ACTION CURRENT OF ALIMENTARY CANAL

OBSERVATIONS ON THE NORMAL AND OBSTRUCTED BOWELS

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The existence of spike potential in the electrical phenomena of smooth muscle movement, as in the case of striated muscle, has been verified ever since Bozler's research (1938-1949) and the subsequent experiments of Niu (1950). Prior to that time, the electrogram which shows a slow rhythm similar to that of the mechanogram was understood to be action current, but after the discovery of the spike, it has become necessary for us to reconsider fundamentally the physiology of smooth muscle movement. However, a sufficient explanation has not been made yet regarding the question of what relationship the occurrence of such a spike group has to the mechanogram. Furthermore, no electro-physiological study whatsoever has been made public as to the significance of "tonus variation."

It has been proven by our experiments in the past, that the abnormalization of the tonus variation, *i.e.* an abnormally amplified tonus swing, would always appear when an obstruction was created in the alimentary canal. On the other hand, by applying this pathological fact as a means for smooth muscle research, we should understand the electro-physiological significance of the tonus variation. The following is a report of interesting findings which I obtained, along with Dr. Toyama and Dr. Kamei, by recording the action current of both normal and obstructed alimentary canals and the simultaneous recording of mechanogram and cinematography of intestinal movement.

METHOD

(A) *Experiments with 14 healthy rabbits and 10 marmots*; approximately 5 cm. of intestinal loop was excised at a point 40-50 cm. above the end of the small intestine, and placed horizontally in Tyrode-solution. Almost all of the surface of the specimen was above fluid level while recording the internal pressure curve by Trendelenburg's method. One electrode was in contact with the surface of the intestinal loop and another was dipped into the solution in which the intestinal loop was placed. While recording the action current, which accompanies the intestinal movement, a register of the internal pressure curve and the cinematographic recording of the intestinal movement was performed, therefore an electro-physiological analysis of the movement was achieved. The mechanogram was recorded (fig. 1 B) on the same film with electrogram by

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means of a mirror connected directly to the tambour, or recorded on another kymograph by a writing rod (fig. 1 A). To make the electrogram, non-polarizable Ag-AgCl electrodes of 0.1 mm. in diameter, R.C. amplifier (time constant 3 seconds), electromagnetic oscillograph (Vibrator H-type) were used.

FIG. 1. Experimental apparatus.

A apparatus registers the internal pressure curve (Pr') by the modified Trendelenburg's method by means of a tambour and writing rod.

B apparatus: A mirror is attached to the second tambour which is connected to the circuit of A. Internal pressure curve (Pr) is concurrently recorded on the same film as the action current (Ac).

E^1 is the first electrode placed on the intestinal wall, which lies exposed on the surface of the Tyrode fluid (T);

E^2 the second electrode put into the surrounding fluid;

Vi the H type vibrator of the oscillograph.

(B) *Experiments with 13 rabbits and 5 marmots:* Intestinal obstruction was created by simple ligation of the same intestinal segment as that used for the normal experiment; 22 hours or 48 hours after obstruction, the intestinal segment immediately above the obstruction was excised, and the action current and mechanogram were observed by the method mentioned above.

RESULTS

The electrogram of the rabbit's intestinal movement, recorded by the above mentioned method, delineates, as in fig. 2, a complicated wave group (A) identical

FIG. 2. A concurrent recording of action current of normal rabbit's intestine (A) and the internal pressure curve, i.e. Tambour-Mirror curve (B).

with internal pressure curve, *i.e.* Tambour-Mirror curve (*B*). A group of spike potentials superimpose on a slow wave and together they compose a mixed wave, which corresponds to a single rhythm of an internal pressure curve. Furthermore, the spike group appears at the early stage of the ascending phase of the mechanographic wave.

As shown by the arrow signs in the cinematographic picture (fig. 5) of the rabbit's intestinal movement, single peristaltic rings pass the electrode at intervals of 4 seconds, which correspond to the period of single waves on the Tambour-Rod curve (fig. 3). Each wave of the internal pressure curve is coincident with one peristaltic ring, and also with one slow potential wave which is superimposed upon by a group of numerous spikes.

FIG. 3. Internal pressure curve of normal rabbit's intestine.

The single wave (wave height approx. 1.5 cm. H₂O) indicated by arrow sign corresponds to a group of spikes in fig. 4. Signal indicates the time of cinematographic recording (fig. 5).

FIG. 4. Action current of normal rabbit's intestine. Numerous spike potentials are massed on top of one slow potential wave and corresponds to the wave indicated by the arrow sign in fig. 3 and to the contraction shown on the moving pictures (photo. 2 in fig. 5).

Generally, a single macroscopically observable peristaltic wave is underlaid with a number of excitations, so that its electrogram assumes a complex form consisting of two components, *i.e.* the slow wave and the frequent spike potentials. In the case of rabbits, the maximum amplitude of spikes is approximately 0.4–0.8 mV and the interval approx. 1/6–1/11 sec.; the spikes are more frequent and larger in size, at the upper portion of the small intestine than at its lower portion, where the slow wave becomes conspicuous. In the case of rabbits the slow wave is larger than in the case of marmots, which demands a special consideration.

