ON SPLANCHNIC MOTOR RESPONSES OF STOMACH
MOVEMENTS PRODUCED BY STIMULATION
OF THE MEDULLA OBLONGATA
AND SPINAL CORD

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It has already been reported by many authors that the motor center of the
stomach is located in dorsal nucleus alae cinerea (the dorsal nucleus of the vagus
nerve) in the medulla oblongata5), and that the motor pathways to the stomach
from medulla are contained only in the vagus nerves6,10).

However, as it was previously reported by one of the present authors,
regarding the augmented motor reflexes of stomach movement from urinary
bladder13), distal colon15) and ileum12), and regarding the motor effects of the
central stimulation of the sciatic14) and vagus nerves17), the efferent pathways
of these motor reflexes were demonstrated not only in the vagus nerves but
also in the splanchnic nerves.

These findings are also supported by the facts that the augmented motor
responses of stomach movement were obtained by the stimulation of the periph-
eral end of the splanchnic nerves and thoracic sympathetic trunk under
certain conditions16). Therefore, if the medulla is stimulated, it may be ex-
pected to demonstrate the splanchnic motor effect of the stomach movements,
through the spinal cord to the splanchnic nerves, as well as to obtain the
motor effect through the vagus nerves. The stimulation of the spinal cord
will also produce the augmented motor effect of the stomach.

The present study was undertaken in order to obtain the motor responses
of stomach by the stimulation of the medulla oblongata and the cervical and
thoracic regions of the spinal cord. The stimulated positions were examined
histologically.

METHODS

Dogs (weight 5-12 Kg) were used in all experiments. They were fasted for 24
hours before experiments, and anesthetized with intra-venous injection of Nembutal

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GASTRIC MOTOR RESPONSES

Dogs were held in a supine position, and a mid-line incision was made into the abdomen. Movements of the stomach were recorded by the balloon tambour method on the kymograph, and at the same time, the systemic blood pressure was recorded at the carotid artery by a mercury manometer. Then, the animal was held in ventriculcumbent position. A basilar portion of the occipital bone, i.e. from the region of cerebellar fossa to the anterior portion to the crista cerebello-medullaris, was excised. Thus the caudal portion of the floor of the 4th ventricle and the dorsal surface of the medulla oblongata were exposed by slight lifting of the vermis of the cerebellum. The spinal cord of the cervical and thoracic regions was exposed on the back of the animal, and the spinal dura mater of this region was resected.

A stimulator (Nihon Kohden Co. MS-1A) was employed with an intensity from 0.5 to 3 V, frequency from 1 to 40 CPS, duration 0.5 msec. and period from 10 to 40 seconds. A mono-polar electrode (enameled steel wire, with the exception of the tip which is exposed, 25, 30 and 52 μ in diameter) was used as a cathode for direct stimulation, and a 2x4 cm² silver plate was used as an indifferent electrode, placed in the abdominal cavity. A stimulating electrode was put vertically into the medulla and spinal cord from its dorsal surface in any desired depths. Sometimes, the spinal cord was transected previously and the stimulating electrode was applied on the section of the caudal portion of the cord.

When changes are noticed in the response of the stomach as a result of stimulation, the polarity of the stimulating electrode was reversed before its position is changed, and 0.2 mA current was applied for a few seconds to thermally cauterize the stimulated area. Thus the position of the electrode was determined in future histological examination.

For the histological examination, the dog was sacrificed by bleeding. The medulla oblongata and spinal cord were removed, and fixed in 10% formalin or 70% alcohol solutions. After paraffin embedding, serial coronal sections of the medulla and spinal cord were prepared at 30 μ. From the strips of serial sections, alternate slices of tissue were stained by Weigert-Spielmeyer method. The corresponding tissue sections which remained were stained by Nissl's method. In this manner, pair sections of the preparation could be examined histologically on its nerve fibers and cells.

RESULTS

Experiment A: Vagal motor responses of the stomach.
The bilateral splanchnic nerves (major & minor) were previously severed, and the vagus nerves were intact in this experiment.

The typical vagal motor effect caused by the stimulation of the medulla oblongata was shown in Fig. 1A. In this example, the electrode (30 μ in diameter) was placed vertically about 1 mm in depth into the central portion of the right alae cinerea on the dorsal surface of the medulla oblongata. An intensity 1 V, frequency 20 CPS and duration 0.5 msec. were applied to stimulate. The systemic blood pressure fell from 130 to 70 mm Hg, accompanied by a decrease in heart rate. The motor effect (increase of contraction and tone) was followed by a temporary inhibitory effect of the stomach.

After the successive severances of the bilateral vagus nerves on the same specimen, the stimulation of almost the same area which was used to cause the
motor effect produced no changes in the motility of the stomach.

