THE MYENTERIC REFLEX AS EXHIBITED BY THE EXTERIORIZED COLON OF THE DOG

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In 1899 Bayliss and Starling investigated the movements and innervation of the intestine, and concluded, “that if cerebrospinal reflexes be excluded, excitation at any point of the gut excites contraction above, inhibition below. This is the law of the intestine.” Since then, many other investigators have confirmed the general truth of this statement, but the fact must be emphasized, that this “myenteric reflex” (Cannon, 1912) cannot be demonstrated invariably, and that it occurs typically only under very special conditions (denervation, purging).

Previous work in this field has been done with intestinal strips (Magnus, 1904) or with anesthetized animals. The changes in motility have been recorded by means of x-rays, balloons put into the bowel through a cut in its wall, or by enterograph of Alvarez (1924). All of these methods cause trauma, although the enterograph method seems to offer the least objection on this score. A more important objection can be found against the mode of stimulation of the bowel. In the researches of Bayliss and Starling, the stimuli were applied either to the serosal surface, or to the mucosa, by means of cotton pledgets or other “bolus-like” material. The bolus stimulus is much better than one applied to the serosa, a surface of no importance in the digestive activity of the intact animal. Distention is to be regarded as the normal mechanical stimulus for both large and small intestine. In studies directed toward localization of action, distention causes a reaction too widespread to be useful.

Alvarez (1924) states that in studying peristaltic activity with “6 or 7 recorders attached to the bowels of rabbits,” he was “surprised to find that ordinarily the bowel not only did not relax in front of the advancing wave, but it often became more active, and served to stop the rush, especially in the lower ileum.” Alvarez and Starkweather (1919) found that the usual response to peritoneal stimulation of rabbit intestines was contraction above and below. The objection to these experiments, which has been duly appreciated by Alvarez (1924), has been that only the motility of the longitudinal coat of the intestine was being recorded. It will be shown
later that this objection holds the key to the situation, and explains many of the discrepancies reported in the literature.

METHOD. The technic used in the present investigation was described in the preceding article. It consists essentially of the exteriorization of a piece of bowel (colon, in the present study) of a dog, so that the mucosal surface is exposed to the air. When the dog has recovered from the operation, he is trained to lie quietly, while the motility of the intestinal transplant is recorded by means of a modified enterograph lever. The longitudinal and transverse musculature may be studied separately or simultaneously, while the chosen stimulus is applied to the mucosa. We have shown already that there is present in the intact graft a reflex which depends upon the adequate sensitivity of the mucosa to a tactile stimulus, since it is abolished by cocaine. The reflex reaches the muscle by way of the para-sympathetic myoneural junctions, for it disappears after atropine. However, the myenteric reflex persists after section of the pedicle which connects the intestinal graft with the central nervous system. The stimulus which was used to elicit the reflex response was applied by stroking the mucosa by means of a dull teasing needle, with as uniform pressure as possible. This stimulus has proved adequate to elicit a reflex response on the part of the intestinal musculature, but does not otherwise disturb the dog.

A few preliminary experiments were performed on pithed cats, with the enterograph attached to the serosal surface of the ileum (Mulinos, 1931).

RESULTS. A. In pithed cats, maintained by artificial respiration, the intestinal motility of which is being recorded graphically, stimulation of the vagus nerve in the neck or chest elicits a strong motor response, which varies in duration with the age of the specimen, the amount of trauma and exposure. It was observed that in about half of over 100 such stimulations the enterogram would indicate a marked relaxation to follow the primary contraction. Of these, about 90 per cent occur when the bowel is dilated initially. Visual examination of the gut during the "relaxation," on the contrary, showed the bowel to be in such severe spasm as to be bloodless. During the contraction of the circular muscle, the intestine between the recording strips was lengthened, giving the appearance of depression or relaxation of the longitudinal muscle, an unwarranted conclusion. These observations led us to refer to further investigation the inference that—

a. The primary contraction recorded was due to a shortening of the longitudinal fibres of the ileum which we were recording, and that

b. The longitudinal contraction was soon followed by a contraction of the circular muscle, which was sufficiently potent to overcome the longitudinal shortening, and to lengthen actually these fibres.

