SYMPATHETIC INNERVATION OF THE MAMMALIAN GASTRO-INTESTINAL TRACT

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The sympathetic innervation of the walls of the esophagus, stomach, and duodenum in cats was investigated by the method of detection of catecholamines in air-dried preparations. An abundant sympathetic innervation was found in all layers of these walls. The terminal sympathetic plexus of the smooth-muscle layers of the outer coat and the muscularis mucosae is formed by adrenergic axons from three sources: 1) axons arising from the perivascular plexuses, 2) axons arising from the intermuscular plexus, and 3) axons of adrenergic neurons contained in the intramural ganglia. Preganglionic adrenergic axons forming synaptic structures on the intramural neurons of the walls of these parts of the gastro-intestinal tract, are found. Adrenergic neurons are present in the wall of the duodenum.

In monographs dealing with the innervation of gastro-intestinal tracts published within the last decade [2, 5] the authors have drawn from an extensive literature and their own experience and have concluded that still very little is known of the distribution and endings of sympathetic fibers in the wall of the gastro-intestinal tract and that this is due to the difficulty of identifying sympathetic nervous structures.

The old question of the sympathetic innervation of the gastro-intestinal tract is now being discussed in a totally different light in connection with the results obtained by luminescence microscopy [7-9, 15]. These results show the following:

1. Many adrenergic fibers, forming synaptic connections with the intramural cells of the esophagus [8, 9], stomach [7], and intestine [15, 17], are found in the intermuscular and submucous nervous plexuses.

2. The adrenergic innervation of the muscular coat in the walls of the gastro-intestinal tract, according to some investigators [17], is very poorly developed and has no marked direct influence of the smooth musculature. These workers suggest that both motor and inhibitory effects are achieved through parasympathetic influences on the wall of the digestive tube.

3. Other workers [7, 9, 16] have found a well-developed adrenergic plexus in the muscular coat in various parts of the gastro-intestinal tract of man and mammals, and they consider that the smooth musculature of the stomach and intestine is under the direct influence of a mediator secreted by this terminal plexus.

Since the results of investigations of the adrenergic innervation of the gastro-intestinal tract described in the world literature are contradictory and since only one paper [6] exists in the Soviet literature, it was decided to investigate the adrenergic innervation of the walls of the gastro-intestinal tract in mammals. This paper gives data on the adrenergic innervation of three regions: the esophagus, the stomach, and the duodenum of the cat.

