ON NON-UNIFORM CHANGES IN THE ELECTRICAL ACTIVITY OF THE RESPIRATORY MUSCLES ASSOCIATED WITH EXPERIMENTAL INJURY OF THE PERITONEUM

THE QUESTION OF SEGMENTAL REACTIONS OF THE RESPIRATORY MUSCLES

T. I. Goryunova

Laboratory of Experimental Pathology of the Nervous System (Head – Prof. S. I. Frankshtein) of the Institute of Normal and Pathological Physiology (Dir. – Active Member of the Akad. Med. Nauk SSSR Prof. V. V. Parin) of the Akad. Med. Nauk SSSR, Moscow

(Presented by Active Member of the Akad. Med. Nauk SSSR V. V. Parin)
Translated from Byulleten' Éksperimental'noi Biologii i Meditsiny, Vol. 52, No. 11, pp. 30-35, November, 1961
Original article submitted January 7, 1960

In previous investigations, devoted to studying disturbances in respiration associated with organic diseases of the lungs and upper respiratory passages, we recorded non-uniform changes in the electrical activity of the individual respiratory muscles (decreased activity in the diaphragm during simulated asphyxia and decreased activity of the homolateral diaphragmatic cupola with injury of the lung [2, 4]), using the electromyographic method; this was seen against the setting of elevated activity in the other respiratory muscles. Further investigations in this field were carried out by In' Chi-Chzhan in our laboratory. He confirmed the non-uniform changes in the activity of the diaphragmatic cupolae following injury of the lung, and showed that this dissociation of the respiratory movements includes the intercostal muscles of the fourth-fifth interspaces, but does not involve the obliquie muscles of the stomach. He also found that after vagotomy this dissociation was not only retained, but enhanced [10]. Therefore, it was shown that changes in the activity of the respiratory muscles can be caused by local disturbances in the afferent impulsation at the segmental level, due to a pathological process.

Up until recently, the role of the spinal centers in modifying the respiratory act has been considered unimportant, despite the fact that data have been present for a long time on the segmental reflexes of the respiratory muscles [19, 24, 28], particularly to proprioceptive stimuli. This is possibly due to the concept of the actually existing spinal centers of the respiratory muscles often being confused with the concept of the so-called spinal respiratory centers, i.e., centers capable of generating rhythmic respiratory impulsation. The existence of these latter centers in intact animals has never been considered proven.

In the last few years interest has again increased in the question of what role is played by the excitability state of the motor neurons to the respiratory muscles in modifying their reaction to impulsation from the respiratory center [11, 12, 14, 15, 20, 21, 25, 27, 30, 31, 32]. This work is also devoted to that question, and was designed to study the dynamics of changes in the activity of the respiratory muscles under the influence of such a known spinal [8, 9, 16] pathological reflex as the defense musculaire (contracture of the peritoneal wall associated with injury to the peritoneum).

Electrophysiological analysis of this phenomenon was performed on the rectus abdominis in works by L. N. Zefirov and G. I. Poletaev [9]. Judging from the graph presented by the authors, the respiratory rhythm in the rectus abdominis disappears during the defense musculaire. The activity of the other muscles participating in respiration was not studied in this work.

EXPERIMENTAL METHOD

The experiments were set up on 5 dogs and 8 rabbits, fixed in the lying position without anesthesia. Simultaneous recordings were made of the activity of the diaphragm and rectus abdominis, and, in addition, either the internal oblique, or the internal intercostal, muscles (the intercartilaginous portion of the fourth or fifth interspace), using the DIZA electromyograph and electrodes that were sutured into place several days before the experiment. The starting background activity of the muscles was recorded for 2-3 days. Details on the suturing of the electrodes have been described earlier [3, 10]. The peritoneum was injured in the dogs by the injection of 1 ml of turpentine. In the rabbits, markedly apparent contractures of the peritoneal wall were caused by the injection of 1-2 ml of a saturated sodium chloride solution. The injurious fluid was injected into the upper third of the abdomen; after introduction of the needle near the linea alba, it was directed toward the side opposite to the one in which the electrodes were sutured.

