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TRANSMISSION FROM INTRAMURAL EXCITATORY NERVES TO THE SMOOTH MUSCLE CELLS OF THE GUINEA-PIG TAENIA COLI

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SUMMARY

1. A study has been made of transmission from intramural excitatory nerves to the smooth muscle cells of the guinea-pig taenia coli.

2. Only ten cells out of eighty gave depolarizing (i.e. excitatory junction potentials, E.J.P.S) on stimulating the intramural nerves, the remaining cells gave hyperpolarizing responses (i.e. inhibitory junction potentials, I.J.P.S). E.J.P.S were recorded in cells which were less than 1 mm away from cells which gave I.J.P.S.

3. In some cells stimulation of the intramural nerves with single pulses of maximal strength gave E.J.P.S of about 20 mV amplitude after a latency of 100–200 msec. In quiescent cells these E.J.P.S gave rise to action potentials. Repetitive stimulation above 1 c/s depolarized the membrane for less than about 1 sec, and during the remainder of the stimulation no action potentials fired, even in spontaneous cells.

4. In some cells stimulation of the intramural nerves gave an I.J.P. The largest sized I.J.P.S were generally only about half the size of the I.J.P.S recorded in atropinized preparations. The decreased amplitude of the I.J.P.S enabled rebound action potentials to be fired by successive I.J.P.S when the intramural nerves were stimulated at about 1 c/s. At higher frequencies all spontaneous activity was suppressed.

5. The effect of neostigmine (10^{-9}–10^{-7} g/ml.) on the transmission was studied. There was no detectable increase in the number of cells giving E.J.P. responses in the presence of neostigmine.

6. The electrophysiological characteristics of intramural excitatory and inhibitory nerve transmission are discussed.

INTRODUCTION

The inhibitory effect of both sympathetic nerves and intramural inhibitory nerves to the smooth muscle cells of the guinea-pig taenia coli has recently been described by Bennett, Burnstock & Holman, 1966*a*, *b*.

However, no study has yet been made of the transmission of excitation from intramural excitatory nerves to these cells, although the effects of acetylcholine (ACh) on the membrane potential have been described (Burnstock, 1958; Bülbring & Kuriyama, 1963*a*).

The transmitter released by the intramural inhibitory nerves has not yet been identified, and the action of these nerves on smooth muscle cells has not been blocked pharmacologically (Burnstock, Campbell & Rand, 1966). It is therefore not possible to examine the characteristics of the excitatory responses of some cells on intramural nerve stimulation, without taking into account the possibility that these cells are to some extent affected by the intramural inhibitory nerves. Also cells which give an inhibitory response on intramural nerve stimulation in unatropinized preparations may be affected by the intramural excitatory nerves. A study has therefore been made of the characteristics of the excitatory responses on intramural nerve stimulation and of the differences in the inhibitory responses in atropinized and unatropinized preparations.

METHODS

Strips of the taenia were dissected from the caecum of guinea-pigs of either sex in a manner already described (Bennett *et al.* 1966*a*). The recording technique was also the same as that previously described. The intramural nerves were stimulated with single pulses of 200 μsec duration. The strength of stimulation was always sufficient to give the maximum depolarizing or hyperpolarizing response in the smooth muscle cells after stimulating the nerves with a single pulse.

RESULTS

Stimulation of the intramural nerves of the taenia coli with single pulses gave hyperpolarizing responses in some smooth muscle cells and depolarizing responses in other smooth muscle cells of the same preparation. The hyperpolarizing responses have been called inhibitory junction potentials (I.J.P.S) (Bennett *et al.* 1966*b*). The depolarizing responses will be called excitatory junction potentials (E.J.P.S). However, it must be noted that cells which give either of these responses may receive an innervation from both intramural inhibitory and excitatory nerves, in which case the potential change across the smooth muscle membrane is determined by the resultant action of both these kinds of nerves.

