THE NERVOUS CONTROL OF RESPIRATION IN KITTENS

HELEN C. COOMBS AND F. H. PIKE

From the Department of Physiology, New York Homeopathic Medical College, and Columbia University

Received for publication September 20, 1930

Certain observations made on very young animals in an extended study of the neuro-muscular mechanism of respiration have led us to suspect that there are certain differences in the action of the respiratory mechanism of the young as compared with adult animals.

One of us has therefore made a systematic survey of the nervous mechanism for the control of respiration in kittens from birth to sixty-three days old. We selected kittens for this study because our available data on cats afford a basis of comparison between the older and the younger forms.

EXPERIMENTAL PROCEDURES.

Ether was given by tracheal cannula. The anesthesia was kept fairly light and in many cases could be intermitted for long periods. Small stethographs were placed around the thorax and abdomen at the level of the diaphragm and connected with recording tambours to register costal and diaphragmatic respiration. In a few cases, respiration was registered from the tracheal cannula connected directly with a recording tambour. After taking a control record of respiration, the analysis of the nervous mechanism was begun by a study of the effects of section of the elements, afferent, central and efferent, which our previous experience indicated belonged to this nervous mechanism.

Division of the vagi. Silk ligatures were placed around each vagus in the neck. One nerve was then divided and a record of thoracic and diaphragmatic movements was taken. After an interval of about a minute, the second nerve was divided without interrupting the record. While section of one vagus does not cause much change in the form of the respiratory movements, it appears that following double vagotomy, there is not only the slowing of rate observed in the adult, but there is sometimes a diminution in the amplitude of the diaphragmatic respiratory movements which is not observed in older animals. Often, also, the diaphragmatic movements take on the sobbing form usually seen in the adult cat only after section of the midbrain (Coombs, 1930). In short, double vagotomy

1 The experimental portion of this paper was prepared by Doctor Coombs and the discussion was prepared by Doctor Pike. The cost of animals for the study was met by a grant to Doctor Coombs from the American Association for the Advancement of Science.
in the kitten appears to affect diaphragmatic respiration more than in the adult. Moreover, cats with both vagi divided can live indefinitely, but this appears not to be the case with young kittens or puppies. They usually survive double vagotomy for only a few hours or even less. Just as in the case of full-grown cats, there are "vagus" kittens in which the functional activity of the vagus appears to assume a rôle of greater importance than in other kittens, and the proportion of these "vagus" kittens seems to be higher than in the case of full-grown cats. In such animals, following double vagotomy, gasping and dyspnea followed by death supervene earlier than in others. Even in kittens forty to fifty days old, double vagotomy causes death in a few hours. Several such animals had the vagi cut aseptically in the hope that they might survive. None did, however.

Section of the dorsal spinal nerve roots. Laminectomy in the thoracic or cervical region, or both, was done; the laminae being broken off bit by bit with a pair of forceps as gently as possible, since rongeurs or bone forceps are too heavy to use in work on new-born kittens. Great care was taken to avoid hemorrhage. Judging by the form of the respiratory movements after completion of the laminectomy—similar to the control records—respiration was not appreciably affected by the preliminary operation. When clearly exposed, the dorsal roots were cut with a pair of fine scissors, and further tracings of the respiratory movements were taken.

When the dorsal roots of the spinal nerves are divided in the thoracic region, costal respiration in kittens from birth to ten days old almost ceases; it is diminished in older kittens, but to a less extent than in the very young animals. But, since normal costal respiratory movements are relatively slighter in kittens than in full-grown cats, the diminution in them which comes after section of the dorsal spinal nerve roots may be of less significance than in adult animals. Following such an operation, failure of costal movements is adequately compensated for from birth onward by an increase in the depth of the movements of the diaphragm.

When the dorsal roots of the cervical nerves are sectioned, the movements of the diaphragm are much cut down and the respiratory rate is slowed, at no matter what age (Coombs, 1929). In adult cats, compensation for such a section is effected by means of deeper costal respiration, but this is not the case in young kittens, even though the thoracic spinal nerve roots are all intact. It has been found that there is very little thoracic compensation for diminution or failure of diaphragmatic respiratory movements under twenty to twenty-five days of age.

