ELECTROMYOGRAPHIC INVESTIGATION OF ESOPHAGUS, IN ANIMALS

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I. Introduction

Many investigators have studied the anatomy and physiology of the esophagus. However, very little has been done with regard to electrophysiology of the esophagus⁽²¹⁾.

The esophagus is the organ for deglutition which consists of two muscular layers with muscularis mucosa and mucous membrane. Histologically, it consists of striated muscle in the upper part of the organ and smooth muscle located in the lower part of the organ. The mid-esophagus is a mixture of both types, and the proportion varies from one individual to the other. This was described by Lerche⁽¹⁸⁾.

Branches of the vagus nerve and cervical sympathetic fibers innervate the cervical esophagus, and vagal and thoracic sympathetic fibers go to the thoracic esophagus^(11,16).

The tetanic contraction of esophagus was observed directly by Kao Hwang⁽¹³⁾ who stimulated the pharyngo-esophageal nerve

which comes off vagus nerve superiorly to the ganglion nodosum, however, this author demonstrated direct observation of esophageal contraction via esophagoscopy by stimulating the cervical portion of the vagus nerve.

It has been claimed that the cricopharyngeus muscle is a functional sphincter clinically. Denervation of this muscle by cutting the vagus results in the increased tonus of the muscle and dysphagia. These studies have been done by Kirchner recently⁽¹⁶⁾.

The state of tone of this muscle at rest is still not understood⁽²⁰⁾. The author tried to measure the resting potentials by means of electromyography.

Many clinicians have observed that increased tonus of this muscle produces dysphagia. This is attributed to the disfunction of vagus nerve or hyperactivity of cervical sympathetic nerve⁽¹⁶⁾.

The sphincter action of the lower end of esophagus has been discussed by many scholars for a long time, however, no definite conclusions have been made^(4, 19).

No anatomical sphincter has been demonstrated. Respiratory effects on the closing mechanism have not been elaborated clearly. Jackson emphasized the pinch cock mechanism of the diaphragm on the sphincter action of this part of esophagus⁽¹⁵⁾.

Action potentials of the diaphragm were recognized by Agostoni, however, this was done indirectly, not by inserting a needle directly into diaphragm⁽²⁾.

The author tried to measure the action

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potentials by direct method. We inserted a needle into the esophageal muscle layer, confirming the location of the needle point by means of a muscle identifier. This permitted clear identification of the action potentials of the esophagus and diaphragm.

Achalasia of the esophagus has been investigated by many scholars for the years. Recently, a most excellent work on achalasia of the cardia by Adams and his group was done^(1, 22). The etiology of this disease is not yet determined satisfactorily.

Since Cannon found and wrote about "the law of denervation",⁽⁴⁾ strong emphasis on the defect in cholinergic innervation has been considered important in the etiology of achalasia. A comparative study of this disease to Hirschsprung's disease was done by Trounce⁽²²⁾. Dysfunction of the plexes of Meissner and Auerbach are considered by many to be etiologically significant.

Experimentally, the administration of anticholinesterase agent to animals induced achalasia in dogs. Many subsequent investigators confirmed these observations⁽¹⁰⁾.

Action potentials of the muscles after administration of this drug were found to be increased in amplitude and frequency. These agents are said to induce dysfunction of the neuro-muscular junction after long administration with maximum dosage. The author tried to measure normal and abnormal potentials and also tried to induce achalasia.

Long et al observed distinct difference in action of esophagus after bilateral cervical vagotomy⁽¹⁷⁾ and induced surgical achalasia by this method⁽¹⁸⁾.

Congenital achalasia of the dog is observed by veterinarians occasionally. This author measured the action potentials from the esophagus of such a dog.

Electromyography has been used for the

diagnosis of lower motor neuron disease and for other research purposes for the past few years⁽³⁾. The author considers the fibrillation potentials, positive sharp waves and polyphasic potentials as signs of denervation of lower motor neuron origin. On the other hand, the amplitudes and frequencies are carefully measured.