Only ten cells out of eighty gave E.J.P.S in response to intramural nerve stimulation, the remaining cells gave I.J.P.S. The distance between cells which gave E.J.P. responses and those which gave I.J.P. responses was sometimes less than 1 mm. In one preparation a number of impalements were made along a 1·5 cm length of taenia and only a small area of about 1 mm^2 contained cells which gave E.J.P. responses, the rest of the cells gave I.J.P. responses. Figure 1 shows the responses of two cells which were less

than 1 mm apart and which were both quiescent before the intramural nerves were stimulated. In Fig. 1*a* and *c* the intramural nerves were stimulated with a single pulse which in the case of one cell gave an E.J.P. leading to an action potential and in the other cell gave an I.J.P. whose recovery phase led to a rebound action potential (Bennett, 1966*a*). When the intramural nerves were stimulated repetitively one cell gave a depolarization which fired a single action potential, the depolarization re-establishing itself after the action potential (Fig. 1*b*). In the other cell repetitive

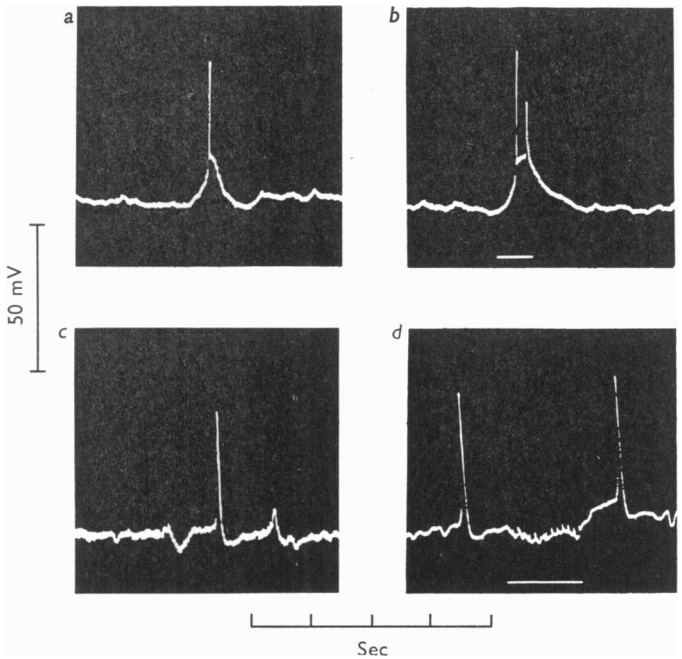

Fig. 1. Effects of intramural nerve stimulation on two quiescent cells from the same preparation less than 1 mm apart. Stimulation with single pulses in *a* and *c*. Repetitive stimulation at 20 and 10 c/s in *b* and *d* respectively, during the period given by the horizontal line. Pulse duration 200 μsec. Note the rebound action potential at the end of the I.J.P. in *c* and *d*. Action potentials retouched.

stimulation gave a hyperpolarization which lasted throughout the period of stimulation (Fig. 1*d*). In all preparations in which cells giving an excitatory response were observed, inhibition was recorded in other cells. The characteristics of these two types of transmission will now be described.

Excitatory transmission

In some cells which were quiescent, stimulation of the intramural nerves with single pulses gave a depolarization of the cell membrane of

up to 20 mV occurring 100–200 msec after the stimulus. The effect of stimulation with single pulses on such a quiescent cell is illustrated in Fig. 2*a* and *c*. Each pulse gave an E.J.P. which led into the rising phase of an action potential. The duration of the E.J.P. was much greater than that of the action potential. The E.J.P. took from 200 to 400 msec to reach its maximum height after the stimulus, and although it lasted from 500 to 800 msec only one action potential ever occurred during an E.J.P.

Stimulation with single pulses of intramural nerves to spontaneously active cells introduced a slow component of depolarization at the foot of the action potential which immediately followed the stimulus (Fig. 3). The action potentials tend to fire after the E.J.P.s have reached their full height, whereas in quiescent cells the rising phase of an E.J.P. leads directly into the rising phase of the action potential. This may be seen by comparing the E.J.P.s in Fig. 2*a* with those in Fig. 3*a*. It is possible that the action potentials were initiated by the E.J.P.s in quiescent cells, whereas in spontaneous cells the action potentials were initiated elsewhere and invaded the cell during the E.J.P.s.