When the dorsal roots of both thoracic and cervical nerves are divided, kittens live only one or two hours and respiration is dyspneic. This is particularly the case in kittens under two weeks of age, in which no compensation takes place.
Section of the midbrain. After temporary occlusion of the carotids with serrefines to decrease hemorrhage, the sutures of the parietal bone were cut in the midline—the skull being as yet not very much ossified—and followed around laterally just over the tentorium. Guided by the tentorium, a thin-bladed knife was pushed down vertically just behind it. In this way, either unilateral or bilateral section of the midbrain could be done without much hemorrhage. It was found that section of one side at a time was less likely to cause a disturbance of the respiratory movements than if total transection were done all at once. Following the death of the animal, the operation was always checked by autopsy to verify the location of the section. Section of the posterior corpora quadrigemina in young animals slows respiration somewhat, but it does not give rise to the uncontrolled movements of the diaphragm which are frequently observed in old cats after this procedure. Moreover, costal respiration remains unaffected in those kittens from one to ten days old in which the midbrain has been divided. A tracing taken from the trachea of an eight day old kitten shows the regularity of the respiration following transection of the midbrain (fig. 1). The younger the animal, also, the longer appears to be the period of survival after the operation. The longest survival period noted was that of a two-day old kitten which lived twenty-four hours after complete section of the midbrain, during which time respiration remained unaltered. It is probable that death, when it occurred, was due to other causes than the primary action upon respiration. By the time that costal respiration begins to appear, the survival period following section of the midbrain is much cut down.

Section of the phrenics. Silk ligatures were placed under the phrenics in the neck, and the nerves were then removed, care being taken to get all three branches on each side, so as to deprive the diaphragm completely of phrenic innervation. The paralysis of the diaphragm thus induced is attended by more severe results in kittens than in full grown cats. The fact that the costal mechanism is unable to make adequate compensation is emphasized very strongly by this operation. It was shown earlier in the paper that when the dorsal roots of the phrenics are divided in the
cervical region, there is no costal compensation for the reduced diaphragmatic respiration. When the entire phrenic is divided, this lack of ability to compensate becomes even more apparent, as respiration fades out after a short time. As the animals grow older, there is a greater degree of compensation which begins to be apparent at about three weeks, and in the 60 to 65 day old kitten, the reaction is that of the adult cat—that is, the thoracic movements have become adequate to maintain respiration indefinitely.

The following table indicates the relative severity of the various single lesions, varying with the age of the animal.

**TABLE 1**

The effect of single lesions, as related to the age of the animal

<table>
<thead>
<tr>
<th>LESION</th>
<th>BIRTH-10 DAYS</th>
<th>11-21 DAYS</th>
<th>22-45 DAYS</th>
<th>49-64 DAYS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Division of dorsal thoracic nerve roots</td>
<td>Stops costal respiration</td>
<td>Cuts down costal respiration</td>
<td>Cuts down costal respiration</td>
<td>Cuts down costal respiration</td>
</tr>
<tr>
<td>Division of dorsal cervical nerve roots</td>
<td>Cuts down movements of diaphragm. Slow respiration.</td>
<td>Same</td>
<td>Same</td>
<td>Same</td>
</tr>
<tr>
<td>Excision of phrenics</td>
<td>Stops diaphragmatic respiration. Early death</td>
<td>Same</td>
<td>Stops diaphragm movements. Some dyspnea</td>
<td>Same</td>
</tr>
<tr>
<td>Division of posterior corpora quadrigemina</td>
<td>No effect</td>
<td>May cause slightly earlier death</td>
<td>Earlier death. Cuts down thoracic respiration</td>
<td>Earlier death. Cuts down thoracic respiration</td>
</tr>
</tbody>
</table>

**Combined lesions:** *Division of vagi and midbrain.* The effect of division of both vagi and posterior corpora quadrigemina in very young animals (under eight days) appears to be no more severe than division of the vagi alone. Kittens from one to seven days old survived the double operation from two to ten hours. The protocol of such an experiment follows.

December 16, 1929. Kitten, 1 day old. Light ether, tracheotomy
2:40 p.m. Control tracing of respiration
2:45 Both vagi divided. Respiration slowed
2:50 Section behind posterior corpora quadrigemina
3:04 Respiratory record taken
3:25 Respiratory record taken
3:35  Respiratory record taken
3:45  Respiratory record taken
     No dyspnea. Some costal, as well as diaphragmatic respiration.
     Costal respiratory movements observed
5:00  Respiratory record taken. Costal respiration good
     The animal was then surrounded by warm cotton and placed where it
     could be observed every few minutes throughout the evening and night
8:00  Respiration regular
10:00 Respiration slower, considerable respiratory effort of the thorax
11:00 Same as the preceding hour
1:00 a.m. Terminal gasps after a period of dyspnea

Autopsy showed complete section behind the posterior corpora quadrigemina.