In the cases of pendular and segmenting movements, where the movement appears weaker than in the peristaltic movement, the spike potential is sparse and small, the slow wave has a tendency to be smaller.

During the early stage of the Trendelenburg's survival-experiment, the regular

FIG. 5. Cinematographic views of normal rabbit's peristalsis. This fig. corresponds to fig. 3 and fig. 4; interval between each photo. is 1 sec. Arrow sign shows the contraction as it passes the electrode approximately at an interval of every 4 sec.

fundamental peristaltic rhythm of the internal pressure curve and the numerous large spike potentials in a mass group appear. However, when the specimen has been surviving for a long period, and loaded by continuous internal pressure, *i.e.* at a later stage of the experiment, the contraction shows a strengthened pressure-raising power and a tendency for the continuous type, the fundamental rhythm fuses and groups, but on the contrary the spikes become comparatively small and fewer in number.

If intestinal obstruction is created by the above mentioned method, the difference seen between the early stage and the later stage of the surviving specimen becomes all the more conspicuous. The more severe the ileus, the greater the abnormality in the internal pressure curve and electrogram from the earlier stage of survival. The simultaneous record of the electrogram and mechanogram shows, as in the normal case, the fact that a single wave of internal pressure curve (*B*) corresponds to one group of spikes of electrogram (*A*), but the internal pressure curve shows a marked ascension, in comparison to normal cases, the amplitude (and sometimes number) of spikes a marked decrease, and the period of the respective single fundamental rhythm is conspicuously prolonged (fig. 6).

In the severe case of ileus where the obstruction has continued especially for a long period, the internal pressure curve (fig. 7) shows grouping or enormous waves from the beginning of the survival; the contraction shows a continuous

FIG. 6. A concurrent registering of action current (A) and the internal pressure curve, i.e. Tambour-Mirror curve (B) in the case of rabbit's ileus.

FIG. 7. Internal pressure curve of rabbit's intestine 48 hours after intestinal obstruction was produced. *a, b* indicate two enormous continuous contractions, and correspond to *a', b'* parts of the electrogram (fig. 8) and to the arrow sign in the cinematographic pictures (fig. 9). The signal indicates the time of cinematographic recording.

type; during such continuous contraction the peristaltic rhythmic phenomena are hardly recognizable; although the height of the internal pressure wave is very marked, electrographically the amplitude of the spike diminishes conspicuously. Simultaneously with two large movements (*a, b*) in fig. 7, there

FIG. 8. (upper): Electrogram which corresponds to fig. 7.

The three layer of electrograms are a succeeding continuation.

a', b' parts represent respectively a group of amplified slow potential waves. This fig. corresponds to the two enormous pressure waves *a, b* in fig. 7.

FIG. 8' (lower) is an enlarged appearance of part *a'* and a swift swing which resembles a trace of spike can be discovered at the arrow sign.

are found on the electrogram (fig. 8, 8') respective amplified slow wave groups (a' and b'). While the internal pressure curve shows one large wave, 2-4 clearly separated slow waves are recorded; the cycle of the respective slow waves is approx. 3-4 sec. and is similar. However, a clear spike is not delineated on the respective slow wave. In this example, as the arrow signs of fig. 8' show, only swift swings are discernible which barely suggest the latent existence of spikes.

On the simultaneous cinematographic record (fig. 9) of these two large movements, a wide-spreading sustained strong contraction (arrow sign) which becomes enlarged analward slowly, appears twice. During each gross contraction, it is not clear by macroscopic observation whether peristaltic rhythmic variation of muscle shortening actually exists or not. These sustained gross contractions are considered to be extremely strengthened "tonic contractions" and clinically to correspond to "Spasms."

FIG. 9. Cinematographic view of rabbit's intestinal movement in the case of ileus.

This fig. corresponds to the intestinal movement delineating fig. 7a, b and fig. 8a', b'; the interval of each picture is 1 sec.; arrow sign indicates a conspicuous "tonic contraction."

DISCUSSION

Fifteen years have elapsed since Bolzer proved for the first time that the spike potential was the main element of the intestinal action current, but relatively few researches have been performed along these lines. By employing a new experimental method, *i.e.* concurrent observation of electrogram, mechanogram and cinematographic record, we were able to prove that a single wave of the mechanogram corresponds to a single peristaltic movement and this one rhythm corresponds to a group of numerous spike potentials. Furthermore, we recognized that each rhythm of the mechanogram was always accompanied each time by a slow potential wave, and conceived that the latter, too, had some