EXPERIMENTAL RESULTS

Without disturbance, the activity of the diaphragm in inspiration in the dogs and rabbits appears to be an impulsation of the interferential type; in expiration – of the simple or intermediate type. The internal intercostal muscles (intercartilaginous portion of the fourth-fifth interspace) show activity of the interferential type in inspiration, usually in the form of a clear volley of impulses. With no interference, the peritoneal muscles are active primarily in expiration. The oblique muscles of the abdomen, in the rabbits and dogs, more clearly reflect the respiratory rhythm than the recti, and their activity is manifested in the form of clearly shaped volleys of the intermediate or interferential type. The rectus muscles are more subject to the respiratory rhythm in the dogs than in the

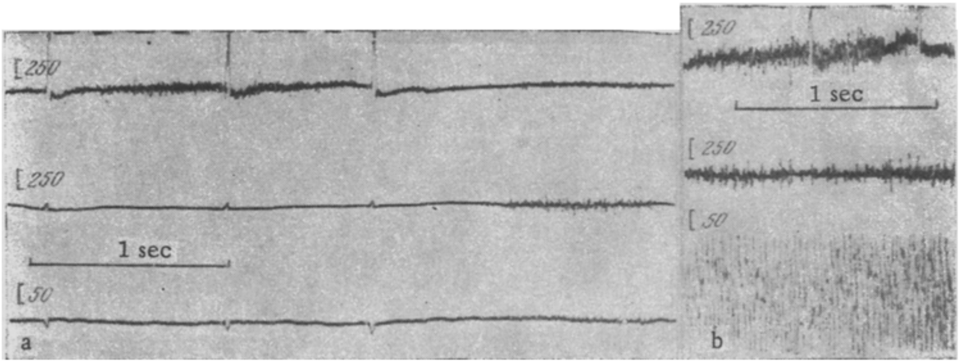

Fig. 1. Electromyograms of the muscles prior to, and at the moment of, injury to the peritoneum (in the dog, Gypsy). Meaning of the curves (from above downard): diaphragm; internal oblique muscle; rectus abdominis; a) undisturbed respiration. Clear respiratory rhythm in all muscles (inspiration is designated by a dotted line); b) at 2-3 seconds after injury of the peritoneum. Marked increase in the activity of all muscles, especially the rectus.

rabbits, but in both animals their activity was very low in the absence of disturbances – ten microvolts, versus 150-250 microvolts in the diaphragm and intercostal muscles (Fig. 1a). From time to time we observed impulse groups which were usually related to shivering, and could be removed by warming the animal. More detailed data on the electrical activity of the different respiratory muscles without interference, under conditions of a long term experiment, have been presented earlier [4, 10].

In the first seconds after infliction of the injury, a marked increase in the activity up to maximum level (Fig. 1b) was observed in all the muscles, related to the animal's defense reaction and usually lasting about a minute. Then, the activity of the peritoneal muscles decreased sharply, down to complete disappearance, and the respiratory rhythm disappeared. Previous investigators [9] have also observed this period in connection with the rectus muscles. At the same time, the activity of the diaphragm and intercostal muscles retained a clear respiratory rhythm, although it diminished somewhat (Fig. 2a).

The first single impulses appeared after 5-15 minutes (first in the oblique muscle, then in the rectus), along with the clinical signs of contracture of the peritoneal wall. At this time, the respiratory rhythm was absent from the impulsation of these muscles. Then, the impulsation frequency gradually increased, and 20-30 minutes after the injury the activity became uninterrupted (Fig. 2b, left side). Following this, the respiratory rhythm normally began to appear in the oblique muscles, while, in the recti, the uninterrupted activity continued, first uniform in amplitude and frequency, then showing some weakening in inspiration (Fig. 2c, 3b).

It is important to note that the amplitude of the continuous activity in the peritoneal muscles during contracture, with complete absence of any kind of supplementary irritation, did not exceed 100-200 microvolts, i.e., came far from attaining the maximum for these muscles (for example, during the defense reaction – see Fig. 2b), remaining within the bounds for a discharge from an individual motor unit. In addition, the tracing can be placed in the intermediate, and not the interferential, type, which also indicates the absence of spatial summation during this form of muscular reaction to a pathological stimulus. These characteristics of the electromyogram (EMG) for the peritoneal muscles, as well as the ability for prolonged maintenance of continuous activity, all serve as evidence for activation of the tonic, and not phasic, α-motor neurons [26, 29, et al].