It may be noted from the above protocol that costal respiration was
unaffected by section of the midbrain, whereas, in older cats, it would
be very much cut down. The effect of the combined lesions in this case
was obviously no greater than the single operation of double vagotomy.

Fig. 2. a shows control thoracic (upper tracing) and abdominal (lower tracing)
respiration in a 14-day old kitten; b shows respiration following cervical laminectomy
and section of the cervical dorsal roots. Note the slowing of the respiratory rate.
c shows respiration following section of the midbrain behind the posterior corpora
quadrigemina.

Division of dorsal thoracic nerve roots and midbrain. When division of
the dorsal spinal nerve roots in the thoracic region is followed by division
of the posterior corpora quadrigemina, the degree of change brought about
in the character of the respiratory movements depends to a considerable
extent on the age of the kitten. In animals under ten days old, respiratory
movements persist for some hours following these two combined lesions
and are chiefly diaphragmatic, as in the very young normal kitten. In
older kittens, in which section of the midbrain is attended by more marked
effects upon the respiratory movements, the survival period is much cut
down.
Division of dorsal cervical nerve roots and midbrain. When the dorsal roots of the spinal nerves have been divided in the cervical region, and the posterior corpora quadrigemina sectioned, the age of the animal is again an important factor in determining the effect of the lesions. In the kitten under ten days old, the chief effect of this double operation is the cutting down of the diaphragmatic movements, which are not compensated for by any increase in thoracic respiration. Figure 2 shows this condition in a fourteen day old animal. The protocol of the experiment from which this tracing was taken follows.

February 13, 1930. Kitten, 14 days old. Ether, tracheotomy
11:15 Control record of respiration
11:30 Laminectomy in cervical region and section of cervical dorsal roots
   Record of respiration taken
12:05 Section behind posterior corpora quadrigemina; artificial respiration until
   spontaneous respiration returned at 12.10
12:10 Record of respiration taken
12:25 Record of respiration taken. Note—no compensation by intercostals when
   diaphragm is not active
12:45 Respiration fades out

Autopsy. Section of the posterior corpora quadrigemina complete except for a
small median portion of the tegmentum.

By the time that thoracic compensation for the diminished movements of the diaphragm after section of the dorsal roots of the phrenics occurs, section of the midbrain, which has hitherto been without any marked effect upon the respiratory movements, decreases or eliminates such compensation.

Division of dorsal thoracic nerve roots and vagi. Division of the dorsal thoracic nerve roots followed by division of both vagi, affects the respiratory movements severely. This is to be expected, since division of the vagi alone, without additional lesions, brings about an early failure of respiration. If the following protocol of such an operation be compared with that of division of vagi and midbrain (December 16th), it may be seen that the very young animal cannot withstand division of the dorsal thoracic roots and vagi quite as well as division of the dorsal thoracic nerve roots and the corpora quadrigemina.

December 18, 1929. Kitten, 3 days old. Light ether, tracheotomy
12:30 Control tracing of respiration
12:40 Laminectomy in thoracic region (thoracic respiration disappears)
1:05 Dorsal roots of spinal nerves cut in thoracic (respiration completely dia-
   phragmatic)
1:50 Vagi divided. Respiration becomes labored
2:30 Respiratory record taken
3:05 Respiratory record taken
3:60 Respiratory record taken. Respiration dyspneic
4:30 Respiratory record taken. Terminal gasps
NERVOUS CONTROL OF RESPIRATION IN KITTENS

Division of dorsal thoracic nerve roots and phrenics. When, in addition to section of the dorsal roots of the thoracic nerves, the phrenics are excised, there is an early failure of respiration. It has been shown for adult cats (Pike and Coombs, 1922) that if the dorsal roots are divided in the thoracic region, and costal respiration thereby cut down, thoracic respiratory movements will return with greater amplitude than in the control period, if the phrenics are divided. But this compensation does not occur at all in kittens under three weeks of age, and begins to show only slightly at that time. Instead, after a few weak gasps, respiration fades out.