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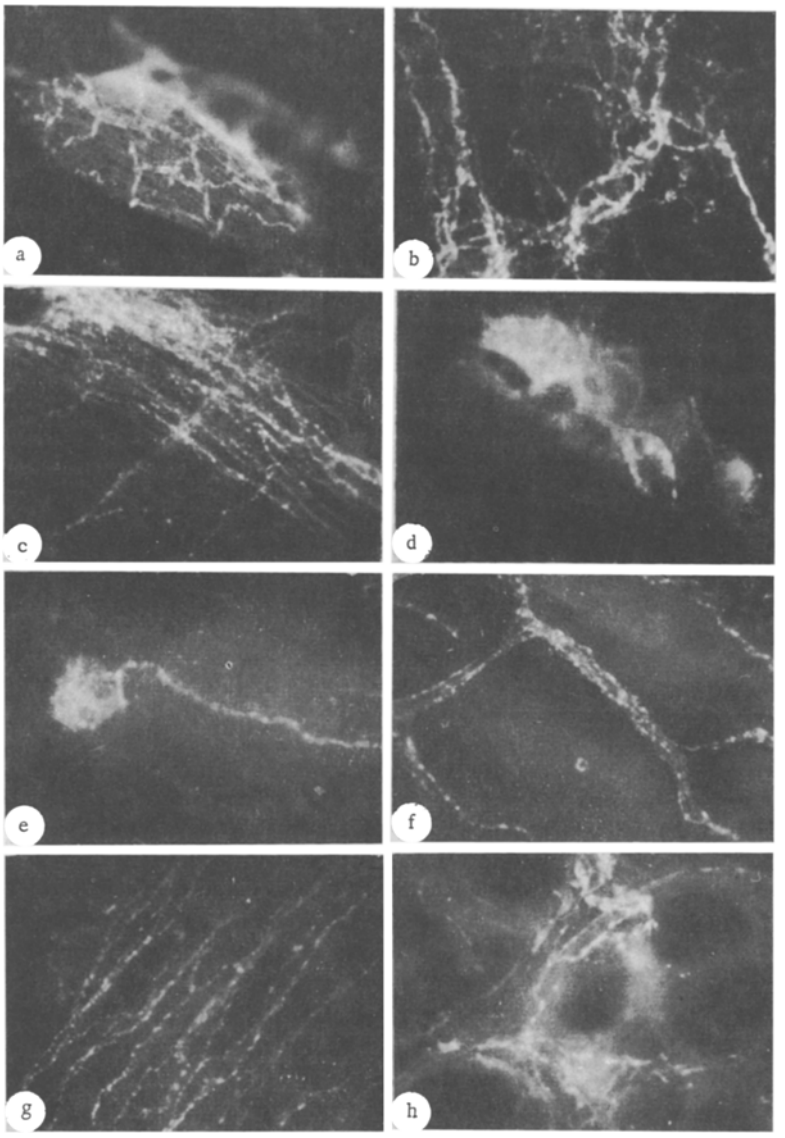

Fig. 1. Luminescence of adrenergic nerve fibers (a-h). Explanation in text, 360×.

EXPERIMENTAL METHOD

The animal was killed by exsanguination under general anesthesia. The pieces of tissue removed were washed in physiological saline. Thin sections for histochemical treatment were cut as described in [3], and the histochemical procedure of Falck and Owman [12] was carried out. Unmounted sections were studied in the ML-12 luminescence microscope during the 2 days after histochemical treatment. The autoluminescent structures were identified by heating the sections in the absence of paraformaldehyde.

EXPERIMENTAL RESULTS

Specifically luminescent nerve fibers were found in both the adventitia and the muscular coat of blood vessels of the esophagus, stomach, and duodenum. The muscular coat in arteries of large caliber was identified by the presence of an autoluminescent elastic stroma, interweaving with a network of specifically luminescent adrenergic fibers (Fig. 1a). The striated muscle of the oral portion of the esophagus had a poorly developed adrenergic innervation connected anatomically with the perivascular plexuses (Fig. 1b).

In the walls of the caudal portion of the esophagus, the stomach, and the duodenum the outlines of the intermuscular nervous plexus and its intersections with the cluster of ganglionic cells were identified by

the presence of whitish,autoluminescent,thin, smooth fibrous structures, components of the intramural intermuscular nervous plexus.

The intermuscular nervous plexus contained varicose fibers, with specific bright green luminescence, running "en passant" through the clusters of ganglionic cells whose bodies were not luminescent (Fig. 1c).

Not all adrenergic fibers in the intermuscular plexus ran through "en passant," but some terminated on the neuron bodies as specifically luminescent synaptic structures (Fig. 1d). The bodies of these neurons were not luminescent.

The intramural plexus of the duodenum contained individual nerve cells with specific luminescence of their cytoplasm and processes (Fig. 1e).

A terminal adrenergic plexus was clearly distinguished in the outer and inner layers of the smooth-muscle coat of the esophagus, stomach, and duodenum. The axons forming it were connected anatomically with the perivascular adrenergic plexus or with the intermuscular nervous plexus, which they left as thin bundles or single terminals and ran along the smooth-muscle cells. Both the bundles (Fig. 1f) and single axons (Fig. 1g) had a well-marked varicose structure.