II. Apparatus, Equipment and Materials

Model-P meditron made five channel electromyograph which permits simultaneous recordings and display was used. Four channels are identical A-C amplifiers and preamplifiers. The last one is D-C pressure transducer. Each beam can be monitored on the other screen making it possible to introduce easily small amplitudes of the order of 100 uv fibrillation denervation potentials.

Viking V.U. (62) 4 track recorder was employed for immediate recordings to permit convenient playback.

Sinesquare wave signal generator, precision model E 310 microattenuator, and Simpson 260 adaptor were directly connected to the electromyograph for necessary calibration for same qualitative and quantitative data for each time.

A Crass Camera was used for having selective tracings for photography from the prerecorded tracings. Speeds of 500 mm/sec and 250 mm/sec enable one to distinguish the fibrillation potentials from normal motor units potentials of short duration were employed.

Specially devised curved monopolar electrodes were applied and inserted into the selective esophageal muscle layers by means of a pair of foreign body forceps via various sizes of Jacksonesophagoscope.

Three dogs had their vagus nerves cut completely on one side and crushed on the other side, at the level below superior lary-

ngeal nerve.

Two dogs were vagatomized on one side at the level below the superior laryngeal nerve, followed by the same procedure on the other side.

One of two dogs with achalasia, 6 months old, had congenital achalasia. The other, 6 years old, had acquired achalasia with dysphagia, emesis and weight loss for 6 months.

Three cats were given Humorsol (Demecarium bromide), one of the anticholinesterase agents, with the dosage of 0.012~0.02 mg/kg body weight, intramuscularly, two times a week for 4~5 months.

Three other cats had their cervical vagus nerves severed on one side below superior laryngeal nerve, followed by the same procedure on the other side.

The last two cats were used as a control and kept and fed under the same condition as the other previously mentioned.

Nembutal was a choice of anesthesia with a dosage of 25 mg/kg body weight, intraperitoneally for cats and intravenously for dogs.

III. Method

Passing the suitable scope into the esophagus, an active electrode was inserted into the selective muscle layer over the scope as close as possible to the tip of the scope, at various levels 5 cm apart in dogs and 3 cm apart in cats, on each muscle layer, from the cardia up to the cricopharyngeus muscle.

By direct stimulation of muscle by a 0.01~0.1 mA. current the location of the tip of electrode in the muscle layer was identified. The action of circular layers or longitudinal layers was clearly noted by this stimulation.

The esophagoscope itself was the inactive electrode and this made a distance between

active and inactive electrodes of not more than 1 cm avoiding any undesirable artifacts.

With weaker anesthesia, better action potentials were obtained; the animal was well grounded before each examination. Two channels were used; one for the esophageal muscle and the second was for the intercostal muscle to obtain respiration action potentials.

Hollinger's endoscopic camera was used to visualize and demonstrate the difference of action after stimulation, between circular and longitudinal layers of esophageal muscles.

Careful anatomical dissections of vagus nerves in the neck of cats was done to trace the small fibers and branches from vagus trunks to the muscles of the esophagus with the aid of a Zeiss operative microscope.

IV. Results

- 1) By the methods above, it was hard to obtain the resting potentials from normal esophagus on both layers, on both animals.
- 2) Spontaneous discharges from cricopharyngeus muscle of cats and dogs were obtained. Action potentials were always recorded from the posterior part of the muscle so that one could avoid the interference from cricoaryteroid posterior muscles.

Amplitudes ranged from 100uV to 1000uV with frequencies of 8-30/sec. (Fig. 1). The action of this muscle was observed and shown by high speed endoscopic camera.

Concentric contraction was observed (Fig. 2).

- 3) Respiratory effects were noted on the lower part of esophagus on both cats and dogs. From 1-2 cm below the esophogogastric junction to 2-3 cm above the esophogogastric junction, to 3-4 cm above the esophogogastric junction on dogs.

Spike action potentials were synchroni-

Fig. 1

Upper beam: E.M.G. from intercostal muscles.
The firing on inspiration.
Lower beam: E.M.G. from the cricopharyngeus
muscles. The firings are independent to respiration.

Fig 2 (A)

The action of cricopharyngeus muscle. Photographed by the Hollinger's camera. The muscle is fully contracted.