intimate relation to contraction. When the movements of normal intestine are actively repeated, the spike potential, too, appear strongly and frequently. Inversely, with the inactivity of the movement, the number and amplitude of the spike usually diminish. However, when the experiment of survival is continued for a long time, *i.e.* at a later period of survival, the contraction assumes a tendency to be of the continuous type; internal pressure waves group together; the width of each single wave widens and the period prolongs; and in spite of the increased rising of internal pressure, the number and amplitude of spikes tends to diminish. This is thought to be due to gradual deterioration in survival conditions and unphysiological continuation of internal pressure load. The deterioration in these conditions has some similarity to the unfavourable environment of the intestinal canal above the obstructed portion in the case of ileus. At the upper part of the obstructed intestinal canal, in the case of ileus, the peristaltic rhythmic movement on the mechanogram becomes obscure; the so-called tonus variation or the so-called tonic contraction becomes extremely conspicuous. In such a case, in spite of the height and width of the enormous wave shown by the internal pressure curve, the spike potential diminishes and furthermore almost vanishes, which is a very interesting fact that has not yet been noticed. In view of this paradoxical result, we can discern two factors in intestinal motor activity for raising the internal pressure, *i.e.* first the excitation which is accompanied by the spike potential, and secondly a certain motor phenomenon deprived of spike potential. The second movement factor can be understood to be chiefly responsible for the so-called tonus shortening.

Regarding striated muscle, it is a well established fact that muscle contraction is accompanied by electrical phenomenon but tone is not; but the problem as to whether this relationship can be applied in the same manner to the tonus variation of smooth muscle, is still unsettled, perhaps due to the fact that the existence of the spike was not generally known. Winton, Singh, Otani, Kawabata, and Masai pointed out that in a smooth muscle contraction there exist 2 kinds of shortening, *i.e.* phasic contraction and tonic contraction.

These investigations however, in spite of their valuable contributions to smooth muscle physiology, cannot be considered as elucidating clearly the nature of the so-called tonus variation. In my opinion, this tonus variation should at least be treated separately from a continued shortening, *i.e.* "tone" as in the case of ligament of the bivalve; it is more reasonable to interpret the "tonus variation" as a phenomenon similar to the popularly called "contraction." This "tonic contraction," however, has a marked feature different from the peristaltic movement, that it shows in general relatively feeble spike potentials, in spite of its strong power in raising inner pressure. I have once proven by concurrent observation through the abdominal window and of the mechanogram that the so-called tonus variation becomes gradually conspicuous with the aggravation of ileus. Therefore, it can be reasoned conversely that the physiological tonus variation has no direct relation to spike-excitation. Although our experimental apparatus was not the same as Bozler's, nevertheless, the fact that all of the slow potentials that we recorded quite resembled the wave form of Bozler's probably signifies that we were able to register the same phenomenon. While

these amplified slow wave groups were occurring, the intestinal wall appeared in a continued contracted condition and there was found macroscopically no rhythmic phenomenon which might be considered to bring about some deformation potential. Accordingly, it can be inferred that the slow potential wave we recorded was probably a kind of action current which is indispensable in a single rhythmic movement of the intestine. However, whether this slow wave corresponds to the Singh's so-called tonus contraction or not cannot be affirmed as yet.

From what has been stated above, it is at least unquestionable that the "phasic contraction" which is accompanied by the spike potentials and the "tonic contraction" which is not accompanied by them, co-exist in a single rhythmic movement of intestinal peristalsis. The phenomenon of "phasic contraction" occurs instantaneously and determines the rhythm of peristalsis, and that of "tonic contraction" means a motile function which sustains the condition of this instant shortening for a certain brief time. In the normal muscle state, these two different functions occur together moderately and cause the fundamental peristaltic rhythm and the so-called tonus variation (Magnus-Baur), *i.e.*, the slight base-line undulation of the mechanogram perhaps due to the periodic variation of the degree of tonic contraction. When a certain pathological condition (*e.g.* strong distension above the obstruction which disturbs blood circulation) exists, the ability for the normal repetition of spike potentials diminishes, and in its place the other function "tonic contraction" is abnormally strengthened and it is imagined that spasm occurs.

CONCLUSION

A new experimental method was employed in the electro-physiological research of normal intestinal movement; *i.e.* the registering of the Trendelenburg's pressure curve, the action current and the cinematographic recording of the intestinal movement were simultaneously performed. It was proved by this method that a single fundamental rhythm of a mechanogram corresponds to a single peristaltic movement, which, electro-physiologically, corresponds to a group of electrograms which includes numerous spike potentials. Each spike group accompanies one slow potential wave.

When an alimentary canal obstruction, especially ileus, is experimentally produced, the so-called tonus variation of the intestine becomes infallibly conspicuous above the obstructed portion of the intestine, and finally an extremely continuous powerful contraction like spasm is discerned.

This pathological fact was employed as an experimental means and the relation of the so-called "tonus variation" or "tonic contraction" to the electrical phenomenon was observed. In a continuous powerful contraction above the obstruction, the Trendelenburg's internal pressure curve shows a wave of enormous height and duration, while electrically the spike potentials diminish and almost disappear and the slow potential waves often become conspicuous.

There are two co-existing factors of intestinal contraction for raising internal pressure, one which is accompanied by spike potentials, and another which has no direct relation to spike *i.e.* so-called "tonic contraction."

Generally, in a single contraction of a normal intestine these two factors are always included perhaps in a proper degree; if the intestine falls into a pathological condition, the occurrence of normal excitation becomes difficult, but in its place, it is thought that the factor of the "tonic contraction" is conspicuously strengthened.

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