Division of vagi and phrenics. Division of both vagi and phrenics in kittens is attended by early failure of respiration, since in this case, the main afferent and efferent respiratory pathways are cut off. In animals under ten days old, owing to lack of thoracic compensation, death occurs usually within an hour. In animals over three weeks old, when some degree of thoracic regulation has set in, respiration fails after a slightly longer interval, as the following protocol shows.

April 21, 1930. Kitten, 26 days old. Light ether, tracheotomy
10:40 Control tracing of respiration
10:45 Right vagus cut, continuous respiratory record taken
10:46 Left vagus cut, continuous respiratory record taken
11:04 Respiratory record taken
11:11 Right phrenic excised, respiratory record taken
11:12 Left phrenic excised, respiratory record taken
11:13 Respiration fails and artificial respiration is given for 3 minutes
No ether has been given since 10:45
11:16 Respiration has returned. Artificial respiration stopped. Record taken
11:40 Respiratory record taken
12:15 Terminal gasps

Fig. 3. a shows the effect of division of the right vagus in a kitten 26 days old; b shows the effect of division of the left vagus; c shows the effect of section of the phrenics. Note the costal compensation which has been established in d.
It may be seen from the respiratory tracings of this experiment (fig. 3) that the respiratory mechanism has evolved at this stage beyond the earlier type and that compensation for failure of diaphragmatic movements is being made by the intercostals. On the other hand, it can be seen that the influence of the vagus upon phrenic activity still persists, since section of the vagi not only slows respiration, but cuts down the amplitude of the movements of the diaphragm, which acquire the slightly sobbing character typical of interruption of some part of the proprioceptive pathway (Coombs, 1930).

Division of phrenics and posterior corpora quadrigemina. When phrenics and posterior corpora quadrigemina are both sectioned, the effects of the double lesion are at all times severe, but from different causes. In very young animals, where section of the midbrain is practically without effect, excision of the phrenics alone, causes failure of respiration in a short time, and in older animals, where thoracic compensation has been established, section of the now functionally active midbrain at the level of the posterior corpora quadrigemina interrupts this newly opened pathway at a different level, so that there is equally early failure of the respiratory movements. The following protocol is typical of such an experiment at the period when the thoracic mechanism is just beginning to be active.

April 16, 1930. Kitten, 21 days old. Light ether, tracheotomy
11:18 Carotids temporarily ligated
11:20 Section of right inferior colliculus
11:22 Carotids released, tracing taken
11:26 Complete section of posterior corpora quadrigemina
   Respiratory record taken
11:38 Respiratory record taken, respiration is dyspneic, diaphragmatic
12:07 Respiratory record taken
12:30 Respiratory record taken, respiration mostly diaphragmatic
12:40 Right phrenic excised, respiration becomes more costal
12:43 Left phrenic excised, respiration is strongly costal, no active movements of diaphragm
12:55 Respiratory record taken
1:25 Respiratory record taken
1:53 Respiratory record taken
2:10 Terminal gasps

Autopsy showed complete section just behind posterior corpora quadrigemina. No clots.

It may be noted from the tracing of this experiment (fig. 4) that after section behind the midbrain, respiration regains a regular rhythm. But when the phrenics are removed, respiration becomes irregular and acquires a gasping character as it fades out. This is also the case in adult animals.
Fig. 4. Shows respiration as recorded by tracheal cannula following complete section of the midbrain at the level of the posterior corpora quadrigemina in the kitten 21 days old, followed by removal of both phrenic nerves. Note the immediate gasping of the respiration.

<table>
<thead>
<tr>
<th>TABLE 2</th>
<th>Effects of combined lesions on kittens at different ages</th>
</tr>
</thead>
<tbody>
<tr>
<td>LESIONS</td>
<td>BIRTH-10 DAYS</td>
</tr>
<tr>
<td>Division of vagi and corp. quad.</td>
<td>Same as section vagi alone. Respiration fails after some hours</td>
</tr>
<tr>
<td>Section dorsal spinal nerve roots and corp. quad.</td>
<td>Effect not marked. No costal respiration</td>
</tr>
<tr>
<td>Section dorsal spinal nerve roots and vagi</td>
<td>Early respiratory failure. No costal movements</td>
</tr>
<tr>
<td>Section of vagi and phrenics</td>
<td>Early respiratory failure. No thoracic compensation</td>
</tr>
<tr>
<td>Section of corp. quad. and phrenics</td>
<td>Same as section of phrenics alone. Early respiratory failure. No thoracic compensation</td>
</tr>
<tr>
<td>Division of dorsal thoracic roots and phrenics</td>
<td>Early respiratory failure. No thoracic compensation</td>
</tr>
</tbody>
</table>
Table 2 illustrates the effects of combined lesions of the respiratory system, as related to the age of the animal.