Fig. 2 (B)

The action of cricopharyngeus muscle. Photographed by the Hollinger's camera. The muscle is partially contracted. Both concentric and spiral actions (contraction) are observed.

Fig. 2 (C)

The action of cricopharyngeus muscle. Photographed by the Hollinger's camera. The muscle is fully dilated.

Fig 3

Upper beam: E.M.G. of intercostal muscle.
Discharges on inspiration.
Lower beam: E.M.G. of esophageal muscle (circular layer) 3 cm above G. E. junction.
Discharges synchronize to inspiration.

zed with each inspiratory phase and equally noted on circular layer and longitudinal layer (Fig. 3). No respiratory effects were seen on the middle and upper parts of esophagus. These spike potentials are not confused with diaphragmatic potentials because the needles were known to be (see experiment method) in the esophageal muscle layer.

4) To identify the muscle layer to be

Fig. 4

Dog 83, 15 kgm. 2 weeks after unilateral Cervical Vagotomy (LT.)

	Anterior		Posterior		Left		Right		Remarks
	Cir.	Long	Cir.	Long	Cir.	Long	Cir.	Long	
20 cm. (Cricophar. M.)	+++		+++		+++		+++		All normal motor unit potentials
25 cm.	—	—	—	—	—	—	—	—	
28 cm.	+++	++	—	—	++	+	—	—	All fibrillation volages with posssharp potential
30 cm.	+++	++	+++	+++	++	+	+++	+	Fibrillation with pos. sharp potential; normal motor unit
33 cm.	+++	++	+++	++	+++	++	+++	++	Same above
35 cm.	+++	+++	+++	++	+++	++	+++	++	Same above
38 cm.	+++	+++	+++	++	+++	+++	+++	++	Same above
40 cm.	++	+	+	+	+++	+	+++	++	Same above
43 cm.	++	—	++	—	++	—	++	+	Same above
45 cm.	—	—	—	—	—	—	+	—	All fibriltion potentials
47 cm. (G-E junction)	—	—	—	—	—	—	—	—	

examined, greater amouts of amperes were needed to get satisfactory contraction of muscle on unilaterally vagotomized animals.

Fibrillation denervation potentials, positive denervation potentials and polyphasic potentials, which are clearly seen in the denervated skeletal muscles usually, were shown on every side of esophageal wall and in both layers, eight to tan days after the dogs and ten to fourteen days after the cats had unilateral cervical vagotomy (Fig. 4).

With the dogs, these abnormal potentials were seen anywhere from 2.5 cm above the esophagogastric junction or 45 cm below incisor up to 25 cm below incisor or 5 cm below cricopharyngeus muscle (Fig. 4).

On the cats, these fibrillation denervation potentials were picked up from 30 cm below incisor on the beginning of the cardia up to 15 cm below incisor or 5.0 cm

below cricopharyngeus muscle. Low 1/5 of esophagus consists of smooth muscle and other of striated muscle in cate (Fig. 5, chart).

Fig. 5

Upper beam: E.M.G. from lower part of esophagus. Marked fibrillation potentials are seen.

Lower beam: E.M.G. from inter costal muscle, on silent stage.

Action potentials were found in increased frequency and higher amplitude in circular layer than longitudinal layer of muscles on both animals (Fig. 6, tracings). This is

Fig. 6 (A)

E.M.G. from longitudinal layer of esophageal muscle on cat, after cervical vagotomy. Fibrillation potentials are seen.

Fig. 6 (B)

E.M.G. from circular layer of esophageal muscle on cat, after cervical vagotomy. Fibrillation potentials are seen in higher amplitudes and higher frequencies, than those of longitudinal layer.

easily shown on experiment when the author moved the needle from the longitudinal layer into the circular layer.

Signs of regeneration were seen 9 weeks after unilateral vagotomy on dogs and 12 weeks on cats, by recognition of giant motor unit potentials, nascent motor unit

potentials, and polyphasic potentials. Respiratory effects on these esophagi were observed besides spontaneous denervation voltages, and these were found more active in frequencies and amplitudes than those of normal intact animals. No denervation potentials were measured from cricopharyngeus muscle.