Repetitive stimulation of the nerves at frequencies greater than 1 c/s did not lead to the summation of individual E.J.P.s but to the membrane being depolarized for some time during the period of stimulation. This is shown in Fig. 2*b* in which the nerves to a quiescent cell were stimulated at 2 c/s. After the initial depolarization of 16 mV the membrane repolarized to a level which was only 2–6 mV from the resting potential. As the frequency of stimulation was increased the membrane was maintained in a depolarized state for longer times; however the depolarization never exceeded 20 mV, the maximum amplitude of a single E.J.P. This is illustrated for a quiescent cell in Fig. 2*c* and a spontaneous cell in Fig. 3*b* and *c*. Although the depolarization lasted for a longer time at the higher frequencies, this did not enable cells to fire more than one action potential. For example during the depolarizations shown in Fig. 3*b* and *c*, only one action potential fired in each case. Thus although high frequencies of stimulation maintained the membrane potential at a depolarized level for longer times than did single pulses, only one action potential occurred regardless of the frequency of stimulation.

In spontaneously active cells which gave excitatory responses to intramural stimulation, no action potentials occurred at all after a second of stimulation, even though the membrane potential had reached its resting value during stimulation. This effect is illustrated in Fig. 4 where the membrane potential remains near its resting value after 1 sec of stimulation at 4 c/s, and is hyperpolarized beyond its resting value after 1 sec of stimulation at 10 c/s. It is possible that after some seconds of intramural nerve stimulation the effects of iuhibitory nerves began to dominate

those of the excitatory nerves. This is perhaps why the membrane potential returns to about its resting level, and why no action potentials occur. In some cases there was an increase in the rate of action potential firing at the end of nerve stimulation in cells which gave E.J.P. responses. Presumably this increased rate of firing represents a rebound from cells which

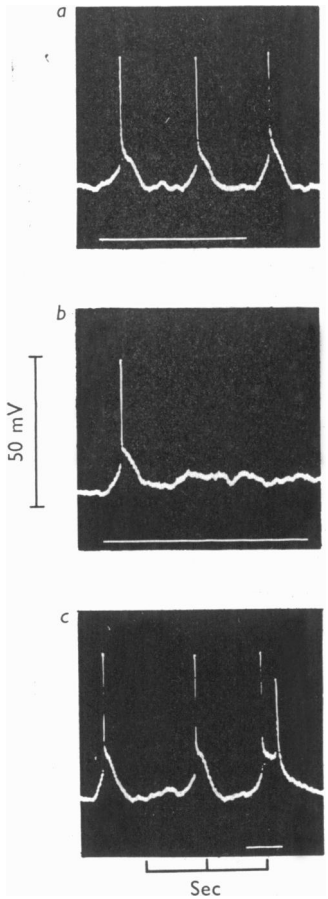

Fig. 2

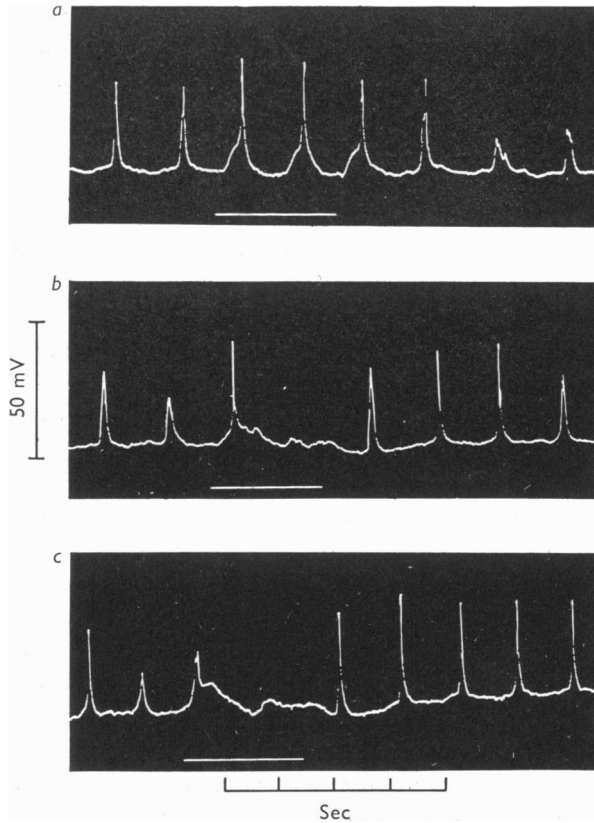

Fig. 3

Fig. 2. Excitatory responses of a quiescent cell on stimulating the intramural nerves at different frequencies. Frequencies of stimulation 1, 2 and 20 c/s in *a*, *b* and *c* respectively for the period given by the horizontal line. Two single action potentials in *c* due to stimulating the nerves with single pulses. Pulse duration 200 μsec. Action potentials retouched.