**Fig. 1 A.** The vagal motor effect. The central portion of r-alae cinerea was stimulated. Bilateral splanchnicotomy. The description of curves is from the top downwards: systemic blood pressure, motility of stomach, signal and time marks (6 secs).

**Fig. 1 B.** The location of the stimulated area in Fig. 1 A. The coronal section through the level of 1-r-central portion of alae cinerea. Weigert-Spielmeyer stain. → stimulated area. 20×

**Fig. 1 C.** Diagram shows the coronal section through the central level of alae cinerea. Solid circles show the area which produced vagal motor effect.
According to histological examinations, the area which produced the above motor effect is situated in nucleus alae cinerea as shown in Fig. 1B. Diagram Fig. 1C shows the distribution of the motor areas which were found in several specimens on the same level. The motor areas were always found within nucleus alae cinerea, particularly in the dorsal part of it.

The same experiment was performed in the tuberculum and at different levels of alae cinerea. The motor responses were also obtained after the severance of the bilateral splanchnic nerves. The vagal motor responses were obtained 3 examples in the level of 10 mm oral to the obex, 2 examples in the level of central portion of the lower half of alae cinerea, and 3 examples in the level of obex. These motor areas were all found within nucleus alae cinerea on the histological examinations. The splanchnic nerves were previously severed in all specimens, and so the motor pathways from medulla oblongata were confined only in the vagus nerves in these experiments.

Thus, the areas which produce the motor effects of stomach through the vagus nerves, are located in nucleus alae cinerea. When the motor areas which were obtained from the above experiments are projected to the dorsal surface of the medulla oblongata, they are situated as shown by filled circles in Fig. 2. The expanse of the motor areas correspond to the expanse of nucleus alae cinerea. That is, they are located in the floor of the 4th ventricle, alae cinerea and fasciculus dorsalis, and occupy parallel to the intermedian sulcus, and their caudal limits are on the level of clava.

**Fig. 2.** The motor areas which were obtained from the histological examinations, were projected to the dorsal surface of medulla oblongata.

- ○ vagal motor areas
- ▲ splanchnic motor areas
**Experiment B**: The splanchnic motor responses of the stomach.

In the experiment which was shown in Fig. 3A, a level of 5 mm caudal to the obex, and 1 mm to the left of the dorsal median sulcus was stimulated, using an electrode of 52 µ in diameter with an intensity 1 V, frequency 20 CPS, duration 0.5 msec. and 15 secs. period. The bilateral vagus nerves were previously severed in the cervical region. The splanchnic nerves were intact.

A remarkable motor response of the stomach was obtained, and it was accompanied with a temporary inhibition (see Fig. 3A). No differences were

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**Fig. 3 A**. The splanchnic motor response. The stimulation at the level of 5 mm caudal to the obex and 1 mm to the left of the dorsal median sulcus. Bilateral vagotomy. (The description of curves is the same as in Fig. 1 A)

**Fig. 3 B**. The location of the stimulated area which was shown in Fig. 3 A. Coronal section through the fasciculus dorsalis at the level of 5 mm caudal to the obex. Weigert-Spielmeyer stain.

→ stimulated area.  20×

**Fig. 3 C**. Diagram shows the coronal section through fasciculus dorsalis at the level of 5 mm caudal to the obex. Solid circles show the positions for splanchnic motor responses.
observed in the movements of the stomach between the motor response of the vagal effect and that of the splanchnic one. The motor response of stomach had not been influenced by the removal of bilateral suprarenal glands; but after the severance of the splanchnic nerves, the increase of tone and movement of the stomach disappeared completely.

The stimulated area was examined histologically, and it was found to be located in the lateral portion of nucleus alae cinerea as shown in Fig. 3B.

Fig. 3C shows the distribution of the splanchnic motor areas of 4 specimens which were obtained on the same level. They were all found within nucleus alae cinerea.

The same experiments were performed in the fasciculus dorsalis, clava and alae cinerea. The motor responses were also obtained after the severance of the bilateral vagus nerves. That is, 9 specimens of the splanchnic motor responses were obtained in the level between 1-3 mm caudal to the obex, as shown in Fig. 4, 11 were obtained in the level between the lower half of the alae cinerea and the obex in the clava as shown in Fig. 5. They are all found in nucleus alae cinerea.

**Fig. 4.** Diagram shows the coronal section through the dorsal fasciculus at the level of 1-3 mm caudal to the obex. Solid circles show the splanchnic motor areas.