5) These studies were followed by cervical vagotomy on the other side, which permitted the animals to live only 5-7 days, 10 weeks after first vagotomy on dogs and 28-32 weeks on cats.

Frequencies and amplitudes of action potentials found in circular layer were much higher than in longitudinal layer in both animals.

Respiratory effect on the denervated esophagus was observed, besides the spontaneous denervation potentials. No denervation potentials were recorded from cricopharyngeus muscle after bilateral vagotomy.

Direct visualization of lower part of esophagus showed the evidence of contraction of lumen and dilatation of middle part by bilateral vagotomy on 2 of the 3 cats.

6) It is interesting to note that definite fibrillation potentials and positive sharp waves were seen at the lower end of esophagus of cats after bilateral and unilateral vagotomy (Fig. 7). This part proved consist of smooth muscle entirely, by histological study.

Denervation potentials were not seen in lower part of esophagus of the dogs in spite of the presence of striated muscles.

7) Electromyographic findings on achalasia dogs were quite interesting. One dog was a 6 months old Irishsetter with congenital achalasia (Fig. 8, X-ray). The entire length of esophagus was 45cm below incisor and lower 5cm was constricted. The other was a 7 year old Newfoundlander with acquired achalasia with persistent dysphasia, emesis

Fig. 7

Upper beam: E.M.G. from lower end of esophagus of cat after cervical vagotomy. Definite positive sharp wave potentials are seen. Lower beam: E.M.G. from inter costal muscle on silent stage.

Fig. 8

x-ray film of 6 mos. old dog with achalasia (congenital) E.M.G. from the esophagus of this dog is shown in Fig. 9.

and a prolonged deglutition time for 6 months. The entire length of esophagus was 53 cm from incisor and it had dilated all the way to the cardia. Electromyographic studies were done in same manner under nembutal anesthesia.

On the former dog, a tremendous amount of fibrillation denervation potentials and positive sharp potentials were picked up from the dilated part of the esophagus at any level and site, especially from the low-

Fig. 9

E.M.G. of the achalasia dog. Marked fibrillation potentials are recorded from the dilated part of this esophagus (see Fig. 9).

er part of dilation (Fig. 9). No fibrillation potentials were obtained from the cardia. This represents the severance of lower motor neurons which innervate the dilated part of esophagus, by any cause, in any part.

On the latter dog, no fibrillation potentials were seen. But, normal motor units were obtained from the dilated portion of the esophagus. This was more apparent at the level of 40-45 cm. On both dogs, more electrical activity, both normal types, were seen in the distal areas of dilation.

8) For the purpose of induction of achalasia, humorsol was given to 3 cats. One hundred days after drug (humorsol) administration, fibrillation denervation potentials with positive sharp waves were obtained from the esophagus and intercostal muscle of cats.

Atropine was necessary to compensate for the overaction of cholinergic effects such as hypersecretion and edema of the tissue, particularly pulmonary edema. Humorsol administration was stopped at the end of the 5th month because the animals were becoming weak.

Three cats showed some evidence of achalasia 13 weeks after administration started. This was observed as fairly dilated part

on middle and lower esophagus and tightened area on lower esophagus by means of esophagoscope.

Microscopically, the distal 1/5 of esophagus in these cats was composed of smooth muscle.

9) The actions of criopharyngeus muscle, longitudinal and circular layers of esophagel muscle were photographed by endoscopic camera. Stimulation by the muscle identifier gave the definite position of the needle and these muscles were photographed separately. Electrical stimulation of vagus nerve on one

Fig. 10 (A)

The action of esophagus by the electrical stimulation of the cervical vagus nerve.

Fig. 10 (B)

The action of circular layer of the esophageal muscles by electrical stimulation.

Fig. 10 (C)

The action of longitudinal layer of the esophageal muscles by electrical stimulation.

Fig. 11

Cat # 11:

Dissected esophagus after unilateral cervical vagotomy. No evidence of dilatation.

Cat # 9:

Dissected esophagus after long term administration of humorsol. Moderate dilatation on lower esophagus.

Cat # 24:

Dissected esophagus after bilateral cervical vagotomy. Marked dilation of mid-lower esophagus.

side at the level of thyroid cartilage caused contraction of the entire esophagus. This was observed, by an endoscopic camera (Fig. 10).

