INVESTIGATION OF THE MECHANISM IN THE PHYSIOLOGICAL ACTION IN CLOSED, ARTIFICIAL PNEUMOTHORAX

COMMUNICATION I. THE EFFECT OF ARTIFICIAL PNEUMOTHORAX UPON THE ACTION POTENTIALS OF THE VAGUS AND PHRENIC NERVES

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The widely-held opinion as to the mechanism of the respiratory act, the nature of the intrapleural pressure, and the mechanism of lung collapse following artificial pneumothorax has its basis mainly on purely physical concepts of lung biomechanics not associated with the physiological activities of the organism. In line with this concept, the therapeutic goal of artificial pneumothorax has been to put the lung at rest by means of filling the pleural space with air and thus either completely or partially collapsing the lung and so excluding its function of respiration. The logical explanation of the physiological and therapeutic mechanisms involved in artificial pneumothorax was the assumption that it was the rest which produced the desired result.

Contemporary physiological and clinical data which have been gathered [1,3,4,5,6,7,8,11,15] cannot be fitted into the old concepts of the biomechanics of the lungs during artificial pneumothorax, and demand an experimental study of this problem and, in part, a clarification of the role played by the nervous system in the mechanism of the action of artificial pneumothorax.

The present investigation was undertaken with the goal of studying the interoceptive reflexes of the respiratory apparatus as the organism becomes adapted to pneumothorax. In this communication are presented the experimental findings on the effect exerted by artificial pneumothorax upon the afferent impulses in the vagus nerve and the efferent impulses going down the phrenic nerve.

It is well known that electrophysiological studies have markedly widened and deepened our understanding of the mechanisms regulating respiration and have demonstrated the great effect upon the regulation of breathing exerted by afferent nervous impulses arising within the respiratory system itself from various mechanical and chemical stimuli.

Many investigators [2,9,10,12,13,14,16,17,18] have established the electrophysiological characteristics of the afferent impulses going up the vagus nerve and the efferent impulses travelling down the phrenic nerve during normal respiration and have proven their importance in the coordination of the respiratory act.

EXPERIMENTAL METHODS

These experiments were performed on rabbits and cats which were narcotized by means of a 15-20% solution of urethane injected into the femoral vein, the dose being 0.5-1 g per kg of animal weight.

The neck of the animal was opened and the vagus and phrenic nerves dissected clear of their sheaths.

As the vagus nerve within the cervical region has numerous afferent fibers conducting sensory impulses from the lungs, respiratory and digestive tracts, the heart, the arch of the aorta and the large veins, in our experiments we separated the main stem of the nerve into individual small bundles. Those bundles which were seen clearly to carry respiratory impulses were used for the testing of their electric potentials. Then the bundle was severed and the potentials were tested from the peripheral end of the cut. With the phrenic nerve, the potentials were tested from the central (upper) end of the cut.

The action potentials of the indicated nerves were obtained with the aid of platinum electrodes with a space of 3-5 mm between the poles. The impulses from the nerves were recorded by a double-ray cathode oscillograph produced in the experimental equipment factory of the Acad. Med. Sci. USSR. The frequencies of the amplifier were from 10 to 1500 cycles. During the experiments the animals were kept in a shielded chamber.

During the course of each experiment the potentials of the nerves during normal respiration before the induction of the pneumothorax, at the moment of producing the pneumothorax and at various times after that were registered in succession. Air was introduced into the pleural space in amounts of 25-50 cc, a regular pneumothorax machine being used.

EXPERIMENTAL RESULTS

As already stated in the literature [9,10,12,13,19], during normal respiration we observed regular oscillating streams in the vagus and phrenic nerves associated with the phases of the respiratory movements of the animal (Fig. 1, a). During inspiration, there was observed in the vagus an increase in the frequencies of the impulses and a rise in their amplitude, attaining a maximum at the height of inspiration. In the expiratory phase, the afferent impulses in the vagus nerve diminish sharply.

The volleys of efferent impulses in the phrenic nerve also have a characteristic pattern. Before the onset of inspiration and in the phase of its development the frequencies of the impulses and their amplitude increases to a given maximum, after which the impulses weaken sharply, disappearing entirely during expiration. This sharp decrease in the efferent impulses of the of the phrenic nerve with consequent total disappearance coincides in time with the moment of maximal development of the afferent impulses in the vagus nerve.