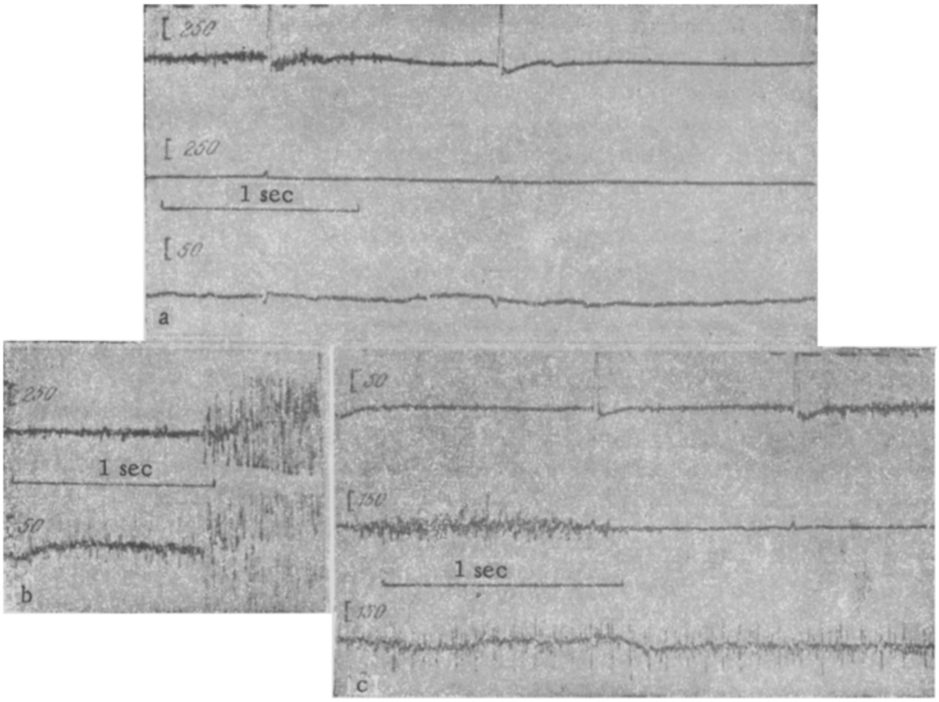

Fig. 2. Electromyograms after injury to the peritoneum. Meaning of the curves (from above downward): diaphragm; internal oblique muscle; rectus abdominus. a) At 21 minutes after injury. Complete absence of activity in the peritoneal muscles and no expiratory activity in the diaphragm. Inspiratory activity does not differ from the original pattern; b) at 35 minutes after injury. Activitity of the peritoneal muscles (above – oblique, below – rectus). On the left – uninterrupted activity of the intermediate type, characteristic of contracture of the peritoneal wall; on the right – defense reaction to additional irritation – interferential activity of maximum amplitude; c) after 45 minutes. Clear respiratory rhythm in the internal oblique muscle and first signs of appearance of a respiratory rhythm (decrease in frequency of the low amplitude peaks on inspiration) in the rectus muscle.

The described changes lasted for 1-1½ hours, during which the activity of the peritoneal muscles periodically increased and decreased in both amplitude and frequency (initially every 3-6 minutes, then less often). This is possibly related to fluctuations in cortical activity, since in the periods of decreased impulsation activity the animal seemed to be sleeping, while in the periods of elevated impulsation activity the animals appeared somewhat more alert.

Then, at various intervals in the different animals, the respiratory rhythm also returned to the rectus abdominus, being superimposed on the continuous activity; the latter lasted several hours, and, sometimes, even a day (24 hours).

Similar changes in the MEG were also observed in the rabbits, although the external changes in the tonus of the peritoneal muscles were more weakly manifested in them.

Our observations showed that the inspiratory activity of the diaphragm and intercostal muscles remained essentially unchanged following injury to the peritoneum, which also corresponds to clinical observations [7, 18]. The activity of the diaphragm at expiration depended on the activity of the peritoneal muscles – it disappeared with absence of the latter, and appeared with its restoration.

Thus, the most pronounced changes were in the activity of the peritoneal muscles, i.e., those whose spinal centers were subjected to the pathological stimulus to a large degree. Only in these did we observe lasting disturbances in the respiratory rhythm for a period of ten minutes, at the same time that a clear respiratory rhythm continued to be seen in the diaphragm and the muscles of the fourth-fifth interspace, whose spinal centers were not directly affected by the pathological stimulus (Fig. 3).

