AFTEREFFECTS OF BILATERAL PARALYSIS OF THE DIAPHRAGM IN KITTENS

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The normal respiration of newborn infants [3] and the young of mammals is usually described as diaphragmatic. Unilateral paralysis of the diaphragm caused by birth trauma leads to severe disorders of respiration and frequently to death [4]. Data are available which indicate that after bilateral phrenicotomy three-month-old rabbits die, whereas mature animals easily undergo this operation [5]. The value of the contractions of the intercostal muscles for ventilation of the lungs of neonates is either negated or acknowledged as secondary [6, 7]. The reason for this is considered to be the arrangement of the ribs at a right angle to the spinal column, as if in a state of constant inspiration, in connection with which their movement cannot lead to an increase in the volume of the thoracic cavity. According to other data [1], oblique arrangement of the ribs and a diaphragmatic-costal type of respiration are characteristic of most neonates. It is known that in dyspnea (for example in toxicosis) an evident costal respiration can be observed at this age [8]. Thus, the question of the relationship between diaphragmatic and costal respiration during early postnatal development requires further study.

We observed the aftereffects of bilateral paralysis of the diaphragm in kittens. The selection of the animals was determined by their immaturity at birth and also by the fact that diaphragmatic-costal respiration is characteristic of mature cats, like man.

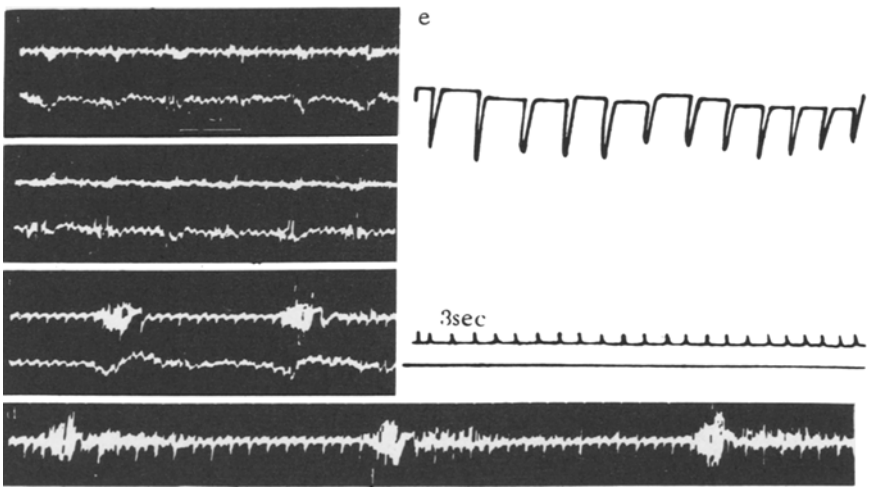
METHOD

The observations were carried out on 25 kittens at an age from several hours to two and a half months after birth. Phrenicoexeresis at this age was complicated by the possibility of damaging the large lymph vessels. To avoid this we searched for the superior branch of the phrenic nerve leading off from the fifth cervical nerve, ligated it, and transected central of the latter. Further, we carefully pulled the superior branch until the inferior branch (issuing from C_6) and the common trunk of the phrenic nerve appeared in the wound. After transection of the lower branch we performed phrenicoexeresis. We immediately operated on the other side. Avulsion of the nerves was usually done at the level of the pericardium. The operation was performed under nembutal (2 mg/100 g, intramuscularly) or ether under aseptic conditions. Muscle and skin sutures were used. If the conditions of the animals after coming out of anesthesia was satisfactory, the kittens were placed with the mother.

Furthermore, we carried out two acute experiments (on kittens several hours and nine days old) with recording of the respiratory fluctuations of pressure in the esophagus and EMG of the respiratory muscles.

RESULTS

The respiration of newborn kittens is uneven in rhythm and depth [2]. Quick (up to 150-180 per minute), superficial eupnea with respect to external signs is mainly diaphragmatic. But with deeper inhalations and especially during crying a distinct enlargement of the thorax, including its oral half, was observed. It was easily established that only the I—III ribs are arranged almost perpendicular to the spinal column. The other ribs (from the attachment of the tractus ileo-costalis to the bend of the cartilege) are directed, during exhalation, at an acute angle to the spinal column. The more caudal the ribs, the more acute the angles they form.