Thus, during normal animal respiration there is a very definite relationship between the afferent impulses of the vagus nerve and the efferent impulses of the phrenic nerve. The flow of interoceptive impulses from the respiratory apparatus to the respiratory center along the fibers of the vagus nerve is one of the factors assuring the regular alteration of the respiratory cycle.

When a closed artificial pneumothorax was induced in the animal, we observed material alterations in the afferent impulses of the vagus nerve and the efferent pulsations of the phrenic nerve. As can be seen from the oscillogram of Fig. 1,b,c, in the cat at the moment of inducing the pneumothorax there is registered in the vagus nerve a decrease of the afferent impulses in the inspiratory phase, while in the expiratory phase complementary impulses appear. At the same time, the efferent impulses in the phrenic nerve increase sharply. After some time, following the induction of the pneumothorax, there is observed a gradual restoration of normal relationships between the impulses in the vagus and phrenic nerves although the levels of the impulses differ from those seen before the application of the pneumothorax (Fig. 1,d,e).

The alterations in the action potentials just described that take place in the vagus and phrenic nerves of cats subjected to pneumothorax occur not only on the operated side but also on the opposite side, this being caused in these animals by an intercommunication between the two pleural cavities, so that a unilateral pneumothorax becomes bilateral.

The character and intensity of the action potential alterations in the vagus and phrenic nerves observed after the induction of pneumothorax depend on the amount of air being introduced into the pleural cavity and the speed of the operation.

When the air is introduced quickly into the pleural cavity, there frequently are seen instances of stoppage of breathing at the beginning of expiration, this being accompanied by continuous flow of impulses along the