10) Autopsy of animals was performed following the above studies. Unilateral cervical vagotomy case showed no evidence of achalasia. Humorsol case showed some

light evidence of dilatation of esophagus on its lower part, but not at esophagogastric junction. The case with bilateral cervical vagotomy showed marked evidence of dilatation of esophagus on its middle and lower portion including esophagogastric junction (Fig. 11).

V. Discussion

1) Lerche⁽¹⁸⁾ described the muscular layer of human esophagus macroscopically and microscopically. The cat esophagus is the most similar to the human esophagus among domestic experimental animals from the histological point of view. Because dog esophagus consists entirely of striated muscle, cat esophagus is the most similar to human for measuring the normal and abnormal action potentials.

2) After careful dissection of cats and dogs under an operative microscope, only small fibers innervating the esophagus from the vagus trunk were seen excepting for the branches from the pharyngeal plexes to the upper portion of cervical esophagus. This means that even slight pathology around these fibers may cause the damage to the fibers and partial denervation of esophagus, such as was seen with the achalasia dog by the electromyogram which showed fibrillation denervation potentials. Further studies are necessary for the investigation of denervation of esophageal musculature.

3) Equality of denervation potentials from every side of esophagus after unilateral cervical vagotomy indicates that innervation of esophagus is bilateral; hence, unilateral denervation does not cause achalasia experimentally.

4) Synchronized action potentials to respiration have been recorded from lower part of esophagus on both dogs and cats in spite of histological differences. No apparent respiratory effects on the middle

and upper parts of esophagus were seen.

5) Fibrillation denervation potentials from the cardia, which consists of only smooth muscle in the cat, should be investigated more: since the experimental data indicates their presence contrary to prior work.

6) The difference of activity between longitudinal and circular layers is very interesting and this was investigated by means of the classical kymograph by Eura in 1937⁽⁹⁾ and pharmacologically by Ellis in 1960⁽⁸⁾. Electromyography clearly showed the difference of electrical activity between both layers.

All the cats and dogs showed these phenomena and the author assumes this applies to the human esophagus. The difference of activity between these muscle layers and dominance of the circular layer is probably attributed to any functional disorder of the esophagus such as, Schatzki's ring, functional constriction of esophagus such as tertiary contraction or tired spasm, achalasia and other functional dysphagia, when the functional balance of these muscles is broken.

7) Long term administration of an anticholinesterase agent to the animals results in constant acetylcholine transmission in neuromuscular junction, thus destroying many myenteric and submucous plexes. This is one way to induce the achalasia, and has been proved histologically.

Electromyographic findings at this point are of great interest. The fibrillation denervation potentials were recorded from various parts of skeletal muscles of the animal as well as from esophageal muscles.

The etiology of achalasia is still unknown. Whether dysfunction of the plexes or diseased lower motor neurons play a part should be investigated further by using electromyography.

8) Spontaneous electrical discharges from

cricopharyngeus muscle were obtained.

The tonus of this muscle is higher than that of the other part of esophageal muscles at resting stage.

9) Autopsy of animals demonstrated distinctly that achalasia was induced in animals by the methods mentioned above, and that upper part of esophagus must have innervation from superior laryngeal nerve and pharyngoesophageal nerve (Hwang) ⁽¹²⁾ and some other branches because there is no evidence of dilation after vagotomy.

VI. Conclusion and Summary

- 1) Seven dogs including two achalasia dogs and seven cats were studied by electromyography of esophagus.
- 2) Spontaneous discharges from the cricopharyngeus muscle were recorded.
- 3) The difference in action potentials between longitudinal and circular layers of esophagus was observed, and the dominance of the circular layer was noted.
- 4) Fibrillation denervation potentials were recorded from the dilated part of achalasia esophagus of the dog.
- 5) Findings indicate one possible etiology of achalasia is damage of lower motor neurons.
- 6) Fibrillation denervation potentials were recorded from the muscles of animals after long term administration of anticholinesterase agent
- 7) The innervation of esophagus is bilateral.
- 8) Electromyography is established as another method of investigating of the pathophysiology of the esophagus.

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