In the submucous and mucous layers of the wall of the esophagus, stomach, and duodenum there were many autoluminescent fibrous structures, against the background of which the specifically luminescent vascular nervous plexuses and single terminal fibers, connected with the perivascular nervous plexuses, stood out clearly. The muscularis mucosae also had a well-marked adrenergic innervation consisting of a plexus of thin, varicose axons. Many adrenergic terminal fibers were found in the connective-tissue stroma at the base of the glandular crypts (Fig. 1h).

The method of luminescence microscopy, which can be used to identify the sympathetic component of the autonomic innervation of the walls of gastro-intestinal tract with great accuracy from the presence of catecholamines in the nervous structures, undoubtedly revealed new facts both for morphology and for physiology. Contrary to the opinion of Hill [13], who denied that sympathetic fibers exist in the autonomic intermuscular plexuses, many workers [9, 15, 16] have found numerous adrenergic fibers in the intramural nerve ganglia of the gastro-intestinal tract.

According to the present experiments, specifically luminescent nerve fibers present in the parasympathetic intermuscular plexuses not only run through "en passant," avoiding the ganglionic cells, but they also terminate on some of them as axo-somatic synapses on the surface of the perikaryons. It can be concluded from this fact that the parasympathetic preganglionic fibers running to the intramural ganglia of the esophagus, stomach, and duodenum also contain sympathetic preganglionic fibers. The intramural ganglia of the gastro-intestinal tract have not only cells of Dogiel's types 1 and 2, but also adrenergic neurons. Such neurons were found in the present investigation in the wall of the duodenum.

Although there is no question regarding the nature of isolated adrenergic neurons with specific luminescence of the perikaryon, with respect to the nature of neurons without specific luminescence in their cytoplasm, but connected synaptically with the preganglionic adrenergic fibers, the question of which component of the autonomic innervation they belong to must be asked.

To answer this question it is useful to resort to the observations of Ehinger and Falck [10]. Adrenergic terminals are very rarely found in the ciliary ganglion of intact animals, and if they are found it is only near blood vessels. No neurons whatever with specific luminescence were observed. If, however, dopamine and a monoamine oxidase inhibitor were given to the animals first, brightly luminescent nerve cells and a thin network of terminal axons around the luminescent bodies of the neurons appeared among the parasympathetic neurons in the ciliary ganglion of these animals. The fact that certain neurons of the ciliary ganglion can "extract" catecholamines from the blood stream has led some workers to suggest that they are similar to adrenergic neurons. The absence of specific luminescence in the adrenergic neurons of the ciliary body of intact animals is explained by Ehinger and Falck on the grounds that the content of mediator in these neurons under normal conditions does not reach the level of concentration capable of histochemical detection. These workers regard the neurons as typical adrenergic neurons manifesting their functional activity with an unusually low concentration of mediator in their cytoplasm.

Neurons of the intermuscular intestinal plexuses whose bodies are not luminescent but have adrenergic synaptic systems can probably be classed as sympathetic neurons.

Neurons of a similar type, as well as neurons with specific luminescence, are found in the intramural ganglia of other internal organs also [4, 11, 14].

The view that all intramural autonomic neurons are parasympathetic and that the smooth-muscle coat of the wall of the gastro-intestinal tract receives a poorly developed adrenergic innervation is incorrect. The results of these experiments show that the muscularis mucosae and both layers of the muscular coat proper of the walls of the esophagus, stomach, and duodenum have an abundant postganglionic adrenergic innervation, probably arising from several sources. The first source consists of axons leaving paravascular nervous plexuses, the second source, of axons running through the intermuscular plexus "en passant." The trophic centers for both these sources lie outside the intestinal wall—in the semilunar ganglia of the solar plexus [1]. The third source consists of axons of adrenergic neurons lying in the intramural ganglia of the gastro-intestinal tract. Inhibitory influences on the wall of the gastro-intestinal tract are thus brought about by the direct action of the extramural and intramural postganglionic adrenergic innervation.

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