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THE TONE OF RESPIRATORY MUSCLES IN ACUTE CHANGES OF CIRCULATION INDUCED BY ACETYLCHOLINE

M. JANOTA and F. ZAJÍC

Institute of Clinical and Experimental Medicine, Prague, Czechoslovakia

Abstract. The role of respiratory muscles in acute changes of circulation and ventilation due to acetylcholine in anaesthetized spontaneously breathing rabbits was investigated. Significant increase of end-expiratory thoracic circumference and insignificant increase of abdominal one was found and was taken as a measure of changed respiratory muscles tone. The authors emphasize the important role of the respiratory muscles in the regulation of the thoracic and the abdominal volume. The increased lung volume is due to the action of the respiratory muscles of thorax and diaphragm. The abdominal muscles and diaphragm may regulate the abdominal volume and play important part in the redistribution of the blood.

INTRODUCTION

The respiratory muscles have two functions: the rhytmical activity regulates the ventilation and the tonic activity controls the thoracic and the abdominal volume (Hill 1895, Mosso 1903, Mead and Agostoni 1964, and others). The muscles of thoracic wall and diaphragm regulate the thoracic volume, where the main changes of functional residual capacity are observed. The muscles of abdominal wall and diaphragm regulate the abdominal volume, which can be changed by the shift of the blood into splanchnic cavity (Verzár 1946, Konno and Mead 1967, Janota and Zajíc 1971).

In previous studies we have observed some changes of the tone of respiratory muscles in pulmonary oedema (Zajíc et al. 1962), in orthostasis, hypervolemia and in noradrenalin induced hypertension. (Zajíc and Janota 1969, 1970). We suppose that the tone of the respiratory muscles could play an important role also in some other circulatory states, as in shock or in hypotension. We decided to study the role of the tone of the respiratory muscles of thorax and abdomen during acute hypotension induced by acetylcholine.

MATERIAL AND METHODS

Eighty experiments were done with eight spontaneously breathing anaesthetized rabbits (urethan 1 g/kg) with closed chest. The trachea, jugular vein and carotid artery were dissected. Catheters for measurement of pressures were induced into carotid artery, pulmonary artery and caudal vena cava and into cranial vena cava for application of acetylcholine. The intrathoracic pressure was measured indirectly in oesophagus.

Spirometer with closed circuit was used for the measurement of ventilation. Body plethysmograph was used for examination of the changes of functional residual capacity. The changes of thoracic and abdominal end-expiratory circumference were measured by pneumographs as a measure of the tonic changes of the respiratory muscles.

The acute hypothesion was induced by intravenous injection of acetylcholine in the dose, that resulted in a marked change of circulation and ventilation (0.15–0.30 μg/kg). All parameters were recorded continuously by an optical kymograph (Zimmermann) and by a direct-writer (Gallileo). The evaluation was concentrated to 1 min before and after the injection, and the control period was compared with the period of maximal pressure decrease. The experiments were repeated after 5 min.

RESULTS

One typical reaction to acetylcholine was demonstrated (Fig. 1). Ten to 20 sec after the injection of acetylcholine (vertical line) the arterial pressure decreased by 65 mm Hg. The pressure in caudal vena cava and in pulmonary artery increased. A transitory decrease of total ventilation of 67 ml per 10 sec was observed (by decrease of tidal volume). Inspiration in spirogram (SPG) as in plethysmogram (PLT) was recorded in the upward direction. At the same time we observed an increase of the oesophageal pressure negativity (P_{OE}) and a shift of the end-expiratory position of the thoracic and abdominal wall (Png T, Png A) in the direction of inspiration. The shift of the end-expiratory position of body plethysmograph towards inspiration suggests an increase of functional residual capacity of 20 ml.

