# STRUCTURE OF THE RESPIRATORY CYCLE DURING EXTINCTION AND RESTORATION OF VITAL FUNCTIONS

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When the brain is subjected to oxygen starvation, produced by circulatory interruption, various types of respiratory derangement is observed [2, 3, 11, 18, 19, 25, 28, etc.]. Recording of the currents in respiratory muscles during clinical and experimental studies permits a more detailed study of the activity of the respiratory center both in the normal and in pathologic states of the organism [4, 7, 10, 12-16, 21, 22, 26, 27, 29, 31, etc.].

The present work was designed to study the structure of the respiratory cycle by electromyographic analysis of the main and accessory respiratory muscles in different stages of the extinction of vital functions during dying from blood loss and in the first $1\frac{1}{2}$-3 h after resuscitation of the animals undergoing 3-5 min of clinical death.

## METHOD

Thirteen experiments were performed on adult dogs weighing 8-25 kg. Under fluothane inhalation anesthesia electrodes were placed in the respiratory muscles to record the EMG [6] and in the cerebral cortex to record the electrocorticogram (ECoG). The electrical activity of the following muscles was investigated: inspiratory (diaphragm, external intercostals), expiratory (internal intercostals, rectus, transversus and obliquus externus abdominis), and the accessory muscles (transverse thyroid, sterno-cephalic and tongue muscles). The EMG, ECoG, EKG, and pneumogram (PG), recorded by a thermosensitive element fixed in the incubator, were inscribed on "Al'var" electroencephalographic

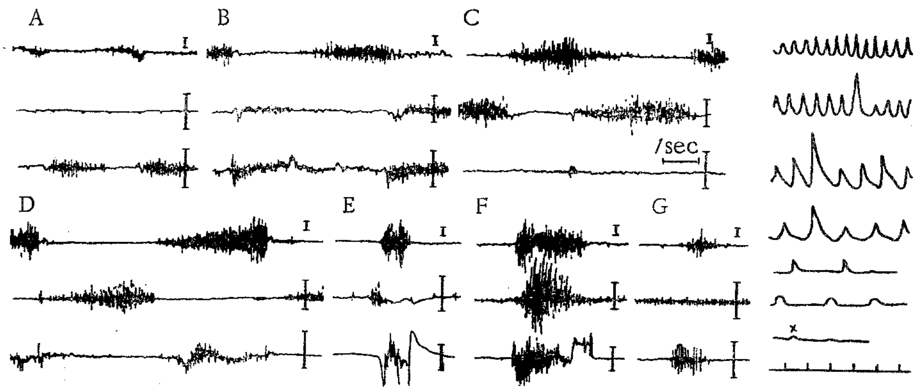


Fig. 1. Change in respiratory cycle structure in the process of dying from blood loss. EMG (scale of amplification 50 microvolts) and PG (marks at 5 sec intervals) of experiment on dog weighing 23.5 kg performed 9/25/62. From top to bottom in all segments of EMG: diaphragm, transversis abdominis, and cricothyroid muscle. A) Before blood loss; B) 1st min; C) 5th min; D) 11th min; E) 19th min; F) 22nd min of dying; G) last agonal inspiration at 22nd min of dying.