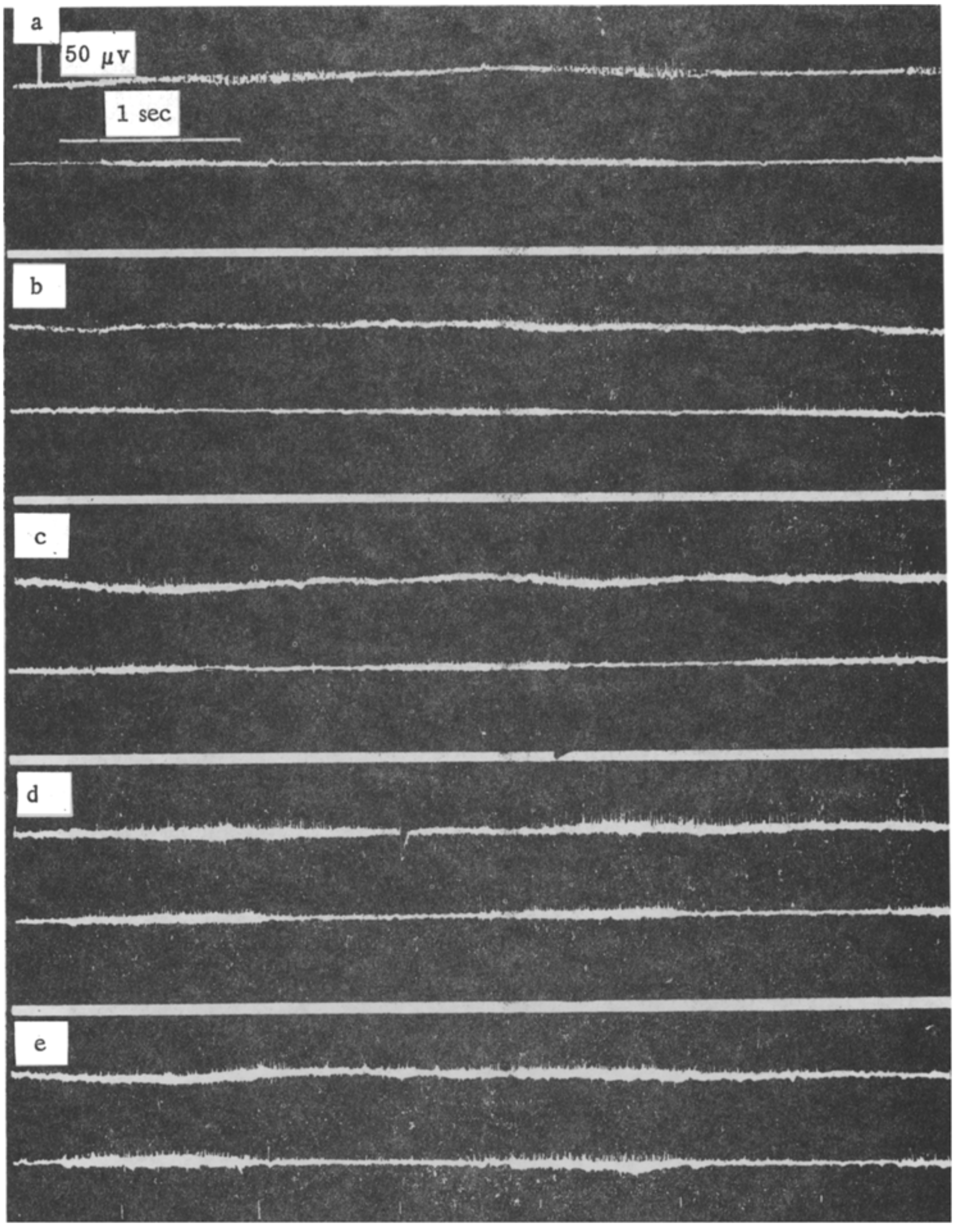

Fig. 1. Alterations in the afferent impulses of the vagus nerve and efferent impulses of the phrenic nerve upon induction of closed pneumothorax.
Significance of curves (from above): action potentials of left vagus nerve; action potentials of right phrenic nerve. Cat 1.9 kg. Experiment done October 30, 1954.
a) action potentials of vagus and phrenic nerves during normal respiration;
b) at moment of induction of pneumothorax by means of injection of 50 cc of air into the left pleural cavity;
c) immediately after the pneumothorax;
d) after one minute;
e) five minutes after the pneumothorax.