Fig. 3. Excitatory responses of a spontaneously active cell on stimulating the intramural nerves at different frequencies. Frequencies of stimulation 1, 5 and 10 c/s in *a*, *b* and *c* respectively, for the period given by the horizontal line. Pulse duration 200 μsec. Action potentials retouched. Note the slow phase of depolarization at the beginning of the action potentials during stimulation in *a*.

were hyperpolarized during stimulation (Bennett, 1966*a*), and from which action potentials then propagated into the cell with the E.J.P. response.

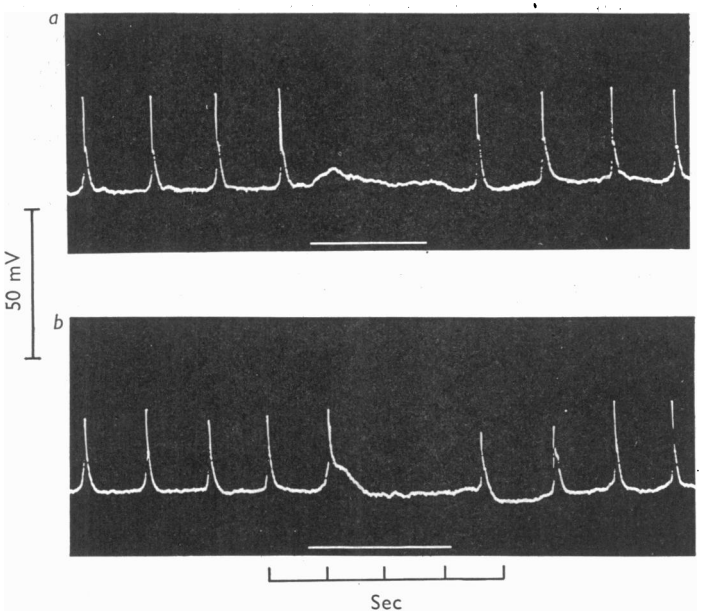

Fig. 4. Return of the membrane potential to its normal value during repetitive stimulation of the intramural nerves to a spontaneously active cell. Frequencies of stimulation 4 and 10 c/s in *a* and *b* respectively, for the period given by the horizontal line. Pulse duration 200 μsec. Action potentials retouched. Note the cessation of spontaneous activity during the period of stimulation.

Inhibitory transmission

In some cells stimulation of the intramural nerves gave I.J.P.s which had a different configuration from the I.J.P.s described on intramural nerve stimulation in the presence of atropine (Bennett *et al.* 1966*b*). In some cells the response to stimulation of the intramural nerves with a single pulse was a transient hyperpolarization which was followed by a depolarization of the membrane (Fig. 5*a*, *b*). Such diphasic responses may be due to antagonistic actions of inhibitory and excitatory transmitter on the same cell. Figure 5*c* shows the more usual response recorded in cells from unatropinized preparations.

The amplitude of the I.J.P. increased with the frequency of stimulation of the intramural nerves, successive I.J.P.s summing as has been described previously (Bennett *et al.* 1966*b*). However, the mean amplitude of the hyperpolarization during repetitive stimulation was much less than that recorded in atropinized preparations. The largest hyperpolarizations recorded from a single cell during stimulation of the nerves at 2 c/s and

4 c/s are shown in Fig. 6*a* and *b* while the smallest hyperpolarizations recorded for the same frequencies are shown in Fig. 6*c* and *d*. The graph of Fig. 7 shows how the mean amplitude of the largest I.J.P.s varied with frequency in unatropinized preparations compared with the amplitude of the I.J.P.s in a cell from an atropinized preparation. Most cells in atropinized preparations gave I.J.P.s twice as large as those in cells from unatropinized preparations. This result suggests that although most of the smooth muscle cells of the taenia coli have a predominantly inhibitory innervation there are some excitatory nerves which also innervate these cells.