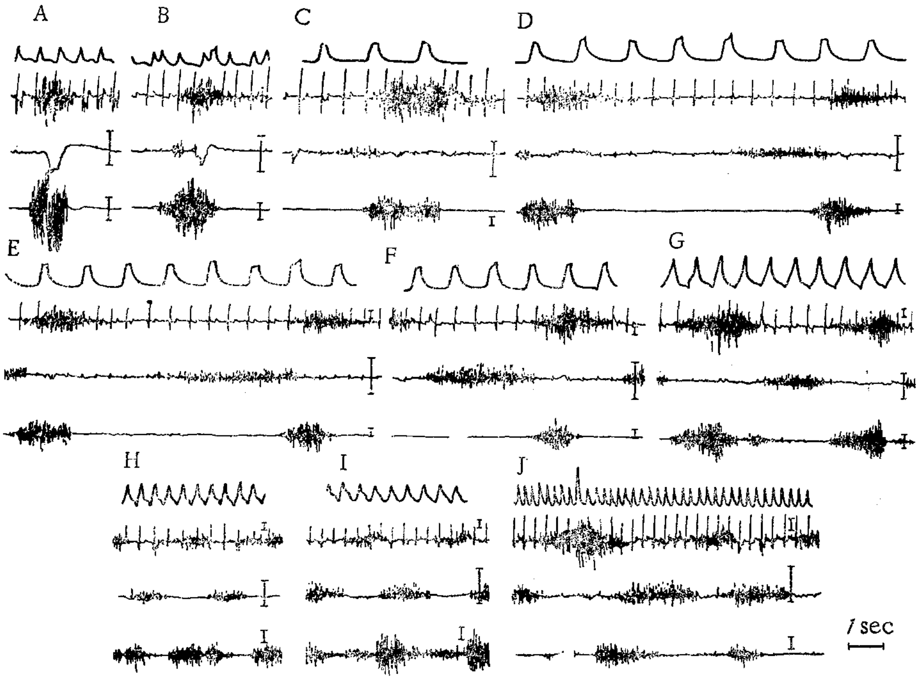


Fig. 2. Change in respiratory cycle structure during restoration of vital functions after clinical death. EMG (scale of amplification 50 microvolts) and PG (marks at 5 sec intervals) of experiment on dog weighing 17 kg. From top to bottom in all segments of the EMG: diaphragm, transversis abdominis, and cricothyroid muscle. A-3rd, B-6th, C-8th, D-9th, E-10th, F-12th, G-15th, H-22nd, I-46th, and J-88th min after beginning of resuscitation.

film and in parallel on a trace oscillograph MPO-2. The arterial pressure in the femoral artery, the PG and the pulmonary ventilation volume [8] were recorded on a tape kymograph. Observations were made of the dynamics of the eye reflexes and the total condition of the animal. After the animal came out of anesthesia (ECoG served as control) it underwent a massive blood removal from the femoral artery (0.8% solution of heparin, 0.5 ml/kg had previously been injected) until the appearance of clinical death. The animals were resuscitated by the method developed by V. A. Negovskii and co-workers (intra-arterial pumping of the blood which had been removed with adrenalin, artificial respiration).

## RESULTS

Changes in the Structure of the Respiratory Cycle During Dying. Up to the bloodletting the activity of the inspiratory and some accessory neck muscles, which contracted either on inspiration or on expiration, were recorded on the EMG. Electrical activity, as a rule, was lacking in the expiratory muscles—expiration usually proceeded passively (Fig. 1A). During the process of dying from blood loss certain stages of change in respiration were observed: respiration became deeper and more rapid, there was alternating respiration, decreased amplitude and frequency of respiratory movements, a terminal pause, after which agonal respiration followed. In the stage of deeper and more rapid respiratory movements in the inspiratory and accessory respiratory muscles the amplitude variation on the EMG rose 2-3 times, while during expiration electrical activity appeared in the expiratory muscles (Fig. 1B). The EMG fluctuations of the inspiratory muscles reached greatest amplitude during intercalary inspirations with predominant amplitude of the respiratory movements. In the stage of decreasing frequency and depth of respiratory movements the amplitude of EMG fluctuation from the respiratory muscles exceeded the initial value by 4-5 times and fell only before the terminal pause. In the accesory respiratory muscles of the neck, for example in the transverse thyroid muscle, during dying, the amplitude of the burst initially increases during inspiration, the activity decreases during expiration, increases again during inspiration; this muscle still contracts only during inspiration up to the occurrence of the terminal pause (Fig. 1 A-D). The sterno-cephalic muscle and the tongue muscles, as a rule, take no part in quiet respiration, but during dying phasic activity during inspiration appears on a background of constant tonic activity.

