EFFECT OF VAGOTOMY OF EXTERNAL RESPIRATION IN THE TERMINAL STATE AND IN THE RECOVERY PERIOD AFTER CLINICAL DEATH

S. V. Tolova

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Afferent impulses traveling along the vagus nerves are known to influence the formation of the rhythmic activity of the respiratory center, while the expiratory center performs the finer regulation of the respiration through reflexes involving the participation of the vagus nerves [6, 8, 9, 13-15].

In the present investigation the effect of division of both vagus nerves on the dynamics of certain indices of external respiration and on the structure of the respiratory act was studied during dying from blood loss and during the first 1.5-3 h after resuscitation of dogs after a period of clinical death lasting 5 min.

EXPERIMENTAL METHOD

Twelve acute experiments were carried out on adult dogs. To record the electromyogram (EMG), the animals were anesthetized with Pantopon and fluothane and electrodes [3] were inserted into the inspiratory (diaphragm, external intercostal muscles), expiratory (external oblique, transversus abdominis muscles), and accessory respiratory muscles (cricothyroid, sterocephalic, and lingual muscles). In addition, to record the electrocorticogram (ECoG) electrodes were implanted into the cerebral cortex. The EMG, ECoG, electrocardiogram (ECG), and pneumogram were recorded on an "Alvar" electroencephalograph with outputs to a loop oscillograph (MPO-2). The arterial pressure in the femoral artery, the pneumogram, and the volume of the pulmonary ventilation were recorded on kymograph paper. After the animal had recovered from the anesthetic (as verified by the ECoG) the two vagosympathetic trunks were divided in turn in the neck (after being first taken on ligatures). When the new rhythm of respiration was established, massive bleeding began from the femoral artery until the onset of clinical death. Resuscitation was carried out by the method of V. A. Negovskii and co-workers [7] by intra-arterial injection of the escaping blood with adrenalin against the background of artificial respiration. If ventricular fibrillation began it was abolished by the discharge of a defibrillator with a voltage of 3000-4000 V by N. L. Gurvich's method [4].

EXPERIMENTAL RESULTS

The mean duration of the terminal process in the vagotomized dogs after blood loss was 19.6±3.9 min. During the first minutes of bleeding despite the fall of arterial pressure to 18-20 mm, in most experiments the phase of an increase in the rate and depth of respiration, always observed in dogs with intact vagus nerves, was absent. In the subsequent minutes the respiration rate increased slightly. Next, with continuing blood loss, the respiration rate fell, its rhythm was disturbed, the amplitude of the respiratory movement diminished, and after a terminal pause, agonal respiration started. The duration of agony in the vagotomized dogs was 3.79±0.91 min, significantly ($P < 0.01$) less than in dogs with intact vagus nerves.

At the beginning of blood loss, the amplitude of the biopotentials of the inspiratory muscles was unchanged in most experiments (Fig. 1A, B). In the subsequent minutes an increase of amplitude was observed, followed by a gradual decrease (Fig. 1C, D). In the expiratory muscles in half the experiments, the amplitude of the biopotentials increased after the first minute of blood loss. The electrical activity of the muscles of expiration then diminished and disappeared entirely before the terminal pause (Fig. 1A-E). In the accessory respiratory muscles of the neck during the terminal process, against the background of

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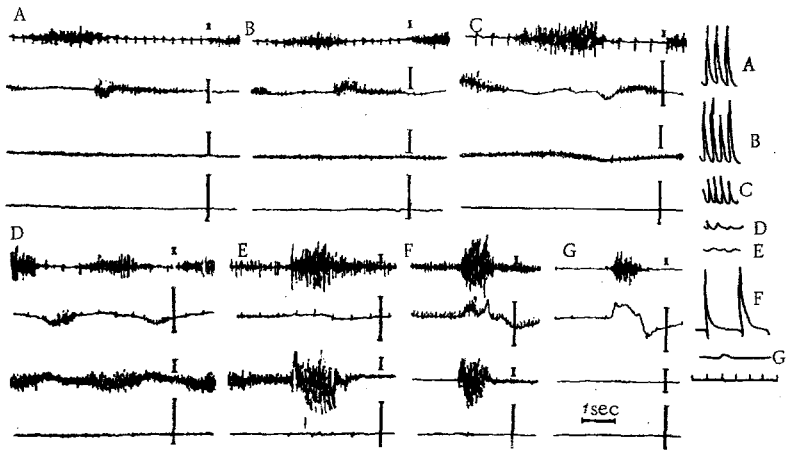

Fig. 1. Changes in the structure of the respiratory act in a vagotomized dog during dying from blood loss. EMG (scale of amplification 50 μV), pneumograms (time marker 5 sec) of a dog weighing 17 kg (experiments on March 25, 1965). From top to bottom in all cuts of the EMG: diaphragm, external oblique muscle, lingual muscle, extensor muscle of the forelimb. A — Before blood loss, B — second minute, C — beginning of 7th, D — end of 7th, E — 8th, F — 11th (agony), G — 12th minute of dying (last agonal inspiration).

tonic activity, fast activity appeared in inspiration (Fig. 1D). During agony the expiratory and all the accessory respiratory muscles contracted simultaneously with the inspiratory muscles at inspiration (Fig. 1F). Just as in the experiments on animals with intact vagus nerves the activity in the expiratory muscles disappeared earlier than in the inspiratory muscles during the process of dying (Fig. 1G).

