PATHOLOGICAL PHYSIOLOGY AND GENERAL PATHOLOGY

INVESTIGATION OF THE MECHANISM UNDERLYING THE PHYSIOLOGIC ACTION OF ARTIFICIAL CLOSED PNEUMOTHORAX

COMMUNICATION II. PULMONARY BIOMECHANICS IN ARTIFICIAL CLOSED PNEUMOTHORAX

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It was shown in the previous communication that artificial closed pneumothorax elicited substantial changes in efferent impulses in the pulmonary branches of the vagus and consequently in the activity of the respiratory center. These data, together with facts described in the literature [1, 4, 6, 9], suggested that an important role in the mechanism of the influence exerted by artificial pneumothorax was played by reflex factors.

This question has not received adequate experimental examination and requires investigation of the concrete mechanisms underlying the functional changes in external respiration during pneumothorax.

The present communication is concerned with the study of pulmonary biomechanics of pneumothorax (by means of investigation and comparison of the distinctive features of respiratory movements of the thorax, intrapleural and intratrachael pressure, magnitude of pulmonary ventilation and arterial blood pressure) at the moment of induction of closed experimental pneumothorax and during adjustment to it.

EXPERIMENTAL METHOD

Two series of experiments were carried out: short-term experiments on 16 cats and prolonged experiments on 2 dogs.

In the experiments on urethane-anesthetized cats (1 g/kg urethane) a study was made of the effect on induced closed pneumothorax and of subsequent aspiration of air from the pleural cavity, on the dynamics of respiratory movements of the thorax, changes in its volume, air pressure in the trachea, intrapleural pressure and arterial blood pressure.

Thoracic respiratory movements were recorded by means of a crimped rubber tube fastened around the thorax and connected with a Marey's tambour. This method of recording respiratory movements permits observation of changes in the mid-position of the thorax and hence relative changes in its volume can be judged.

Fluctuations of air pressure in the trachea during the respiratory phases were recorded by the usual method by means of a tracheal cannula connected to a Marey's tambour. Intrapleural pressure was recorded by means of a system consisting of a hollow needle which was introduced into the pleural cavity, rubber tubes and a water manometer connected to a Marey's tambour. Blood pressure was recorded in the common carotid artery by a mercury manometer and a tonometer. In some experiments the other carotid artery was also exposed. In the course of the experiment a clamp was placed on it for 10-15 seconds from time to time in order to determine the level of reflex excitability of the vasomotor center.

Introduction of air into the pleural cavity and aspiration of air from the latter were achieved by means of a pneumothorax apparatus which was connected by a T-joint to the intrapleural pressure recording system.