Discussion. The differences in respiratory behavior of very young kittens as compared with older animals bring out certain trends in the development of the nervous mechanism of respiration.

While the phrenic mechanism is at all times able to compensate for failure of thoracic respiration—at best poorly developed in animals under twenty-one to twenty-five days old—below this age it appears to be impossible for the costal mechanism to effect a like compensation for failure of diaphragmatic respiration. Moreover, in animals from one to seven days old, the lack of immediate effect upon respiration of division of the midbrain at the level of the posterior corpora quadrigemina, in contradistinction to its marked effect in older animals, shows that as yet that part of the proprioceptive pathway concerned in the regulation of respiration, which traverses the midbrain at that level, has not become functionally active. This is shown in another way by the contrast in the activity of the thorax in adult cats as compared with young kittens, after section of the dorsal roots in the thoracic region, following section of the phrenics. In full grown animals there is a diminution of costal respiration after section of the dorsal thoracic nerve roots. But if, following this, the phrenics are excised, there is a return of costal respiration to a greater depth than before. This compensation does not occur in the kitten under about twenty-one days of age.

The vagus control over the movements of the diaphragm appears to be acquired earlier ontogenetically than regulation by any other portion of the afferent system, and its section is followed by relatively more severe effects in the very young animal, than in the animal in which the nervous system has undergone complete development. This is only to be expected if the vagus is the main source of afferent regulation. Double vagotomy brings about the sobbing type of respiration in the kitten, and also frequently cuts down the magnitude of the movements of the diaphragm, neither of which result from the same operation in the adult cat, in which there are additional afferent impulses coming in from other sources. It is not until the corpora quadrigemina are divided in addition to vagotomy that the diaphragmatic sobbing type of respiration is shown in the full grown animal.

From the evidence at hand, it would appear that at birth the respiratory mechanism has a relatively simple pathway in which the vagi and phrenics are the chief afferent and efferent nerves and the respiratory center in the medulla is relatively unaffected by impulses from nuclei higher up in the brain stem. But as thoracic respiration becomes of greater functional importance, the mechanism of the nervous control of the intercostals superimposes additional regulatory factors and the development of the higher levels of the nervous system multiplies the possibility of central connections above the medulla.
The precise location of the central station or stations at the level of the posterior corpora quadrigemina which are in functional relationship with the afferent pathways from the intercostals has not as yet been definitely settled. It has been shown that such control is ipsilateral (Coombs, 1929). It has been suggested by Allen (1927) that the reticulo-spinal tracts taking origin from the reticular nuclei of the upper medulla, pons and isthmus are respiratory in function, and of these he believes that the lateral reticulo-spinal fibers (both crossed and direct) are the chief ones concerned in the direct conduction of respiratory impulses from cells higher than the medulla to the ventral horn cells of the spinal cord. Since efferent impulses do not arise spontaneously, there are certain possibilities to consider as to the manner in which they are elicited. If these tracts convey efferent respiratory impulses from centers higher than the medulla to the ventral horn cells, their cells of origin must have received impulses by means of changes in the concentration of the blood gases. They must, therefore, be sensitive to such changes in the same way as are the respiratory cells in the medulla; or 2, of impulses from the respiratory center itself. These would have to travel on short, ascending pathways and descend again by the route indicated by Allen; or 3, of afferent fibers from various sources concerned in the regulation of respiration, particularly from the intercostals, which terminate in the central nuclei of the superior and inferior colliculi from which descending fibers carry impulses which are summed up with the blood gas stimuli in the medullary mechanism.

