER, J. L., SARNOFF, S. J., and HARDENBERGH, E. *J. clin. Invest.*, in press.