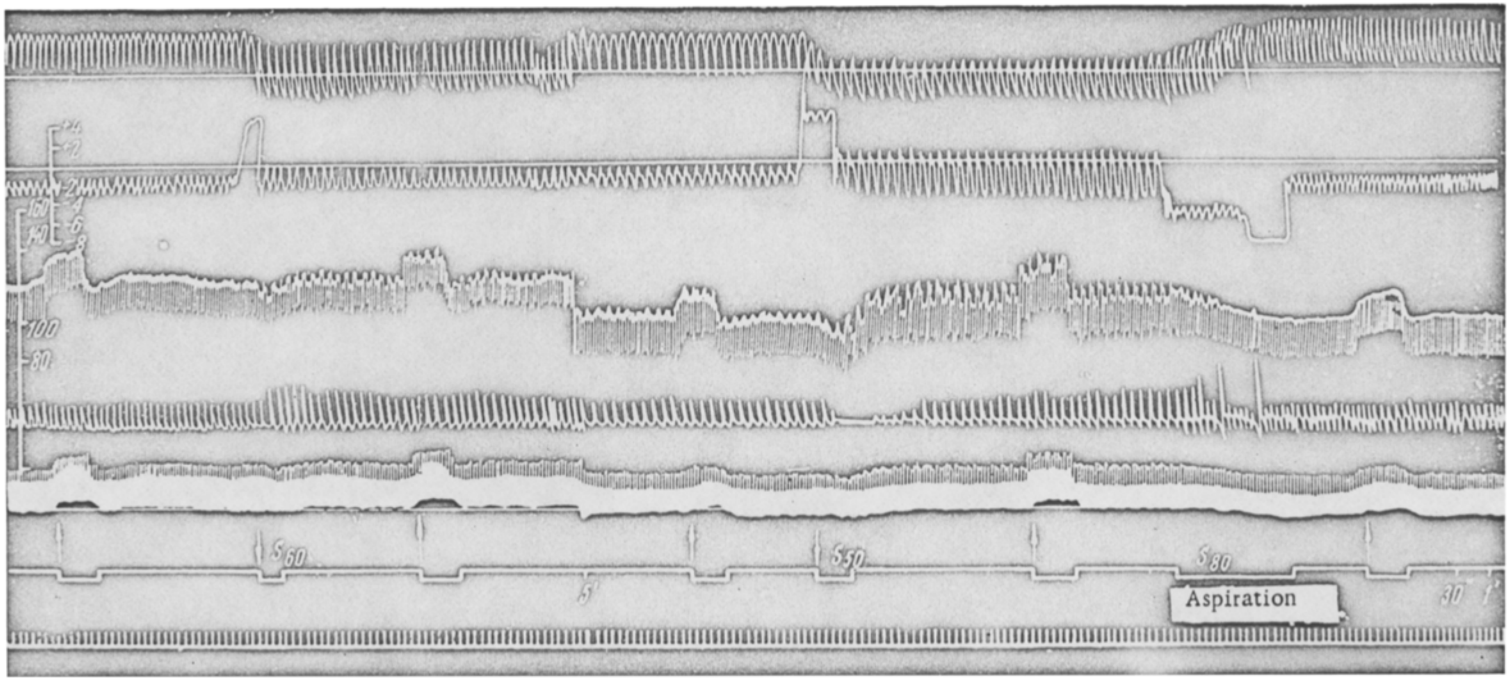

Fig. 1. Dynamics of the changes in thoracic volume, intrapleural pressure, respiration and blood pressure during induction of closed pneumothorax and during aspiration of air from the pleural cavity.

Cat weighing 3.1 kg. Data of experiment September 30, 1954. Records (from above down): respiratory movements of the thorax (inspiration – downward deflection), intrapleural pressure and its base line, blood pressure (mercury manometer), respiration (tracheal record), blood pressure (tonometer), mercury manometer base line, signal line (↓ S_{60} – 60 ml air introduced into the left pleural cavity; ↓ S_{50} – ditto, 50 ml; asp. S_{80} – aspiration of 80 ml air from the pleural cavity; ↑ – compression of the left carotid artery; figures underneath the signal line – time period during which the kymograph was stopped; time marker (2 seconds).

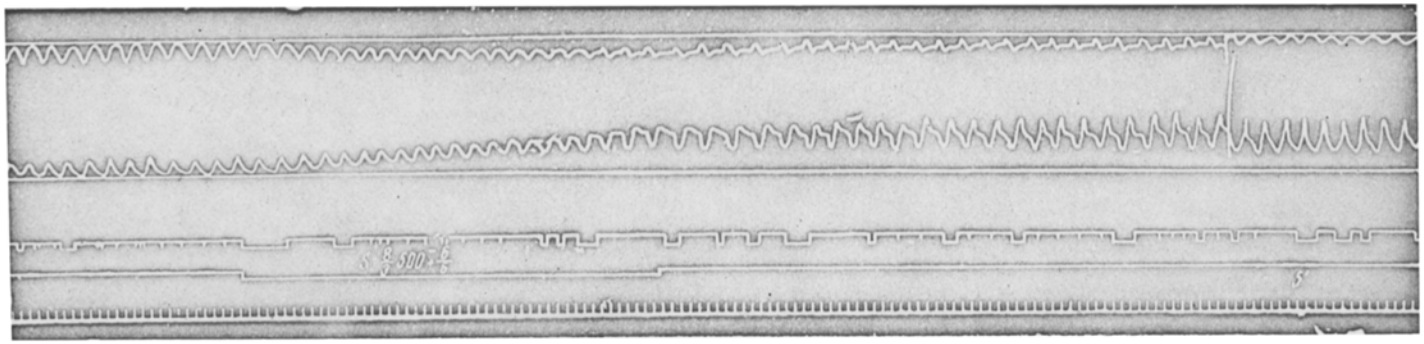

Fig. 2. Compensatory expansion of the thorax, change in the form of the respiratory curve and in the magnitude of pulmonary ventilation upon induction of closed pneumothorax.