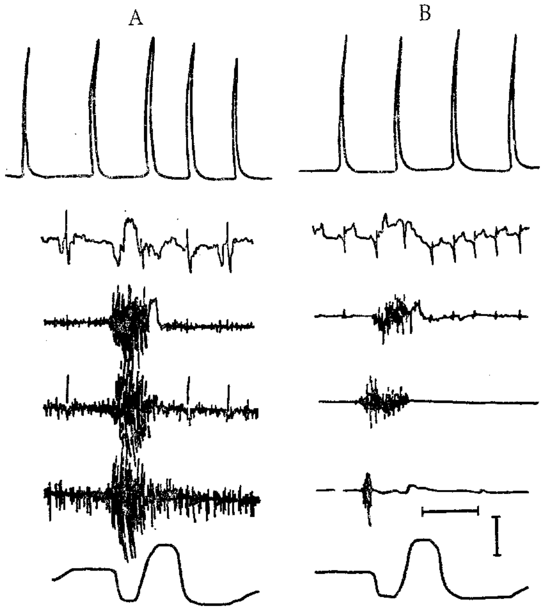


Fig. 3. Respiratory cycle structure during agonal respiration in dying and after resuscitation. Experiment from 1/7/63 on a dog weighing 14.5 kg. A) Structure of agonal inspiration during dying; volume of single inspiration 240 ml, pulmonary ventilation 1.2 liters/min. From top to bottom: pneumogram, EKG, EMG of diaphragm (scale of amplification 50 microvolts), EMG of muscle (scale of amplification 12.5 microvolts) and EMG of transversus abdominis (scale 6 microvolts); B) structure of respiratory cycle during agonal type respiration after resuscitation. Volume of single inspiration 880 ml, pulmonary ventilation 4.4 liters/min. From top to bottom: pneumogram, EKG, EMG of diaphragm (scale of amplification 100 microvolts), EMG of muscle (scale 100 microvolts), EMG of transversus abdominis (scale 12.5 microvolts).

The structure of the respiratory cycle during agonal respiration varied. In the first agonal inspirations the expiratory muscles did not participate, and registered tonic activity. The expiratory muscles contracted during inspiration simultaneously with inspiratory and accessory respiratory muscles during later agonal inspirations. The amplitude fluctuation on the EMG at the time of the agonal respiration was marked (Fig. 1 E, F). Bursts of impulses, coinciding with the respiratory rhythm during agonal respiration, may be detected in practically all muscles of the trunk and extremities. Phasic electrical activity in the expiratory muscles during dying disappeared earlier than in inspiratory or accessory muscles (Fig. 1 G). During clinical death there was no electrical activity in the respiratory muscles.

Recording of pulmonary ventilation permitted comparison of the structure of different types of terminal respiration with its effectiveness. During the phase of rapid, deep respiration pulmonary ventilation increased by a mean of 1.7 liters/min. ($P < 0.05$), then as respiration slowed and the amplitude of respiratory movements decreased, it fell below the initial values by a mean of 1.9 liters/min ($P < 0.05$), but remained at a rather high level for some time. The contraction of expiratory muscles during agonal respiration simultaneously with the inspiratory muscles made inspiration difficult and lowered the effectiveness of external respiration, pulmonary ventilation during the agonal phase being 4.42 liters/min ($P < 0.01$) on the average below the initial value.

Changes in Respiratory Cycle Structure During Resuscitation. Depending on the severity of the central nervous system injury inflicted during the dying process, some type of normalization of the respiratory cycle structure was observed in the resuscitation period. In analyzed experiments the period of dying was $19.5 \pm 7.01$ min, resuscitation was not complicated by fibrillation of the heart, respiration was restored in the first 4 min after resuscitation was begun, corneal reflexes appeared on the average after $11.8 \pm 3.7$ min from the start of resuscitation.

During resuscitation the pathological types of respiration occurred in reverse sequence. After 3-5 min of clinical death produced by blood loss, V. A. Negovskii described 4 basic phases of respiration: initial breaths, agonal type respiration, alternating respiration and respiration with intercalary inhalation. During the initial breaths on a background of artificial respiration, synchronous bursts in the inspiratory and accessory respiratory muscles are observed on the EMG (Fig. 2A). The fluctuation amplitude on the EMG gradually increased as the amplitude of respiratory movements improved. The electrical activity in the expiratory muscles appeared after a mean of $11.2 \pm 1.9$ min. Initially this activity was recorded at the beginning of inspiration as short (0.2-0.4 sec) bursts (see Fig. 2B). Later activity appeared at the end of the respiratory pause and gradually "moved" toward the preceding inspiration and after several minutes occupied the entire period of expiration and the respiratory pause (Fig. 2C, D, E). Short bursts at the very beginning of inspiration disappeared. The restoration of expiratory muscle activity during inspiration coincided in time, in 9 out of 13 experiments, with the appearance of the corneal reflexes. Use of artificial respiration hastens the appearance of expiratory muscle activity during expiration. In the first minutes after the appearance of spontaneous respiration, the transverse thyroid muscle contracted during inspiration (see Fig. 2A-E), then weak activity appeared in it during expiration, which grew stronger, the amplitude of the bursts during inspiration gradually decreasing and the nature of the muscular contraction returning to the original level (Fig. 2 F-I). In the sternocephalic muscle and the tongue muscles phasic activity during inspiration disappeared as respiration became normal and only weak tonic activity remained.

