RESPIRATION AFTER LONGITUDINAL AND TRANSVERSE SECTION OF THE SPINAL CORD IN CATS*

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Porter [9] showed that for warm-blooded animals hemisection of the spinal cord between C1 and C2 causes an ipsilateral paralysis of thoracic and diaphragmal breathing. He also showed that section of the contralateral phrenic nerve will restore the respiratory movements of the paralyzed half of the diaphragm. Porter's results were confirmed and extended by É. A. Asratyan [1], who found that after hemisection of the cord between C2 and C3, the respiratory movements of the ribs on the operated side were restored.

Observations have also been made on changes in the respiration following damage to the cord in man [4, 6, and others]. B. Ya. Peskov showed that it was possible to restore respiratory movements on the same side as the damage to the spinal cord.

The present article reports a study of experiments on cats.

METHOD

The animals were anesthetized with 0.8-1 g urethan per kg, the spinal cord was exposed, and a longitudinal incision was made for a length of 2-3 centimeters, and 1-1½ hours later a transverse cut was made at the level of C3-C4 on the right side (2-4 segments below the section made by Porter, and 1-2 segments lower than that of É. A. Asratyan). We used this modification of the experiment, in order to obtain evidence which would explain the changes in the respiratory movements and the possibility of their restoration. Our second object was to study the effect of afferent impulses on the respiratory changes induced. For this purpose we sectioned the vagus nerve, and stimulated its central end by an induction coil. We also studied the effect of stimulating the femoral nerves, and of injecting 0.3 ml per kg of 0.1% solution of lobeline. The respiratory movements were recorded by the standard method of our laboratory [8]. As a rule, simultaneous records were made of the thoracic and diaphragmal respiratory movements of the right and left sides separately. Normal respiration was recorded before the operation, and subsequently after longitudinal cervical incision of the cord, hemisection, division and stimulation of the vagi and femoral nerves, and after injecting lobeline. In all, 28 experiments were performed.

RESULTS

In the great majority of the animals, before the operation, the respiratory movements on both sides of the thorax were synchronized and symmetrical. During the time when the longitudinal incision was being made, and during the transverse section in the cervical region, respiration became considerably deeper and more frequent, probably as a result of strong stimulation (only in two experiments did the respiration become variable or reduced in depth). There were also changes in the tone of the respiratory musculature, which was either reduced or increased. These changes lasted for 15-90 seconds, and occasionally for 4-4½ minutes. Subsequently, in many of the animals, normal respiration was restored. In six experiments, after making the longitudinal incision in the cervical cord, a marked asymmetry in the depth of respiration occurred; in four experiments there was an increase in the amplitude of the thoracic and abdominal respiration on the right side, and in two on the left. From these results it appears that the decussation of the fibers varies from one animal to another, because the asymmetrical breathing indicates changes in the flow of impulses caused by interruption of the pathways.

After hemisection of the cervical cord, either immediately, or after a time interval of from ten seconds to four minutes, an asymmetry in the breathing movements developed. In three experiments there was a reduction in the depth of thoracic and abdominal breathing on the operated side, and in the remainder it was only the ipsilateral thoracic breathing which was affected. Consequently, hemisection of the cord between C3 and C4 caused a reduction, but not a cessation, of ipsilateral thoracic respiratory movements. It follows,

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then, that there is considerable decussation in the cord of fibers carrying impulses from the respiratory center to the spinal centers of the respiratory muscles. This decussation is not confined to the upper three segments, but continues in lower segments.

Our results agree completely with the anatomical studies of V. M. Bekhterev [2] and P. P. D'yakonov [3], who demonstrated a marked decussation of the afferent pathways. In the four experiments in which the transverse section of the cord was made over two-thirds of its extent or more, apnoea occured in all parts of the thorax. Thus, the apnoea may be caused not only by damage to the pons, as was shown by Lumsden [10] and others, but also by destruction of other parts of the central nervous system, including the cord. It is quite possible that changes in the conduction of impulses along spinal pathways are the cause of this type of respiration [7, 5].

After sectioning the spinal cord as described, dividing either the left or right vagus had no appreciable effect on the respiration. When both vagi were divided, both thoracic and abdominal respiration became increased to approximately the same extent; in two experiments there was a great increase in amplitude on the operated side, and in one experiment the increase was on the contralateral side.

In 25 out of the 28 experiments, stimulation of the vagi after performing the longitudinal incision caused an equal increase in the respiratory movements on both sides of the thorax, and only in three experiments was there any asymmetry of the movements during the stimulation. In 11 experiments, stimulation applied to the vagi after hemisection produced about the same changes in respiratory movements on both sides of the thorax (Fig. 1). In 9 experiments, the respiration on the operated side showed either no change or very little alteration, while on the unoperated side there were marked changes which took many forms. In 8 experiments, on the other hand, more marked changes in the depth and frequency of respiration on the ipsilateral side occurred, and as a result, there was less asymmetry after right hemisection. In one experiment when the right side of the cord was divided between C3 and C4, stimulation applied to the vagi caused inhibition of all respiratory movement; when the stimulation was withdrawn, the asymmetry in the thoracic breathing was less marked. Changes of abdominal respiration on the right and left sides caused by stimulating the vagi were always symmetrical and synchronized.