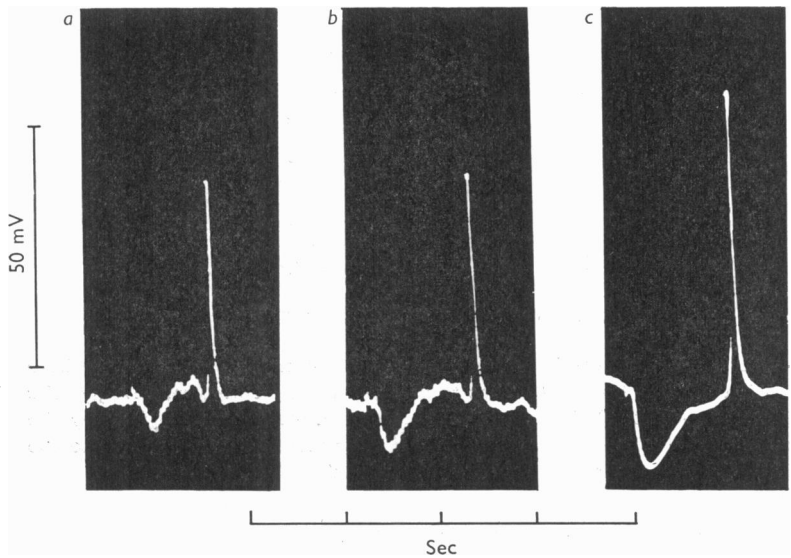

Fig. 5. Diphasic responses in quiescent cells consisting of a hyperpolarization of the membrane followed by a depolarization beyond the normal membrane potential, after stimulation of the intramural nerves with single pulses. *a* and *b*, diphasic responses, *c* normal response. Pulse duration 200 μsec. Action potentials retouched. Note the rebound action potential after each I.J.P.

At frequencies of stimulation of the intramural nerves at about 1c/s, successive I.J.P.s could fire rebound action potentials before the membrane was again hyperpolarized by the next I.J.P. (Fig. 8*a*). Since the normal spontaneous rate of firing of the action potentials was low in this cell, the effect of the I.J.P.s was to increase the rate of firing of the action potentials. When the frequency of stimulation of the intramural nerves was increased to 2 c/s, action potential activity was suppressed for nearly the entire period of stimulation (Fig. 8*b*). Firing of rebound action potentials when the nerves were stimulated at about 1 c/s was never seen in atropinized preparations, probably because the hyperpolarization during

the I.J.P. at this frequency was about twice as large as that recorded in cells from unatropinized preparations.

There was one cell, however, whose responses were exceptional in this respect (Fig. 9). Although the preparation was unatropinized, the response to stimulation of the intramural nerves was an I.J.P. of 36 mV (Fig. 9*a*).