Experiment on the dog Prim, March 11, 1955. Records (from above down): pneumogram (abdominal respiration – inspiration indicated by downward deflection), pneumogram (thoracic respiration – inspiration denoted by upward deflection); pulmonary ventilation (one mark corresponds to 200 ml inspired air); mark denoting induction of pneumothorax; time marker (1 second).

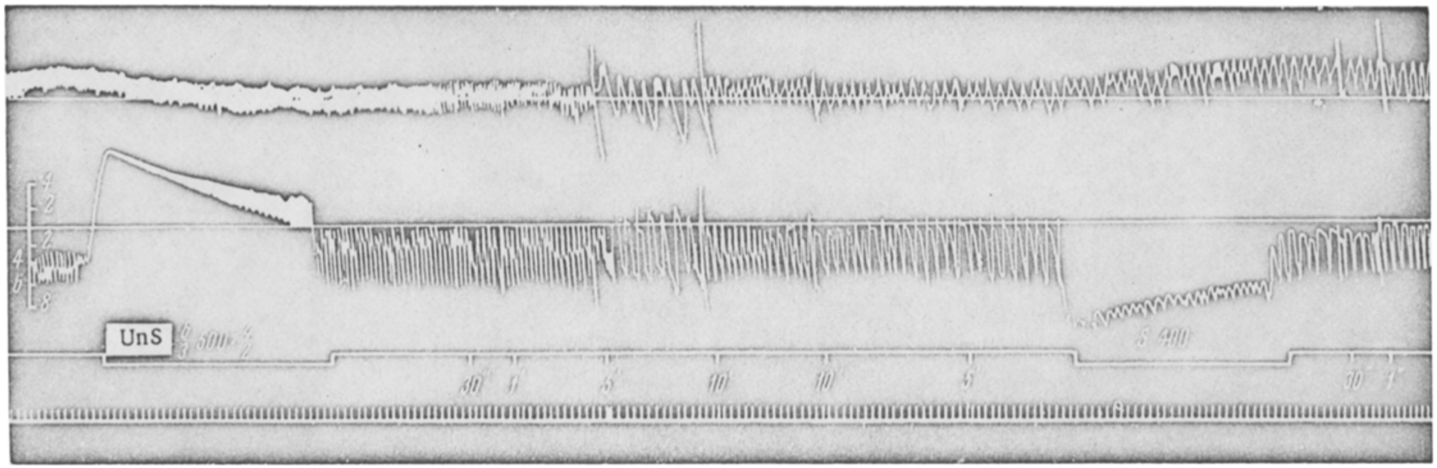

Fig. 3. Changes in thoracic volume and intrapleural pressure upon induction of closed pneumothorax and on subsequent aspiration of air from the pleural cavity. Dog Chernushka, weighing 23 kg. Date of experiment October 7, 1954.

Records (from above down): pneumogram (inspiration – downward deflection, intrapleural pressure and its base line, signal line (UnS_{500} – 500 ml air introduced into the left pleural cavity; asp. S_{400} – 400 ml air aspirated from the left pleural cavity; figures underneath the signal line – period of time during which the kymograph was stopped; time marker (2 seconds).

In the second series of experiments, performed on the dogs Prim and Chernushka, kymographic records were made of the respiratory movements of the thorax and the abdomen, intrapleural pressure and the magnitude of pulmonary ventilation. A hermetic mask was placed on the dog's muzzle in order to record pulmonary ventilation. The expired air passed from the mask by a connecting tube to a gas meter, the movement of whose needle was recorded on the kymograph by means of electric contacts and an electric marker. The marker recorded a mark for every 200 ml of air which passed through the gas meter.

EXPERIMENTAL RESULTS

When 30-60 ml of air was introduced into the intrapleural space of cats (weighing 2.5-3.5 kg) substantial changes were recorded in the interrelation and functions of the intrathoracic organs. The kymograms show (Fig. 1) that immediately after induction of pneumothorax the increase in intrapleural pressure is accompanied by considerable increase of inspiratory tonus of the thoracic respiratory musculature. The thorax passes into the position of inspiration as it were, but its respiratory excursions continue and their amplitude not only does not diminish but is even enhanced to some extent. The volume of the thorax thus increases following induction of pneumothorax.

The amplitude of the curve recorded from the trachea under these experimental conditions shows an increase. The blood pressure in the carotid artery drops by 5-10 mm Hg at the moment of induction of pneumothorax and then returns to the initial level or rises by 10-15 mm Hg.