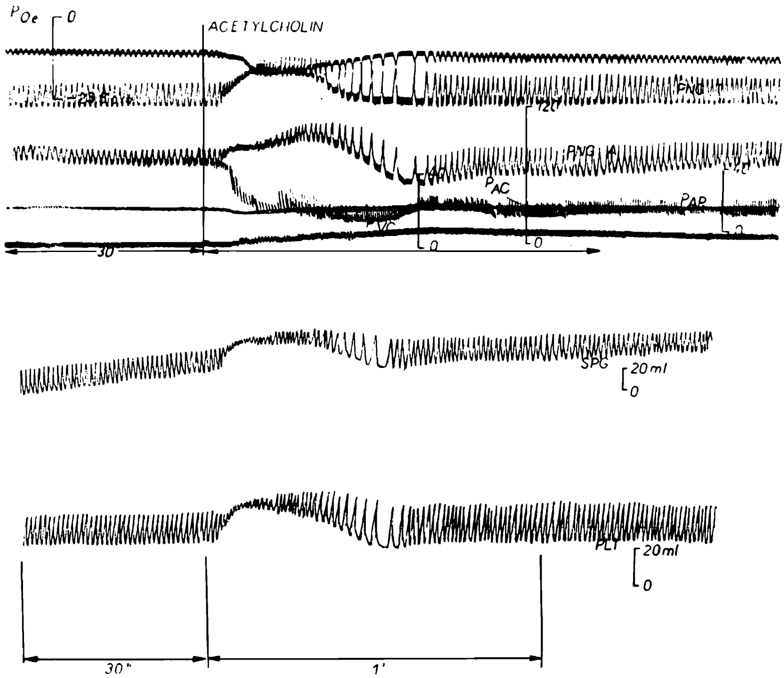

Fig. 1. The reaction to acetylcholine. P_{OE}, oesophageal pressure; Png T, pneumogramma thoracis; Png A, pneumogramma abdominis; P_{AC}, pressure in arteria carotis; P_{AP}, pressure in arteria pulmonalis; P_{VC}, pressure in vena cava caudalis; SPG, spirogramm; PLT, plethysmogramm (inspiration upward).

Our experiments are not so precise to conclude in every case that the change in thoracic volume was due to the change of the lung volume only (FRC). That is why we think of the possible shift of the blood into the abdominal cavity. In some X-ray pictures taken after acetylcholine injection the shadow of the heart decreased in accordance to Fízel and Fízelová (1966) and the diaphragm either shifted in the direction of inspiration or it did not change.

Our experiments confirmed the well known response of circulation and ventilation to acetylcholine (Schweitzer and Wright 1938, Liljestrand 1952, Bělov 1959, Wiemer 1962, and others) (Fig. 2). Some specific changes of thoracic and abdominal circumference, of functional residual capacity and oesophageal pressure were observed (Fig. 3). The results of the 80 experiments are summarized in this Figure. The increase is marked black, decrease, white, and no change, striped. A significant increase of the circumference of thorax (Png T) in 65% ($p < 0.005$) but insignificant increase in the circumference of abdomen (Png A) in 51%

was found. The increase of the FRC in 73% was also significant ($p < 0.001$). The changes of the oesophageal pressure were not significant.