Now it was shown by an ingenious experiment of Flourens (1842) that there are no cells higher than the medulla which are sensitive to changes in the concentration of the blood gases in such a way as to originate respiratory impulses, so the question of a possible higher regulation of respiration by cells sensitive to changes in CO₂ may be dismissed. The choice would seem to lie, then, between the second and third possibilities. That is, between the possibility that the cells of origin of these reticular fibers are activated by afferent impulses arising somewhere in the peripheral respiratory mechanism and that the efferent fibers pursue a course independent of those arising in the cells of the so-called medullary center—the "noeud vital" of Flourens, to the motor cells of the ventral horns, or that these cells of origin of the reticular fibers, activated by afferent impulses from the peripheral respiratory field, terminate in the respiratory center in the medulla and have no further independent efferent pathway. A modification of the first of these two possibilities would be to suppose that the cells of origin of the efferent reticular fibers are activated by impulses coming up from the respiratory center itself.

The experiments of Gad and Marinesco (1893) on burning the cells of the medullary center with hot glass beads would seem to have a bearing on our decision. The destruction of the circumscribed area of the lower
portion of the medulla sufficed permanently to stop all respiratory movements, either diaphragmatic or thoracic, on the same side of the body. One would conclude from these experiments, either that the cells of origin of the reticular efferent fibers are excited by impulses coming up from the respiratory center or that they have no independent pathway lying at any significant distance from the respiratory nucleus in the lower portion of the medulla. Incidentally, the observation of Flourens, that the respiratory movements of the mouth and nostrils ceased after transection above the noed vital shows that there are ascending fibers from the medullary center to the nuclei of the seventh and fifth cranial nerves. It would seem improbable therefore, that the fibers Allen describes have any efferent path independent of the respiratory center in the bulb if they are to be regarded as of very great importance in the ordinary movements of respiration. It would seem more logical to regard them as being associated with some extraneous movements of the thorax and diaphragm such as those accompanying vocalization.

In this connection, one may cite the case mentioned by Hughlings Jackson (1898) in which strictly respiratory movements of the thorax persisted, but the voluntary control of the thoracic movements was lost. So far as the relation of the corpora quadrigemina to the respiratory movements is concerned, it seems more logical to suppose that the afferent impulses coming in over the dorsal roots of the spinal nerves pass up as high as the corpora quadrigemina and there come into relation with cells of origin of afferent fibers to the respiratory center itself. It seems probable that in the cartilaginous fishes, the mesencephalic nucleus of the fifth cranial is one central afferent station (Springer, 1928) for the control of respiratory movements of the mandible. Some mechanism of correlation of the activity of the bulbary respiratory center and the motor fibers of the V, VII and IX cranial nerves seems to be established in Selachians. Judging from what we know of the general deportment of the cells of the bulbary center, the access to it of descending impulses from somewhere in the peripheral field of the fifth cranial nerve seems probable. With the fading significance of the facial and mandibular musculature in respiratory movements in vertebrate phylogeny, the impulses passing from the collicular region down to the bulbary respiratory center appear to have become associated more closely with afferent impulses from the intercostal muscles.

Summarizing briefly, it would seem that afferent impulses from the intercostal muscles come first to cells in the ventral horns of the thoracic region, probably over intercalated neurones, and second, to some central station in the collicular regions. From the collicular central stations, descending fibers pass to the bulbary center wherein the impulses over these descending fibers are summed with the changes in concentration of the gases of the blood, and efferent impulses arising in the bulbary center pass
down the spinal cord, probably over intercalated neurones, to the ventral horn cells, wherein they are summed up with the afferent impulses coming in over the dorsal roots. It would seem that the fibers described by Allen are part of some other system.

CONCLUSIONS

1. Ontogenetic development of the vagus-phrenic portion of the respiratory mechanism has been completed at birth and is functionally active from that time onward.

2. A closer relationship between the vagus and phrenic nerves in respiratory regulation than between the vagus and dorsal spinal nerve roots is demonstrated.

3. Development of the mechanism for adequate thoracic respiration is not completed before the end of the third week after birth in the kitten, as is shown by its lack of ability to compensate for failure of diaphragmatic respiration.

4. The functional relationship of the nuclei in the corpora quadrigemina to the costal respiratory mechanism is not established earlier than ten days after birth and possibly later.

BIBLIOGRAPHY


1930. This Journal, xciii, 640; Science, lxxi, 136.


Flourens. 1842. Recherches sur les proprietes et les fonctions du syst new. 2d ed.

Gad and Marinesco. 1893. Arch. f. Physiol., 175.


Keller, A. D. 1929. This Journal, lxxxix, 289.