**Fig. 5.** Diagram shows the coronal section in the level of obex. Solid circle show the splanchnic motor areas.
If the areas which produced the motor effect through the splanchnic nerves are projected to the dorsal surface of the medulla oblongata, they are situated as shown by triangle marks in Fig. 2. They are distributed in the median region of the fasciculus dorsalis, and extend caudally to the spinal cord. The rostral limit of these expanses is the level of lower half of the alae cinerea.

**Experiment C:** Stimulation of the cervical and thoracic cords.

1) The spinal cord was transected between the cervical and the thoracic region. Two hours after surgical operation, the right dorsal column of the 1st thoracic cord was stimulated with an intensity of 2 V, frequency 1 CPS, duration 0.5 ms. The electrode was put 1 mm depth into the dorsal column of the 1st thoracic cord. The motor response of the stomach was also obtained as shown in Fig. 6.

![Fig. 6. r-dorsal column of the 1st thoracic cord was stimulated on the spinal dog. (The description of curves is from the top downwards: motility of stomach, signal and time marks, 6 secs.)](image)

2) The example which was shown in Fig. 7A, had the intact spinal cord, but the bilateral vagus nerves were previously severed in the cervical region. The electrode was put 1 mm depth vertically into the dorsal surface of the spinal cord 2 mm caudal to the r-2nd cervical dorsal root and 1.5 mm to the right of the dorsal median sulcus. An intensity 2 V, frequency 20 CPS, duration 0.5 msec., period 40 secs. were used for stimulation. The systemic blood pressure fell from 120 to 90 mm Hg, and the increased motor response of the stomach was obtained (Fig. 7A).

The result of the histological examination of this specimen was shown in Fig. 7B. The stimulated position was found in the dorso-lateral portion of the r-lateral column.
The location of the stimulated areas on 10 specimens which produced the motor responses of the stomach in the cervical and thoracic cord were shown in Diagram Fig. 7C. In general, the motor areas were found in the dorso-lateral portion of the lateral column, and in a few examples they were found in the ventro-lateral portion of the substantia gelatinosa dorsalis, near the isthmus of the dorsal column.

Experiment D: The severance of the dorsal roots of the thoracic cord.

In this experiment, the vagus nerves were previously severed, and the medulla oblongata was stimulated in the clava on the level of obex. After confirming that the splanchnic motor response of the stomach was produced by the stimulation, the bilateral dorsal roots from 4 to 13th of the thoracic
cord were severed on the same dog. Then almost the same area was stimulated in the medulla. No motor response of the stomach was observed. However, in this experiment, the systemic blood pressure usually fell to 60 mm Hg and less than it, and so the next experiment was undertaken.

The bilateral dorsal roots between the 4th to 13th thoracic cord were previously severed one week ago. Then medulla oblongata was exposed and stimulated at the central portion of the alae cinerea with 1 V, 20 CPS, 0.5 msec. duration and 15 secs. period. The vagus nerves were intact. The blood pressure fell from 90 to 63 mm Hg by the stimulation and the stomach motility increased remarkably as shown in Fig. 8A (vagal motor effect). On the same animal, 2 mm to the right of the dorsal median sulcus on the level of 6 mm caudal to the obex was stimulated with the same intensity and frequency. The respiratory movements were increased and the blood pressure was increased.

**Fig. 8 A.** L-central portion of alae cinerea was stimulated. Bilateral dorsal roots from 4th to 13th thoracic cord were severed one week ago. (The description of curves is the same as shown in Fig. 1A.)

**Fig. 8 B.** Nn. alae cinerea was stimulated in the level of 6 mm caudal to obex. The same dog as shown in Fig. 8 A. (Description of curves is the same as shown in Fig. 1A.)
from 94 to 104 mm Hg. However, the motility of the stomach was slightly inhibited and no motor response was observed (Fig. 8B). That is, no splanchnic motor effect was observed. These facts show that the splanchnic motor effect was produced via the dorsal root of thoracic cord.

DISCUSSION

1) The results which were obtained from experiment A, show that the vagal motor areas in the medulla oblongata are located in nucleus alae cinerea. The fact that the vagus nerves have an origin in nucleus alae cinerea, has been demonstrated by Kosaka & Yagita who made the histological examination of the medulla oblongata by using the degeneration method of vagus nerve.

On the other hand, Miller, Laughton stimulated this area directly, and they obtained the motor effect of the stomach. However, the electrode employed, were large in diameter. Recently, Sugihara who used an electrode of 80 μ in diameter, stimulated the medulla oblongata. He believed that the vagal motor area was located in fasciculus solitarius and its surroundings.

The more fine electrode of 20, 30 and 52 μ in diameter were employed in this experiment A, and found that the stimulated positions which produced the motor effect of stomach via vagus nerves were restricted within nucleus alae cinerea.