Magnus (1904) observed this same phenomenon in isolated strips, and concluded that as the circular coat contracts, the longitudinal relaxes.
Quite probably what Magnus saw was the predominance of the activity of the circular muscle, which, by constricting, stretched the now relaxing longitudinal muscle. Cannon (1912) believed that the two coats contracted simultaneously. From these experiments, and those which follow, it is obvious that after vagus stimulation in the neck, or from stroking

![Diagram A](http://ajplegacy.physiology.org/attachment.php?attachment_id=123456)

![Diagram B](http://ajplegacy.physiology.org/attachment.php?attachment_id=789012)

**Fig. 1.** Schematic representation of the colonic graft. *P* is proximal, *D*—distal; *R*—right and *L*—left. The solid lines ending in circles represent the attachment of the clips of the recording instrument. Further details in text.

A. With the clips attached at *B*—*C*, stimuli within the area enclosed by the broken lines are effective in eliciting a contraction of the longitudinal muscle.

B. With the clips at *A*—*B*, stimuli within the area of the isosceles triangle of base *A*—*B* and the broken lines are effective in eliciting a contraction of the circular muscle between *A*—*B*.
the mucous membrane, the longitudinal muscle contracts first, and is followed by a contraction of the circular coat.

B. Experiments on the unanesthetized dog. 1. Localization of the position of the stimulus necessary to produce contraction of the longitudinal muscle. With the clips of the recording apparatus attached at any one location, contraction of the muscle recorded by the clips does not follow stimulation of all parts of the mucosa of the graft. The points stimulated are best shown with the aid of a graph, figure 1, a. The circles indicate the position of attachment of the recording clips from time to time while the lines indicate the position of stimulus application. The letters A, B, C, D indicate the position of the recording clips, while C, L, R indicate the center, left and right of the graft.

With the clips at A-B, the stimulus was applied at the various points shown in the graph. The results are shown in the accompanying tables.

*Recording clips attached at A-B (fig. 1-A)*

<table>
<thead>
<tr>
<th>STIMULUS POSITION</th>
<th>EFFECT</th>
<th>STIMULUS POSITION</th>
<th>EFFECT</th>
<th>STIMULUS POSITION</th>
<th>EFFECT</th>
</tr>
</thead>
<tbody>
<tr>
<td>AB-L</td>
<td>Moderate contraction</td>
<td>BC-L</td>
<td>No contraction</td>
<td>CD-L</td>
<td>No contraction</td>
</tr>
<tr>
<td>AB-C</td>
<td>Strong contraction</td>
<td>BC-C</td>
<td>No contraction</td>
<td>CD-C</td>
<td>No contraction</td>
</tr>
<tr>
<td>AB-R</td>
<td>Moderate contraction</td>
<td>BC-R</td>
<td>No contraction</td>
<td>CD-R</td>
<td>No contraction</td>
</tr>
</tbody>
</table>

*Recording clips attached at B-C (fig. 1-A)*

<table>
<thead>
<tr>
<th>STIMULUS POSITION</th>
<th>EFFECT</th>
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<th>EFFECT</th>
<th>STIMULUS POSITION</th>
<th>EFFECT</th>
</tr>
</thead>
<tbody>
<tr>
<td>AB-L</td>
<td>Moderate contraction</td>
<td>BC-L</td>
<td>Moderate contraction</td>
<td>CD-L</td>
<td>No contraction</td>
</tr>
<tr>
<td>AB-C</td>
<td>Strong contraction</td>
<td>BC-C</td>
<td>Strong contraction</td>
<td>CD-C</td>
<td>No contraction</td>
</tr>
<tr>
<td>AB-R</td>
<td>Moderate contraction</td>
<td>BC-R</td>
<td>Moderate contraction</td>
<td>CD-R</td>
<td>No contraction</td>
</tr>
</tbody>
</table>

*Recording clips attached at B-D (fig. 1-A)*

<table>
<thead>
<tr>
<th>STIMULUS POSITION</th>
<th>EFFECT</th>
<th>STIMULUS POSITION</th>
<th>EFFECT</th>
<th>STIMULUS POSITION</th>
<th>EFFECT</th>
</tr>
</thead>
<tbody>
<tr>
<td>AB-L</td>
<td>Weak contraction</td>
<td>BC-L</td>
<td>Moderate contraction</td>
<td>CD-L</td>
<td>Moderate contraction</td>
</tr>
<tr>
<td>AB-C</td>
<td>Moderate contraction</td>
<td>BC-C</td>
<td>Strong contraction</td>
<td>CD-C</td>
<td>Strong contraction</td>
</tr>
<tr>
<td>AB-R</td>
<td>Weak contraction</td>
<td>BC-R</td>
<td>Moderate contraction</td>
<td>CD-R</td>
<td>Moderate contraction</td>
</tr>
</tbody>
</table>

It is obvious that a stimulus applied to the colonic mucosa "below" that is distal to the point which is being recorded, elicits no contraction.
of the longitudinal muscle above. Stimulation of the mucosa above or orad to the point of record elicits strong contractions at and below the application of the stimulus.