Pulmonary ventilation after withdrawal of artificial respiration in the period of agonal and convulsive respiration was 3-12 times lower than the initial level. However, the volume of one agonal-type breath after resuscitation was greater than that during the dying agonal period by pneumographic characteristics but had different structure (Fig. 3A-B). The pulmonary ventilation volume began to increase with the appearance of electrical activity in expiratory muscles during expiration. During a certain period the pulmonary ventilation significantly exceeded the original value (sometimes by 2 times) and as the respiratory cycle structure became normal returned to the original level. A completely normal respiratory cycle appeared after $1^1/_2$-3 h from the start of resuscitation, though respiration on the pneumogram was normal earlier.

Thus, after blood loss, the process of stimulation of the respiratory center is intensified in the phase of rapid and deep respiration, as may be judged by the significant increase in fluctuation amplitude on the EMG of respiratory muscles. In this period, the expiratory muscles are included in the respiratory cycle—expirations become active. The participation of the accessory respiratory muscles in breathing indicates inclusion of supplementary mechanisms. Pulmonary ventilation, over some time, despite the very low arterial pressure (15-20 mm) is maintained at a rather high level as a result of these supplementary mechanisms, although it is attained, as L. L. Shik [21] has said "at a high price" of strong stimulation of the respiratory center, which leads in the end to its complete exhaustion.

During agonal respiration disruption occurs in the reciprocal relations between the inspiratory and the expiratory centers which normally control the rhythmicity of respiration [17, 20, 24, 30, etc]. The synchronous contraction of inspiratory and expiratory muscles during the agonal period indicates the discoordination of all functions of the organism in the extreme stages of dying. A. M. Gurvich [9] has hypothesized that during the agonal period both the nature of the stimulation and the structure and location of the respiratory center itself are altered. According to many workers the center is not strictly localized, but appears as a functionally mobile structure. In the coordination of the respiratory cycle during the agonal period it is possible that the reticular formation, which lies beyond the borders of the classical medullary center, is a participant.

On the basis of the appearance of electrical activity in the expiratory muscles during expiration simultaneously with the restoration of the corneal reflexes it may be hypothesized that the structure which mediates the active expirations is located in the brain stem at the border between the medulla oblongata and the pons Varoli. The central mechanisms which mediate active expiration appear earlier in severe hypoxia. This hypothesis find verification in the work of a number of authors [17, 23, and others], which observe earlier exclusion of expiratory muscles from the respiratory cycle with inhibition of respiration and later inclusion of them when the activity of the respiratory center is restored. I. A. Arshavskii [1] and E. L. Golubeva [5], in studies of the formation of inspiratory and expiratory parts of the respiratory center in ontogenesis, showed that the expiratory center begins to function later than the inspiratory one.

Complete return to normal respiratory function after resuscitation must be assessed only on the basis of complex study of the indices of internal respiration, gas exchange and respiratory cycle structure.

SUMMARY

Acute experiments on dogs were made to study by means of electromyography the structure of the respiratory cycle of the main and accessory respiratory muscles at various stages of extinction of the vital functions during death from blood loss and in the first 1.5-3 h of resuscitation after a 3-5 min clinical death. Dying of the animals is accompanied by disturbances in the reciprocal relations between the inspiratory and expiratory centers, as a result of which in the agonal state the expiratory and accessory respiratory muscles contract during inspiration. The mechanisms ensuring an active expiration are more sensitive to hypoxemia; during dying the expiratory muscles are excluded from the respiratory activity earlier and are restored to function later than the inspiratory muscles. Normalization of the activity of the expiratory muscles depends on the restoration of the parts of the brain stem on the border between the medulla oblongata and the pons Varoli. As evidenced by EMG data, the degree of pulmonary ventilation corresponds to the structure of the respiratory cycle much more than to its pneumographic characteristics.

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**All abbreviations of periodicals in the above bibliography are letter-by-letter transliterations of the abbreviations as given in the original Russian journal. *Some or all of this periodical literature may well be available in English translation.* A complete list of the cover-to-cover English translations appears at the back of this issue.**

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