Action currents of respiratory muscles and fluctuations of pressure in the esophagus of a 5-hour-old kitten. a, b, c) EMG of intercostal muscles (upper recording, inserted electrodes with interelectrode distance of 0.9 mm along course of the fibers of the external intercostal muscles of fifth interspace) and right cupula of the diaphragm (lower recording); d) EMG of intercostal muscles; e) pressure in esophagus recorded simultaneously with d (inspirations at bottom). The EKG was superposed on all EMG's. Calibrations 100 μV. a) Initial pressure; b) after transection of left; c) after transection of right phrenic nerve; d, e) 40 min after c.

Costal respiration was gradually enhanced for several minutes after bilateral phrenicoexeresis in kittens up to 24 h old. The thoracic volume at inspiration was greatly enlarged, especially in a frontal direction. Simultaneously drawing-in of the abdomen occurred. Eupnea at a rate of 40-56 breaths per minute persisted. Cyanosis was absent. After the anesthesia wore off the kittens crawled about and loudly whined. The kittens placed with the mother cat began to suckle. On the following day they differed from the healthy cats only by the more active movements of the thorax. However, in spite of supplementary feeding the kittens lost weight (3-5 g per day). On the 3-5th day their condition deteriorated, and the kittens stopped suckling independently. Respiration became infrequent and deep, crying was weak, and later soundless. The mucous membranes became pale, cyanosis developed. All three kittens of this age died 6 days after the operation. At autopsy we found atelectasis of most of the pulomnary tissues; its parts that retained aeration proved to be emphysematous.

The EMG's of the intercostal muscles and diaphragm recorded in the acute experiment on a newborn kitten, are shown in the figure. Even during calm respiration bundles of action currents of low amplitude and frequency, synchronous with excitation of the diaphragm, were recorded from the intercostal muscles (a). During periods of quick, superficial respiration such activity was absent. Following transection of the left phrenic nerve we observed an enhancement of inspiratory activity of the intercostal muscles and right cupula of the diaphragm (b). After transection of the right phrenic nerve respiration became costal, outwardly increased markedly, and the rate of inspirations diminished. Inspirations were accompanied by strong action currents of the intercostal muscles (c). Later respiration became even more infrequent and deep, with strong active expiration. The latter corresponded to an outburst of action currents of the intercostal muscles, which were separated from the inspiratory potentials by a brief pause (d). Evidently this second outburst corresponded to excitation of the internal intercostal muscles. After paralysis of the diaphragm a distinct drop of pressure (e) occurred in the esophagus during inspirations. Similar data were obtained on a 9-day-old kitten.

Of the 14 kittens operated on at an age from 2 to 21 days, 12 died soon after the operation (survival was from several tens of minutes to 6 h, for some kittens the exact time of survival was not determined, since they died at night, "less than 12 h" in the table). Only one of the 2-week-old kittens survived about 24 h, and one 3-week-old kitten survived two days.

In five of these kittens (aged 2, 4, 8, 14, 21 days) after transection of the second phrenic nerve we observed

Survival Times of Kittens after Paralysis of the Diaphragm

Day of operation		Period of survival or observation	Weight of animal at end of observation period or of body (in g)	Day of operation		Period of survival or observation	Weight of animal at end of observation period or of body (in g)
age (in days)	weight (in g)			age (in days)	weight (in g)		
Less than 1	124	6 Days	91	21	308	2 Days	278
Same	99	6 "	78	21	349	1½ Hours	
"	100	6 "	70	26	400	More than 2 months	735
2	143	3 Hours					
2	150	Less than 12 hours		28	432	3 Days	350
2	145	12 hours		31	505	6 "	413
3	139	6 "		34	500	More than 2 months	1010
4	165	Less than 1 hour					
4	161	2 Hours		41	645	More than 5 months	
4	160	5 Hours					
6	213	Less than 12 hours		51	635	More than 12 months	2200
8	167	1 Hour					
9	207	Less than 12 hours		73	825	16 months	3450
14	278	Less than 1 hour		76	1100	12 "	2300
14	261	1 Day					

a brief period of deepening eupnea, after which gasping or infrequent (5-14 inspirations per minute) deep respiration appeared. Cyanosis developed. The tone of the musculature disappeared. After a certain time tachycardia and respiration ceased. In the other six kittens (aged 2, 3, 4, 4, 6, 9 days) the period of eupnea was longer. Strong motor excitation appeared after 10-30 min. The kittens tossed about the box in which they were placed and attempted to get out of it. Cyanosis developed. Respiration became infrequent, maximally deep, and changed to gasping. Muscle tone and protective reflexes disappear, and then death ensued.

The condition of the kittens after paralysis of the diaphragm distinctly improved for a certain time upon breathing oxygen.