2) On the splanchnic motor response, we have suggested physiologically the existence of the motor pathways to the stomach through the splanchnic nerve via the spinal cord from the medulla oblongata in our previous work and the report of Lim et al. This was supported by the several facts which concerned with the motor reflex of the stomach: that is, on the vesico-gastric motor reflex, on the entero-gastric motor reflex, on the colon-gastric motor reflex, on the motor response from the sensory stimulation, and on the motor response from the central stimulation of the vagus nerve. One of the motor efferent pathways in these reflexes was demonstrated through the splanchnic nerves.

The stimulation of the peripheral end of the splanchnic nerves and the thoracic sympathetic trunk also produced the augmentation of the stomach motility under a certain condition as previously demonstrated.

As shown in Experiment B, the motor responses were obtained in the animal which had the vagus nerves severed (splanchnic nerves were intact) by the stimulation of the medulla oblongata. After the bilateral splanchnicotomy, the motor responses of the stomach completely disappeared. The stimulation of the cervical and thoracic cord on the spinal animal also produced the motor effect of the stomach (Experiment C).

These facts show clearly the existence of the motor pathways from the medulla oblongata to the splanchnic nerves through the spinal cord.
3) Experiment D shows that the pathway from the thoracic cord to the splanchnic nerves is the dorsal roots. If the dorsal roots were severed completely, the stimulation of the splanchnic motor areas in the medulla oblongata did not produce any motor responses of the stomach. It was also demonstrated by SEMBA & HIRAOKA\textsuperscript{16} that the stimulation of the peripheral end of the dorsal root of thoracic cord produced the motor responses of the stomach, in spite of the stimulation of the ventral root produced the inhibition of stomach.

4) The areas of the splanchnic motor response in the medulla oblongata were restricted within nucleus alae cinerea, especially in the lower portion of alae cinerea. It is very interesting that the motor areas both the vagal and splanchnic nerves are located in nucleus alae cinerea in the medulla oblongata. As shown in Fig. 2, the vagal motor areas locate in the alae cinerea from the oral side of clava, and the splanchnic motor areas locate in it of the caudal portion of its lower half.

Thus nucleus alae cinerea connects, on the one hand, to the vagus nerves in the oral part, and on the other hand, it extends caudally to descend through the spinal cord to the splanchnic nerves. It may be concluded that the motor nerve supplies to the stomach are vagus and splanchnic nerves. The diagram of the nervous pathways to the stomach are shown in Fig. 9. We can demonstrate another similar example on the augmented motor response of the colon: that is, the movement of descending colon is controlled mainly through the pelvic nerve (motor fiber) and is partially controlled through the hypogastric nerves (motor fiber)\textsuperscript{11}.

\[\text{FIG. 9. Diagram shows that the motor pathways to the stomach, which have the origin in nucleus alae cinerea in medulla oblongata (M). One is connected to the vagus nerves, and another pass through the cervical (C) and thoracic cord (T) to the splanchnic nerve.}\]
5) On the problem that the autonomic nerve cells in the spinal cord have their origin in the medulla, BRUGSH, DRESEL and LEWY reported that the stimulation of nucleus alae cinerea produced the glycosuria, and the removal of the superior cervical ganglion caused the degeneration of nucleus alae cinerea. CHEN et al showed that the stimulation of nucleus alae cinerea caused sympathetic nerve symptoms in the alimentary canals. HUSTEN, CHIN, SHIZUME and others also suggested the direct connection between nucleus alae cinerea and the autonomic nervous cells of the cervical and thoracic cord from histological examinations. The present results obtained in Experiment B & C show physiologically the existence of the connection between nucleus alae cinerea and the autonomic nerve cells of the cervical & thoracic cord.

CONCLUSION

The medulla oblongata and the cervical and thoracic cord of dog were stimulated by electrodes of 20, 30 and 52 μ in diameter, and the vagal and splanchnic motor effects of the stomach were observed. The stimulated positions were examined histologically and the following results were obtained:
1. Motor response of the stomach was obtained through both the vagal and the splanchnic nerves by stimulation.
2. The areas which produced the vagal motor effect were found in the area of nucleus alae cinerea. They occupy the whole length of the alae cinerea from the oral part of clava on the dorsal surface of medulla.
3. The areas which produced the splanchnic motor effect were also located in the area of nucleus alae cinerea, extending to the grey substance of the spinal cord. They occupy the lower part of the alae cinerea on the dorsal surface of medulla.
4. Therefore, it may be concluded that both the vagal and splanchnic motor areas to the stomach have the same origin in the medulla oblongata, i.e. nucleus alae cinerea. It extends, on the one hand, toward the oral side to the vagus nerves, and on the other hand, it extends caudally through the cervical and thoracic cord and via the dorsal root to the splanchnic nerves.

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