After a certain time has elapsed from the induction of pneumothorax the respiration and circulation settle down at a level somewhat different from the initial one. The inspiratory tonus of the thorax gradually decreases while intrapleural pressure, despite the presence of air in the pleural cavity, displays a tendency to return to the initial level characteristic for the given animal.

Following additional introduction of air into the pleural cavity and creation of a more "tense" pneumothorax (Fig. 1, S_{50}) the inspiratory tonus of the thorax becomes still more marked. The amplitude of the respiratory curve recorded from the trachea at the moment of induction of pneumothorax drops to zero and then increases gradually beyond the initial level. This pnenomenon is apparently determined by changes in the lumen of the air passages.

The blood pressure in "tense" pneumothorax shows a small fall at the moment of pneumothorax induction followed by a rise when fluctuations associated with respiratory phases become considerably enhanced.

• Following aspiration of air from the pleural cavity, respiration and blood pressure gradually return to normal (Fig. 1, S_{80}).

The phenomenon of increased inspiratory tonus of the thorax and the increase in its mean volume after induction of pneumothorax described above has also been observed after preliminary section of the phrenic nerves in the neck. The effect was diminished but not abolished by bilateral vagotomy.

In the long-term experiments on dogs, data similar to those given by the short-term experiments on cats were obtained. The kymograms show (Figs. 2 and 3) that induction of closed pneumothorax is accompanied by a compensatory expansion of the thorax and changes in the inter-relations of the respiratory phases. Not infrequently respiratory arrest at the beginning of expiration was noted at the moment of induction of pneumothorax (Fig. 2).

There is some decrease in pulmonary ventilation and depth of inspiration at the moment of pneumothorax induction and immediately following it, but after only a few minutes the pulmonary ventilation returns to normal or even exceeds that value. The latter indicates that the lungs execute considerable respiratory movement after induction of pneumothorax. The intrapleural pressure in the experimental dogs returned to normal 2-3 days after the induction of pneumothorax, i.e., before the air in the pleural cavity was absorbed.

DISCUSSION

The results obtained show that artificial closed pneumothorax elicits substantial changes in respiration, and, within certain limits, promotes the appearance of a number of compensatory-adaptive reactions of the organism as a whole. There is no doubt that in "unstrained" pneumothorax collapse of the lung is not the main and significant factor in the mechanism of pneumothorax action.

The fact noted by us, viz. that the intrapleural pressure returns to the initial level before the absorption of the air from the pleural cavity, agrees with the data obtained by a number of authors [1, 2, 4, 5, 10, 11] who also observed inconsistencies between the volume of air introduced into the pleural cavity and the magnitude of change in intrapleural pressure.

F. Parodi [11] had used this fact to prove his "theory of pulmonary weight." Other authors regarded it as the basic argument for postulating a theory of pleuro-pulmonary reflex [1, 4, 5, 9].

We conclude on the basis of our experiments that the inconsistency between the volume of air introduced and intrapleural pressure during pneumothorax is the result of compensatory expansion of the thorax elicited by a reflex from the pleural and pulmonary interoceptors affecting the tonus of respiratory musculature. Under conditions of pneumothorax this reflex ensures adaptive changes in the inter-relation of the mean volume of the thorax and volume of the lungs. The possibility of reflex changes in the tonus of bronchial muscles and pulmonary blood vessels must also be kept in mind [3, 7, 8, 10, 12, 13].

The biologic significance of these reflexes should be considered in terms of the importance of maintaining a relative physiologic equilibrium in the system's respiratory apparatus – intrapleural pressure. This equilibrium must be referred to a number of such finely regulated body constants as the physicochemical composition of the blood, body temperature, blood pressure etc.

The tendency of the lung to expand to its natural volume after induction of pneumothorax, as well as the fact of absorption of air from the pleural cavity, favor this concept.

It is not surprising that these reflexes are masked under physiologic conditions and are not immediately detectable. When the organism is placed under extreme conditions these reflexes tend to appear more clearly.

SUMMARY

Short-term experiments were performed on cats and prolonged ones on dogs. It was established that in "unstrained" experimentally-induced closed pneumothorax intensive respiratory movements were performed by the lungs. Pneumothorax causes compensatory expansion of the thorax by reflex mechanism which acts from interoceptors of the pleura and lungs on the tone of the respiratory muscles.

Reflex regulation of the average volume of the thorax and the ratio of the volume of the thorax to that of the lungs is postulated.

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