These three tables show that stimuli applied along the same longitudinal plane as the recording clips will produce contraction only if they are applied between the clips or proximal to them. When the stimulus is applied lateral to the clips the motor response diminishes rather rapidly. Applied proximally, the stimulus is effective over a distance of 4 to 6 cm. Applied laterally, it is effective only within 2 to 3 cm. This reflex reaction becomes intelligible upon the assumption that there are nerve connections which run sensory-motor distal to the point stimulated. *Apparently the mucosa has no nervous connection with the longitudinal muscle above itself.*

**SUMMARY.** Stimulation of the mucosa of the colon causes a contraction of the longitudinal muscle at and below the point of stimulation, but none above. With a linear stimulus, the area of contraction may be represented by an isosceles triangle. Conversely, a given area of the intestine contracts when stimuli are applied to the mucosa above the area. Such a condition acting alone would cause an increase in the volume of the intestinal lumen below the point of stimulation (bolus).

2. Localization of the position of the stimulus necessary to produce contraction of the circular muscle. The diagram (fig. 1b) shows the position of the clips on the graft, and the points stimulated. The clips were attached to A–B. The stimuli were applied transversely, between the clips, and at 2 and 4 cm., on either side. The results are shown in the accompanying table.

<table>
<thead>
<tr>
<th>STIMULUS POSITION</th>
<th>LEFT</th>
<th>CENTER</th>
<th>RIGHT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximal to clips</td>
<td>4 cm.</td>
<td>No contraction</td>
<td>No contraction</td>
</tr>
<tr>
<td></td>
<td>2 cm.</td>
<td>No contraction</td>
<td>No contraction</td>
</tr>
<tr>
<td>Between the clips</td>
<td>Strong contraction</td>
<td>Strong contraction</td>
<td>Strong contraction</td>
</tr>
<tr>
<td>Distal to the clips</td>
<td>2 cm.</td>
<td>Weak contraction</td>
<td>Strong contraction</td>
</tr>
<tr>
<td></td>
<td>4 cm.</td>
<td>No contraction</td>
<td>Weak contraction</td>
</tr>
</tbody>
</table>

It is obvious from these results that the circular muscle responds to stimuli in a manner different than does the longitudinal. All stimuli proximal to the clips are incapable of eliciting a contraction of the circular muscle between the clips. Stimulation of the colonic mucosa at and distal to the recording clips elicits a response. When the stroke stimuli are applied transversely, both the circular and the longitudinal muscles respond by contraction. It may be assumed that there are nerve connections which
run sensory-motor proximal to the point stimulated. The mucosa appears to have no nervous connections with the circular muscle below itself.

Summary. Stimulation of the mucosa of the colon causes a contraction of the circular muscle at and above the point of stimulation, but none below. With a linear stimulus applied transversely, the area of contraction may be represented as an isosceles triangle (fig. 1b). Conversely, a given strip of the intestine contracts to stimuli applied to the mucosa below the strip. Such a condition acting alone would prevent easy access of a bolus toward the stomach; acting together with the longitudinal muscle, there will be an increase in lumen area below the stimulus, a decrease above.

Discussion. The results described in the preceding paper, and under A in the first part of this report show beyond any shadow of doubt that vagus stimulation, or mucosal irritation, elicit contractions of the longitudinal muscle first, and then of the circular. The result of such a mechanism is first to increase the lumen of the gut, and then to decrease or obliterate it. These experiments offer no suggestion that either coat of the colonic musculature is inhibited at any time by mucosal stimulation. If a balloon system is used as a recorder, the effect—longitudinal contraction below, followed by circular spasm above—may be interpreted as inhibition (increased volume of intestinal lumen), followed by stimulation. When the enterograph system is used (Mulinos, 1931) what is recorded is an apparent stimulation (contraction of the longitudinal muscle), followed by relaxation.