The pulmonary ventilation increased at the beginning of bleeding on the average to 162±8.3% of its value after vagotomy ($P < 0.01$), taken as the original level, but later with the slowing of respiration and the disturbance of its rhythm the minute volume of respiration fell to 38±8.8% ($P < 0.01$) of its original level. During agony the pulmonary ventilation was only 16.7±4.7% of its initial value.

Clinical death lasted for 5 min. The vital functions were restored in 10 of the 12 dogs. In 7 animals respiration returned in the first 4 min after the beginning of resuscitation, while in 3 animals during clinical death ventricular fibrillation developed, as a result of which the cardiac activity and respiration were restored at later periods.

In the experiments when spontaneous respiration was restored comparatively early (in the first 4 min) after switching off the artificial ventilation, pathological types of breathing (gasping, paroxysmal, apneustic) persisted for 35±6.6 min after resuscitation, compared with only 28.5±4.43 min in the animals with intact vagus nerves ($P < 0.05$).

On the EMG during the initial inspiration activity was recorded in the inspiratory and in all the accessory respiratory muscles in inspiration (Fig. 2A). The expiratory center began to function later than the inspiratory, just as in the experiments on dogs with intact vagus nerves, on the average by 9.9±0.62 min. The character of respiration of the electrical activity in the expiratory muscles of the vagotomized dogs was the same as in the intact animals (Fig. 2B-I) [11]. In the accessory respiratory muscles activity in inspiration persisted for a longer time, whereas in the dogs with intact vagus nerves it disappeared soon after restoration of the reciprocal relationship between the inspiratory and expiratory centers.

The pulmonary ventilation after resuscitation and before restoration of the electrical activity in the expiratory muscles was significantly less than initially. With the appearance of active expiration the pulmonary ventilation increased, and if the ventricles were not affected by fibrillation, it exceeded the initial level for 1.5-3 h, but in the experiments with late restoration of respiration, it remained below the initial level throughout the period of observation.

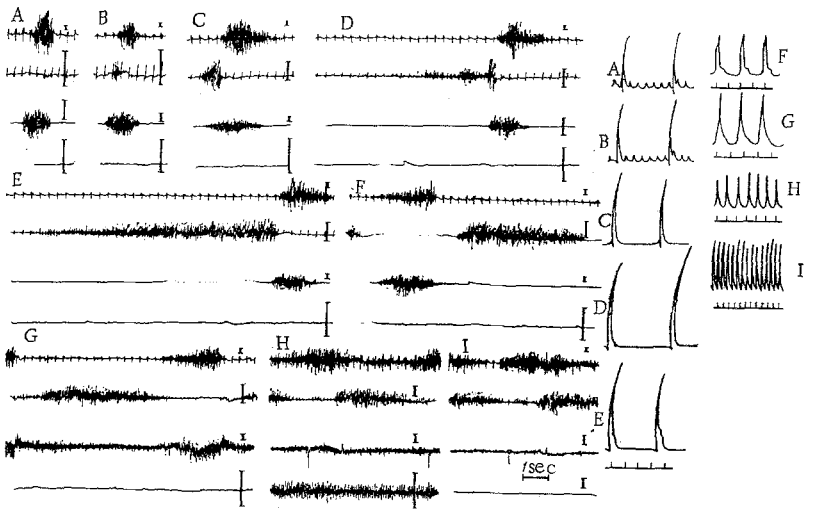

Fig. 2. Changes in the structure of the respiratory act after resuscitation of a vagotomized dog after clinical death lasting 5 min. EMG and pneumograms obtained in the same experiment as that whose results are given in Fig. 1. A) 4th, B) 7th minute after the beginning of resuscitation against the background of artificial ventilation, c) 11th, D) 13th, E) 15th, F) 22nd, G) 33rd, H) 44th, I) 90th minute after the beginning of resuscitation. Remainder of legend as in Fig. 1.

The experiments on vagotomized dogs dying from blood loss in which the vital functions were subsequently restored thus demonstrated the absence of a phase of compensatory increase in the rate and depth of respiration at the beginning of blood loss and also an increase in the amplitude of the biopotentials of the respiratory muscles, indicating lowered excitability of the respiratory center [1, 5, 8]. With deepening hypoxia the respiration rate increased, but to a much lower degree than in the dogs with intact vagus nerves.

Binet and Strumza [12] consider that in the process of dying the terminal pause in respiration or the primary anoxic apnea, arises as the result of an increase in the tonus of the vagus nerve center, and in vagotomized animals the primary anoxic apnea is absent. I. A. Arshavskii [2] also considers that the arrest of the heart and respiration in the third phase of thanatogenesis is vagal in origin. In the present experiments the terminal pause in respiration was clearly apparent despite the vagotomy; in one experiment it lasted 4.5 min. It may accordingly be suggested that the mechanism of the terminal pause is more complex and cannot be explained by an increase in the tonus of the vagus nerve centers alone. Since respiration in the vagotomized dogs in the experiments with an uncomplicated recovery period was restored at the same times as in the dogs with intact vagus nerves, it may be concluded that reflex stimulation of respiration during artificial ventilation at the beginning of resuscitation took place not only on account of afferent influences on the respiratory center from the receptors of the lungs [7, 10].

Vagotomy did not prevent restoration of reciprocal relationships between the inspiratory and expiratory centers after total suppression of respiration, and the vagus nerves did not play a decisive role in the postterminal states in the formation of the rhythmic activity of the respiratory center. However, despite the relatively rapid restoration of spontaneous breathing and reciprocal relationships between the inspiratory and expiratory centers, normal external respiration was not restored in the vagotomized dogs after clinical death and respiratory insufficiency was present, as shown by the participation of the accessory respiratory muscles in respiration and by the presence of hyperventilation.

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