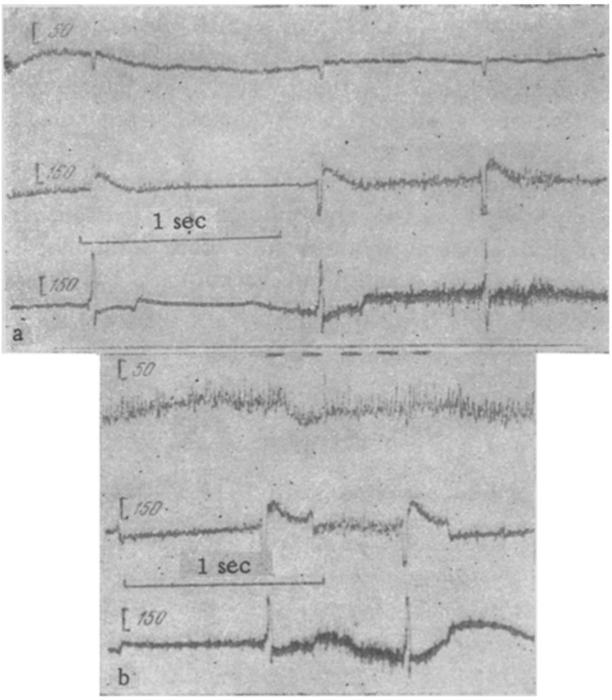

Fig. 3. Electromyograms of the muscles following injury to the peritoneum (in the dog, Buyanka). Meaning of the curves from above downward: rectus abdominus; diaphragm; intercartilaginous portion of the internal intercostal muscles in the fifth interspace. a) Original tracing; b) an hour after injury. Clear respiratory rhythm in the diaphragm and intercostal muscle, with absence of it in the rectus muscle (single peaks and slow oscillations in the curve – induction from the EKG).

The experiments presented confirm the possibility of segmental dissociation in the activity of the respiratory muscles, caused by the presence of a pathological stimulus at the corresponding level.

In discussing the mechanism of non-uniform disturbances in the activity of the respiratory muscles during pathological processes, we repeatedly emphasized the importance of somatic regulation in forming the final reaction of the muscles to impulsation from the respiratory center [2, 4, 5]. Although it is well known that, morphologically, each of the respiratory muscles, as well as any other skeletal muscle, possesses completely distinct connections with the motor centers of the spinal cord, brainstem, striopallidum system and the cortex of the brain, the question of the interactivity of the bulbar respiratory center and the various levels of motor regulation of the respiratory muscles has nevertheless not been adequately studied up until now.

Thus, for example, although the influence of the cerebral cortex on respiratory movements is not doubted, it is postulated that its effect is accomplished only at the level of the respiratory center; the possibility of a change in the excitability of the motor neurons to the respiratory muscles via direct corticospinal, pyramidal, and extrapyramidal pathways has barely been considered, despite the fact that this was recently confirmed by the electrophysiological investigations of Massion et al. [31]. Respiratory disturbances associated with chronic diseases of the striopallidal system are often theoretically explained by simultaneous affection of the bulbar respiratory center, although there are data which show that, both in character and in time of appearance, they correspond exactly with disturbances in locomotive functioning, characteristic for disease of the subcortical centers, and are not accompanied by pathological changes in the region of the medulla oblongata [13 et al]. Parallel development of motor and respiratory disturbances of the extrapyramidal type were also observed by us in dogs with profound decortication, $1\frac{1}{2}$-2 years after the operation [1].

As regards the role of the brainstem centers in respiratory regulation, recently, in connection with a detailed study of the brainstem reticular formation many investigations have appeared devoted to elucidating the "respiratory" and "somatic" structures at this level [17, 23, 33]. However, the anatomical and physiological data on the integration of these functions is still contradictory.

As has already been indicated above, a number of works have also recently appeared dealing with the interaction of respiratory and somatic regulation of the respiratory muscles at the level of the spinal cord. It must be remembered that respiratory muscles, as well as all others, do not receive efferent impulsation directly from the respiratory center, but via the spinal motor neurons, whose excitability can be altered independent of the latter, particularly under the influence of peripheral afferent impulsation [6, 22]. In this regard, the data of the present report are of interest, showing that segmental disturbances in afferent impulsation, caused by a pathological process, can lead to destruction of the respiratory movements at the corresponding level, despite continuous rhythmic activity of the respiratory center, and also showing that respiratory movements, especially under pathological conditions, cannot always be regarded solely as an indicator of the state of the respiratory center.

SUMMARY

Changes of the electric activity were studied prior to and after the peritoneal injury (causing contracture of the abdominal wall) in the diaphragm, intercostal muscles (intracartilagenous portion of the 4th-5th intercostal space), and m. obliquus abdominis and rectus abdominis. This was done on dogs and rabbits with the aid of implanted electrodes.

As shown experimentally, the respiratory rhythm was retained completely both in the diaphragm and the intercostal muscles during the whole observation period. The activity of the abdominal muscles changes, depending on the stage of the pathological process, but the respiratory rhythm therein may be absent for a scope of minutes in the m. obliquus abdominis and up to 1-2 days in the rectus abdominis. These experiments confirm the possibility of segmentary disturbances of the respiratory muscles' function in the presence of a pathological focus at the periphery.