The results obtained by a more careful localization of the relationship between the locus of stimulation and the region of response point definitely to the existence of a “myenteric reflex.” The sequence of events is something like this: A stimulus (bolus) at any point along the colon elicits a contraction of the longitudinal muscle at and below the point of stimulation. The intestinal lumen below the bolus is enlarged, facilitating its passage downward. A few seconds later, there is contraction of the circular muscle at and above the point of stimulation. The intestinal lumen above the bolus is narrowed or obliterated, further facilitating the downward passage of the bolus.

This phenomenon is a true reflex, for it is abolished both by cocaineization of the mucosa, and by atropine sulphate given systemically. It is a true myenteric (local) reflex for it does not depend upon any connection with the spinal cord. All that can be said at this time is that this myenteric reflex occurs in intact, unanesthetized dogs. No denervation or purging is necessary (Bayliss and Starling, Cannon, Alvarez). It is possible that the localized stimulus studied, if continued downward along the colonic mucosa, might result in a “chain” reflex, giving the appearance of peristalsis. No such studies were made.

It has been mentioned already that the mucosa is connected functionally
with the two muscular coats of the colon in a very characteristic manner. Sensory nerves (afferent) connect the mucosa with the longitudinal muscle at and below itself; and with the circular muscle at and above. Furthermore, impulses to the longitudinal muscle become manifest more quickly than impulses to the circular muscle. It is impossible at this time to say whether the difference in rate of response is to be found in the afferent fibers of the nerves, or in the circularly arranged muscle fibers. It may be that in the case of the longitudinal muscle fibers the afferent nerves have their endings, and presumably the source of acetyl-choline or other such hormone (Mulinos, 1929), very near to the parasympathetic myo-neural junctions of the muscle. The quickness of response would be then a function of the rate of diffusion of the "vagus-stoffe" into the cell. Contrariwise, the smooth muscle cells of the circular muscle may lie at a greater distance from the nerve endings, giving a response which is slower than that of the longitudinal muscle by the time necessary to diffuse into the cell. This same delay in transit opens the acetyl-choline to the destructive action of the esterase, so that less of the drug reaches the cell. Such a concept may explain the observation that longitudinal stimulation elicits a response only in the longitudinal muscle, while transverse stimulation elicits contractions from both the coats. We may picture the intestinal mucosa as made up of a mosaic of sensory nerve receptors. These are arranged in rows of pairs, one member of each pair to the circular and the other to the longitudinal muscles. Upon longitudinal stimulation, we stimulate a large number of pairs, but only a few of those which run to any one set of circular muscle fibers. The very little acetyl-choline which is liberated near the circular muscle is destroyed by its esterase before it can diffuse into the cell, and there is no contraction. When the stimulus is applied transversely there is much more response because the impulses to the muscle are manifold those from longitudinal stroking. The longitudinal muscle fibers respond both times because they are situated nearer their corresponding nerve endings. We speak of this as greater sensitivity for want of a better term. We believe that the sensory elements of the myenteric reflex have their cell stations within the gut wall because the myenteric reflex persists after the graft has been isolated from the central nervous system.

One observation deserves mention at this time. After food, the colonic graft seemed to be more irritable, so that a lesser mucosal scratch elicited a response, while the normal stimulus elicited more powerful and longer sustained contractions of the intestinal coats. A plausible explanation is offered of the fact that eating of food (distention of the stomach) causes an increased desire to stool, and that this increase in colonic activity is not dependent upon an increase of the contents of the colon. White, et al. (1934) report a reddening of, and an increased secretion by the mucous membrane of the colon in man immediately on beginning to eat.
SUMMARY

1. The motility of the colon graft elsewhere described was studied on unanesthetized trained dogs. The stimulus is applied to the mucosa.
2. The principle of the "myenteric reflex" has been confirmed, although a new definition became necessary.
3. Our results point definitely to the absence of any inhibition in the make-up of the myenteric reflex—and also demonstrate that no such mechanism is necessary for the propulsion of a bolus along the colon.
4. Thus "the law of the intestine" may be restated as follows: In the colon of the unanesthetized dog, a stimulus applied to the mucosa is followed by contraction of the longitudinal muscle at and below the stimulus, and by contraction of the circular muscle at and above it. The first precedes the latter by 3 to 5 seconds.

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