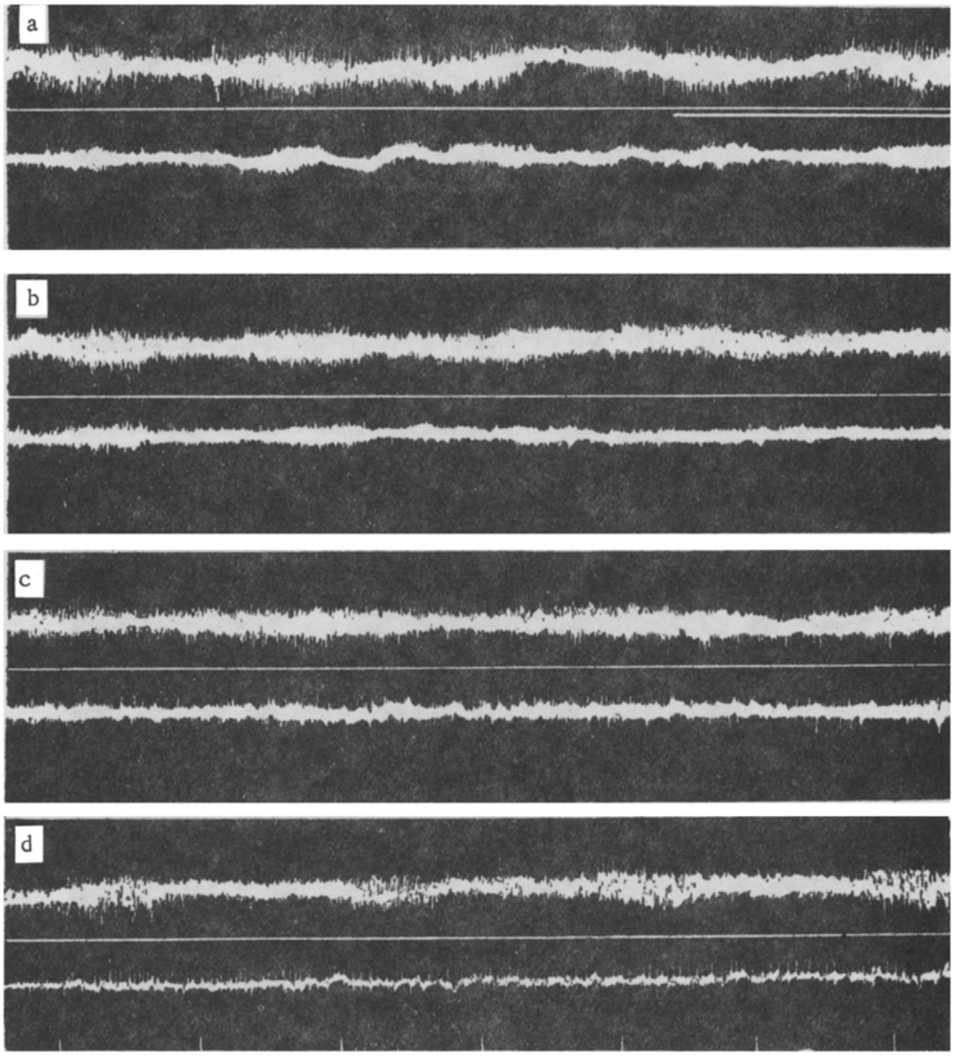

Fig. 2. Alterations of the afferent impulses of the vagus nerve at the induction of closed pneumothorax.
Rabbit weighing 2.5 kg. Experiment of January 7, 1955. Significance of tracings (from above): action potentials of left vagus nerve; action potentials of right vagus nerve.
a) initial back-ground; b) moment of inducing right sided pneumothorax $\frac{-6}{-4}$ 30 $\frac{-4}{+1}$; c) 30 seconds after the induction; d) five minutes after the pneumothorax.

phrenic nerve and a sharp weakening of the flow along the vagus nerve. The fact, recorded by us of the appearance of additional impulses in the afferent sensory fibers of the vagus nerve in the expiratory phase after the induction of pneumothorax, is in agreement with the studies by G. Knowlton and M. Larrabee [13] and by I. Widdicombe [17] as to the presence within the lung tissues of two forms of mechanoreceptors responding to stretching and compression of the lungs. Apparently, induction of pneumothorax affects the receptors reacting to lung compression, this being in the nature of a defense reaction to the collapse of the lung.

Analysis of the oscillograms indicates that, immediately after the induction of the pneumothorax and in the period of readjustiment to it, there is observed some increase of inspiration as compared to expiration when observed against the base level, this apparently being an aid to better gaseous exchange within the lungs.

Very characteristic is the circumstance that, following the introduction of 25-50 cc of air into the pleural cavity by inducing the pneumothorax, the level of the vagal afferent impulses is restored after a very short time to being as high or even higher than before the production of the pneumothorax. This demonstrates that the lung performs considerable expansion even during a hypotensive pneumothorax. This is further proven by the fact that in the presence of the pneumothorax the intrapleural pressure tends to return to the basic pattern characteristic for that animal [1,3], as well as compensatory expansion of the chest we have described previously [3], this occurring as a result of interoceptive reflexes from the pleura and lungs affecting the chest respiratory musculature.

We obtained interesting data in experiments upon rabbits. As is well known, the pleural cavities in rabbits are hermetically sealed off from each other. For this reason, induction of an unilateral pneumothorax in this animal leads to different functional states of the right and left lungs. This can be judged in the data obtained in our experiments of registering simultaneously the action potentials of the right and left vagus nerves with induction of an unilateral pneumothorax (Fig. 2).

The oscillograms in Fig. 2,a,b and c indicate that induction of the pneumothorax caused a sharp depression of the afferent impulses in the vagus nerve on the pneumothorax side and a compensatory strengthening of the vagal impulses on the opposite side. The action potentials of the phrenic nerves in this same experimental situation showed a marked strengthening of the efferent impulses in both the left and right sides. As the animal became adjusted to the pneumothorax, the relationships between the afferent volleys in the vagus nerve and the efferent volleys in the phrenic nerve on both sides tended to attain normal levels.

In some instances, the induction in rabbits of a tension pneumothorax would result in the suppression on the pneumothorax side for some time in the vagus nerve of the usual impulses associated with respiration and there would appear qualitatively new impulses not related to the respiratory movements of the animal (see Fig. 2,d). The character of this impulse resembles the action potentials registered by Widdicombe [16,17] in vagal afferent fibers coming from the tracheobronchial tree.

Thus the findings of our experiments indicate that induction of artificial pneumothorax affects the reflex zones of the respiratory apparatus, producing marked alterations in the character of the afferent signalization and, consequently, changing the activity of the respiratory center and aiding in the activation of compensatory adjusting mechanisms which assure the continued performance of the respiratory apparatus on a new level.

SUMMARY

The reflex arc involved in normal respiration was studied in relation to alterations occurring during and after the induction of artificial pneumothorax. Anesthesized rabbits and cats were employed. Intravenous urethane was the anesthetic agent. The afferent impulses in the vagus nerve and the efferent impulses in the phrenic nerve were tested by means of the standard oscillograph.

The lung is not simply put to rest mechanically by the pneumothorax. A number of adaptive compensatory mechanisms come into play assuring the continued activity of the respiratory reflexes under the new conditions.

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