Intensive movements of the thorax, especially an enlargement of its frontal dimensions, were observed after phrenicoexeresis in all kittens of this age (from 2 to 21 days). It was possible to clearly observe that on inspiration the organs of the abdominal cavity moved forward, drawing into the thorax, and returned upon expiration to the initial position. At autopsy on the kittens that survived from several hours to two days after the operation, atelectasis of the greater part of the pulmonary tissue was noted.

The first (in age) kitten weighing 400 g which safely underwent bilateral phrenicoexersis, was operated on 26 days after birth. On the following day it suckled the mother, was lively, and played. During the first day the kitten lost 30 g, but already on the following day the weight began to increase. Subsequently the experimental kitten developed normally although it somewhat lagged behind the control kitten of the same litter in weight. Thus, at an age of two months their weight was respectively 519 and 640 g. No lag in weight was observed in the kittens operated on at an age of 34 and 41 days. They differed from the control kitten only by greater excursions of the thorax and paradoxical respiratory movements of the abdomen.

However, two kittens aged 28 and 31 days died several days after the operation. Older kittens (34 days and more) underwent bilateral phrenicoexeresis with relative ease (see table).

Long-term observations were made on three animals. They all developed normally. A large volume of the thorax and paradoxical movements of the abdominal wall were characteristic features. Two of them (Filimon, Fedot) a year after the operation weight 3.2 and 2.3 kg, a third (Feya) weighed 2.2 kg. Feya (operated on 51 days after birth) at an age of 11 months gave birth to three healthy kittens.

The autopsies of the operated kittens that lived for a long time showed that the muscular tissue of the diaphragm had completely degenerated and the diaphragm had changed to a thin fibrous membrane. The weight of the dia-

phragm had diminished. Thus, the diaphragm of a kitten (operated on at 26 days of age) at an age of 74 days weighed 2.8 g, whereas the diaphragm of the control kitten weighed 4.5 g. The cupulae of the diaphragm of the kitten Fedot, killed 12 1/2 months after the operation, were also a thin fibrous membrane, but in the vertebral part of the diaphragm several muscular bundles were found which had grown from the spinal column toward the esophageal hiatus.

Thus, in newborn kittens the rib movements during inspiration are accompanied by an increase of the thoracic volume and can participate in ventilation of the lungs. After paralysis of the diaphragm, the thorax during inspiration greatly expands, the pressure in the esophagus (and consequently in the pleural cavity also) drops, and the kittens can squeal. In kittens operated on several hours after bith, the external respiration proved to be sufficient to maintain life for six days. At this age inspiratory, and with active expirations, expiratory stimulation of the intercostal muscles is noted. These data indicate that both the external and internal intercostal muscles can already perform their respiratory functions. Calm respiration of newborn kittens is diaphragmatic mainly, but not exclusively, since a weak inspiratory activity of the intercostal muscles is also detected. The importance of the costal component is enhanced upon deepening of respiration.

However, at an age from 2 to 21 days ventilation after phrenicotomy proved to be insufficient. Kittens of the same age experienced paralysis of the diaphragm differently. In some of the kittens death ensued very quickly. Since the moment of death could be postponed by supplying oxygen, its main cause must be considered hypoxia. In other kittens respiratory disorders ensued later and, as the autopsy showed, were caused by atelectasis of the pulmonary tissue.

It is evident that the cause of death of the kittens is not the absence of the capacity for costal respiration. A decrease in resistance to hypoxia with age could be of importance. However, it is difficult to accept its marked change in the first day of postnatal life. Observations of respiration in kittens after paralysis of the diaphragm convince us that the mechanical characteristics of the respiratory apparatus are of prime importance. The thorax of newborn kittens is short, the diaphragm is situated high and is easily distendable, and the functional reserve capacity of the lungs is small. Upon inspiration the organs of the abdominal cavity are "sucked" into the thorax. During the first hours after birth the volume of the stomach and intestine is relatively small, and ventilation of the lungs of kittens operated on at this age is sufficient to maintain life. Subsequently, the abdomen of normally feeding kittens resembles a sphere on which the thorax is situated in the form of a bell. With an increase of the volume of the contents of the abdominal cavity, pressure on the abdominal surface of the diaphragm increases. Quite unfavorable conditions of pulmonary ventilation are created, atelectasis forms, and the energy of costal respiration goes for useless displacement of the internal organs.

Kittens survive after bilateral phrenicoexeresis from about 1 month of age. The lost functions of their diaphragms are successfully compensated by other respiratory muscles, mainly the intercostal muscles; growth and development of the animals are not disturbed.

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