LITERATURE CITED

1. T. I. Goryunova, in the book: The Problem of Reactivity in Pathology [in Russian] (Moscow, 1954), p. 193.
2. T. I. Goryunova and I. A. Morozova, Byull. Éksper. Biol. i Med. No. 9 (1957), p. 36.
3. T. I. Goryunova, Fiziol. Zhurn. SSSR, Vol. 44, No. 12 (1958), p. 1160.
4. T. I. Goryunova, Byull. Éksper. Biol. i Med. No. 9 (1958), p. 62.
5. T. I. Goryunova, in the book: Questions on Respiratory Regulation under Normal and Pathological Conditions [in Russian] (Moscow, 1959), p. 169.
6. K. D. Gruzdev, Fiziol. Zhurn. SSSR, Vol. 34, No. 5 (1948), p. 605.
7. Yu. Yu. Dzhanelidze, Sobranie Sochinenii, Vol. 4 (1954), p. 227.
8. L. N. Zefirov and G. I. Poletaev, Byull. Éksper. Biol. i Med. No. 3 (1956), p. 13.
9. L. N. Zefirov and G. I. Poletaev, Fiziol. Zhurn. SSSR, Vol. 44, No. 1 (1958), p. 45.
10. In' Chi-Chzhan, Byull. Éksper. Biol. i Med. No. 109 (1960), p. 34.
11. D. A. Kocherga, in the book: Questions on Respiratory Regulation under Normal and Pathological Conditions [in Russian] (Moscow, 1959), p. 137.
12. D. A. Kocherga, in the book: Data from the Scientific Conference on the Problem: Mechanisms of Cortico-Visceral Relationships [in Russian] (Baku, 1960), p. 160.
13. A. S. Kuznetsova, Changes in the Amplitude and Rhythm of Respiration Associated with Diseases of the Brain. Diss. Kand. [in Russian] (Leningrad, 1951).
14. B. Ya. Peskov, Characteristic Peculiarities in the Respiratory Movements of Patients with Organic Diseases of the Central Nervous System. Diss. Kand. [in Russian] (Kuibyshev, 1957).
15. B. Ya. Peskov, Fiziol. Zhurn. SSSR, No. 3 (1960), p. 269.
16. A. F. Popov, On the Mechanism Leading to Contracture of the Muscles of the Anterior Peritoneal Wall. Diss. Kand. [in Russian] (Kazan, 1955).
17. L. M. Popova, Disturbances in Respiration Associated with Acute Poliomyelitis. Dis. Dokt. [in Russian] (Moscow, 1960).
18. N. N. Samarin (editor), Diagnosis of the "Acute Abdomen" [in Russian] (Leningrad, 1952).
19. M. V. Sergievskii, The Respiratory Center in Mammals, and Regulation of Its Activity [in Russian] (Moscow, 1950).
20. L. L. Shik, in the book: The Physiology and Pathology of Respiration, Hypoxia, and Oxygen Therapy [in Russian] (Kiev, 1958), p. 108.
21. L. L. Shik, in the book: Questions on Respiratory Regulation under Normal and Pathological Conditions [in Russian] (Moscow, 1959), p. 108.
22. A. M. Alderson and C. B. Downman, B. J. Physiol. Lond. Vol. 150 (1960), p. 463.
23. A. Brodal, The Reticular Formation in the Brainstem. Anatomical Data and Functional Correlations [in Russian] (Moscow, 1960).
24. E. J. M. Campbell, The Respiratory Muscles and the Mechanics of Breathing. London (1958).
25. C. B. Dewnman, B. J. Neurophysiol. Vol. 18 (1955), p. 217.
26. J. C. Eccles, R. M. Eccles, and A. Lundberg, J. Physiol. London, Vol. 137 (1957), p. 22.
27. Ramos Garcia, J. Acta Physiol. lat.-amer. Vol. 9 (1959), p. 246.

28. K. Geimans and D. Kord'e, The Respiratory Center [in Russian] (Moscow, 1940).
29. R. Granit, XXI Congreso Internat. d. Ciencias Fistol. Buenos-Aires (1959), p. 93.
30. Kotani-Satoru, J. Physiol. Soc. Japan, Vol. 21 (1959), p. 977.
31. J. Massion and M. Moulders, Colle J. Arch. Intern. Physiol. Vol. 68 (1960), p. 314.
32. P. W. Nathan and T. A. Sears, J. Neurol. Neurosurg. Psychiat. Vol. 23 (1960), p. 10.
33. Dzh. F. Rossi and A. Tsanketti, Reticular Formation of the Brainstem [in Russian] (Moscow, 1960).

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.