The results obtained, therefore, show that afferent impulses from the vagi cause profound changes in respiratory movements and may facilitate the passage of respiratory impulses into the cord along crossed pathways, in this manner leading to a restoration of respiration on the half of the thorax whose muscles have been paralyzed through the hemisection.

Having demonstrated the influence of vagal stimulation transmitted through the crossed spinal tracts, we decided to determine whether similar effects may be mediated by the femoral nerves. We found that stimulation of the right and left femoral nerves had approximately the same effect as the vagal stimulation in causing recovery of respiration on the operated side. It appears, therefore, that the vagus is not the only principal afferent pathway concerned in respiration, but that afferent impulses from the femoral nerve exert various influences on the respiratory center, and facilitate the

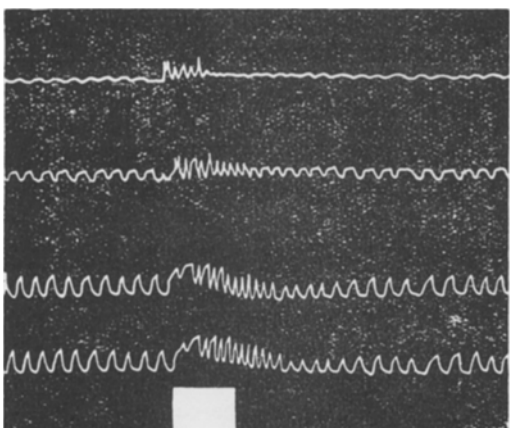

Fig. 1. Increased respiratory movements on the right side of the cat's thorax during stimulation of the left vagus nerve following hemisection of the spinal cord between C3 and C4. Curves, from above downward: thoracic respiration on the right side; thoracic respiration on left side; abdominal respiration on the right; abdominal respiration on the left; stimulus marker; time marker (in seconds).

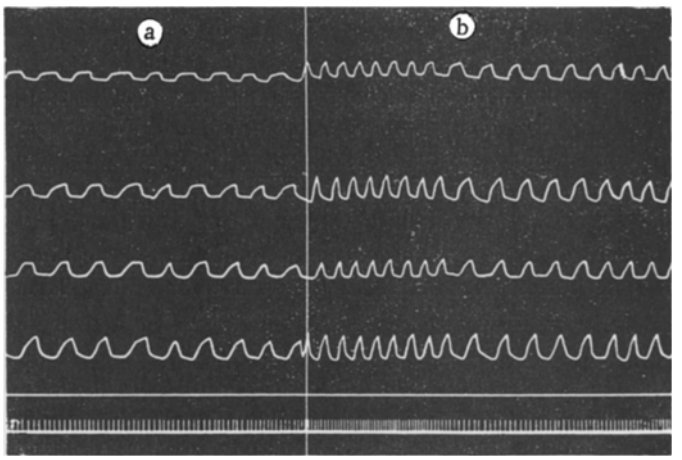

Fig. 2. Respiratory movements in the cat after right hemisection of the spinal cord between C3 and C4 and bilateral vagotomy. a) Before injecting lobeline; b) after injecting lobeline. Curves as in Fig. 1.

transmission of impulses along crossed pathways from the cerebral to the spinal respiratory centers.

Injection of lobeline facilitates the restoration of respiration on the hemisected side. It usually causes some increase in depth and frequency of both kinds of respiratory movements, including those on the operated side; as a result there is a definite recovery of respiration on the operated side. In experiments carried out on January 26-27, 1959, after spinal hemisection and bilateral vagotomy, the respiratory movements showed more or less prolonged pauses at the limit of inspiration. In these cases, also, injection of lobeline caused an increased depth of all respiratory movements (Fig. 2).

Thus, in all experiments, right hemisection of the cord between C3 and C4 caused a reduction, but not a cessation, of respiratory movements on the same side. Stimulation of the vagi or femoral nerves, or lobeline injections, following hemisection facilitated breathing on the operated side. The results indicate that in the cat there is considerable decussation of the fibers descending in the cord from the brain and passing to the spinal centers of the respiratory muscles.

SUMMARY

Respiratory changes following transverse and longitudinal section of the spinal cord were studied on 28 cats under urethan anesthesia. The cord was divided transversely at the lower end of a longitudinal incision, between the 3rd and 4th cervical segments on the right side. Longitudinal division sometimes caused an unequal depth of respiration on the two sides. In all experiments, hemisection of the cord caused only a reduction of respiratory movements on the same side. The afferent impulses from the vagus and femoral nerves and lobeline injections tended to restore breathing on the operated side. The results obtained show that there is a considerable decussation of the spinal fibers conveying impulses from the respiratory center in the brain to the spinal centers of the respiratory muscles.

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