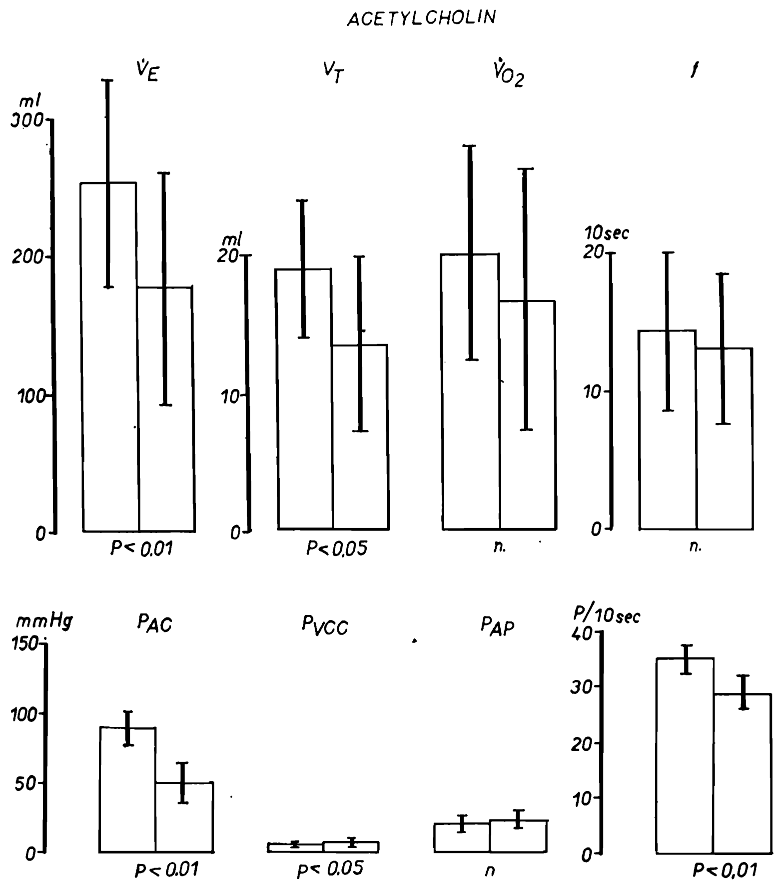

Fig. 2. Ventilation and circulation before (left) and after (right) acetylcholine. $\dot{V}_E$, ventilation; V_T, tidal volume; $\dot{V}_{O_2}$, oxygen uptake; *f* frequency of breathing; *P*, heart rate; P_{AC}, P_{VCC}, P_{AP}, pressure in arteria carotis, vena cava caudalis and arteria pulmonalis.

DISCUSSION

The circumference of the chest wall is sometimes taken as the information of the change in thoracic volume and the circumference of abdominal wall as that of the change in abdominal volume. The scheme is however of limited value only because of the movement of the

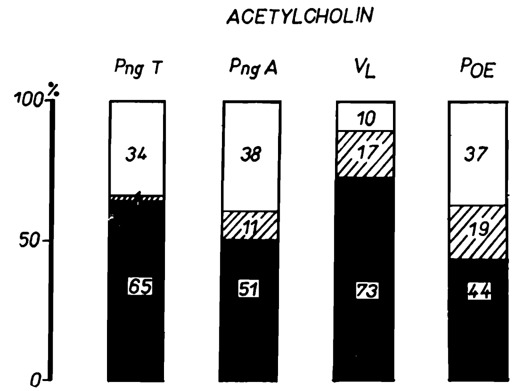

Fig. 3. Changes of thoracic and abdominal circumference (Png T, Png A), functional residual capacity (V_L), oesophageal pressure (P_{OE}).

diaphragm and of possible shift of blood volume between thorax and abdomen. The typical reaction after acetylcholine injection was the increase in the thoracic and abdominal circumference, but in some cases the reaction was variable. This variability can be explained mainly by the shift of the diaphragm and by the redistribution of the blood between the thoracic and the abdominal cavity. These two factors were evaluated only indirectly and this is why we cannot come to definite conclusions in some points.

In some of the experiments we can indirectly ascertain the shift of the diaphragm from the known position of thoracic wall and from increased negativity of the oesophageal pressure. In most of the cases diaphragm shifted towards inspiration. This agrees with the X-rays pictures done after acetylcholine injection. The diaphragm either shifted towards inspiration or was unchanged. The shift of the blood to splanchnic vessels can be expected in the experiments with increased abdominal circumference where no change of diaphragm position was observed, and where diminution of the heart shadow was found.

The increase of the functional residual capacity (FRC) can be due to: (i) the increase of the circumference of the thorax, (ii) the caudal shift of the diaphragm in direction to inspiration, (iii) the shift of the blood volume to the abdominal cavity, (iv) the combination of these factors. If the increase of FRC is caused only by the retention of the air in the alveoli after acetylcholine provoked bronchoconstriction, the chest wall will passively adapt this situation and we could expect a decreased or unchanged negativity of the oesophageal pressure. But the variability of the oesophageal pressure changes is an argument against the importance of the bronchoconstriction in these regulations. It can also be taken as an argument for the active role of the thoracic wall muscles and diaphragm in the regulation of the thoracic volume. It seems that the FRC is the most important acutely changing part of the thoracic volume and can be easily changed by the communication with atmosphere.

Little is known about the changes of the abdominal volume. It is regulated by the abdominal wall and diaphragm and can easily be changed by the blood redistribution. Indirect signs of these changes were observed in our experiments with acetylcholine. In our experimental set up we can exclude the participation of such factors as the intake of food and water, the excretion of urine, excrements and intestinal gases. To learn better the changes in the volume of the abdominal cavity it would be necessary to measure simultaneously thoracic and abdominal wall with diaphragm, pressure changes in the thoracic and abdominal cavity to observe volume changes on the periphery and to measure directly the blood in the abdominal cavity. Such experiment would be very difficult and it is necessary to look for new methods in the next work.

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M. JANOTA and F. ZAJÍC, Institute of Clinical and Experimental Medicine, Budějovická 800, Praha 4, Czechoslovakia.