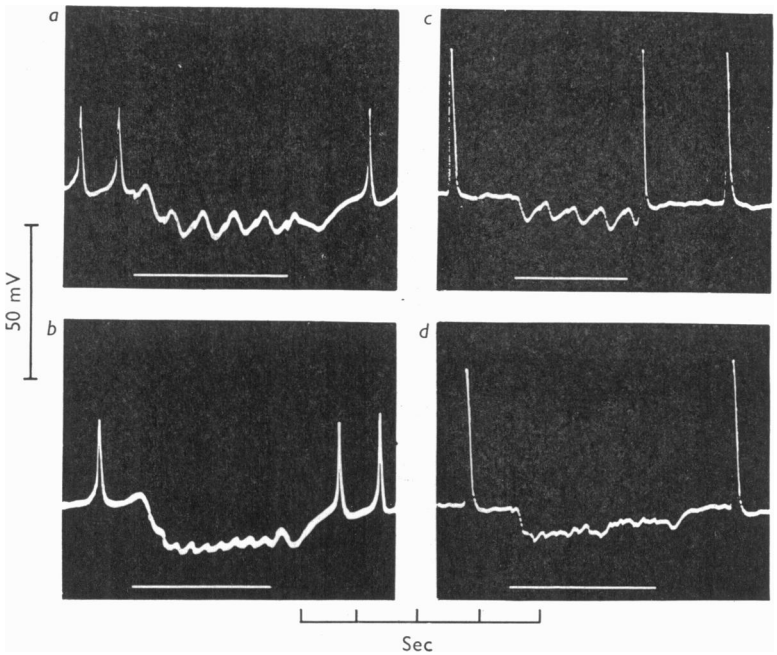

Fig. 6. Inhibitory responses of spontaneously active cells on stimulating the intramural nerves at different frequencies. Frequencies of stimulation 2 c/s in *a* and *c*, 4 c/s in *b* and *d*. Period of stimulation given by the horizontal line. Largest hyperpolarizations recorded during an I.J.P. shown in *a* and *b*. Smallest hyperpolarizations recorded during an I.J.P. shown in *c* and *d*. Pulse duration 200 μsec. *a* and *b* retouched.

This is the largest response recorded in any preparation in which I.J.P.s have been observed. The I.J.P. was followed by a very fast action potential before the membrane became depolarized. During this depolarization the action potentials were reduced in amplitude, and a slow phase was apparent at the foot of the aborted action potentials. When the intramural nerves to this cell were stimulated at higher frequencies (Fig. 9*b*, *c*), successive I.J.P.s still fired action potentials from their recovery phase. However, at the end of stimulation the membrane was so greatly depolarized that the responses consisted mostly of aborted spikes on top of a slower depolarization phase. Figure 9*c* shows very clearly that during the recovery from the depolarization of the membrane which follows

stimulation, there is an increase in size of the slow component at the foot of the aborted action potentials until this slow component merges indistinguishably into the rising phase of action potentials. Depolarization after the I.J.P.s generally occurs during the period of rebound excitation which follows hyperpolarization of the membrane (Bennett, 1966*a*). Generally this depolarization is accompanied by an increase in the rate of action potential firing. In this case, however, although the rhythmic activity goes on at an increased rate, the after depolarization is so great that action potentials fail to arise.

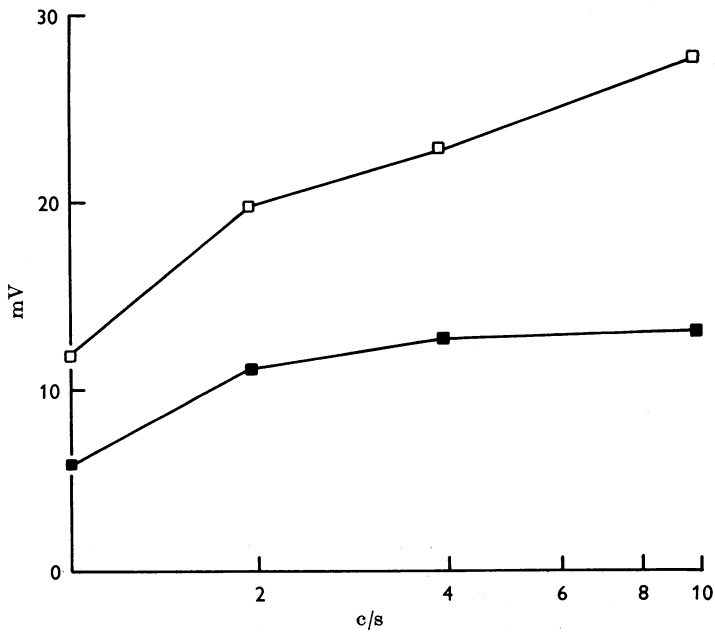

Fig. 7. Change in mean amplitude of the hyperpolarization during the I.J.P. with change in the frequency of stimulation of the intramural nerves. Abscissa, frequency of stimulation log scale. Ordinate, mean amplitude of the hyperpolarization during the I.J.P. Open squares, responses recorded in a cell from an atropinized preparation. Filled squares, largest responses recorded in any cell from an unatropinized preparation.

The normal activity in some cells consisted of slow action potentials which seldom exceeded a height of 30 mV. It was originally thought that cells with such responses must have been damaged by the micro-electrode during impalement, and they were discarded. However, stimulation of the intramural nerves to such cells subsequently showed that they were capable of giving action potentials greater than 60 mV. Thus, in the experiment of Fig. 10 action potentials were recorded during the rebound period which were much larger and faster than those recorded previously

in these cells. The reason for the irregular activity illustrated in Fig. 10 must therefore be other than cell damage.

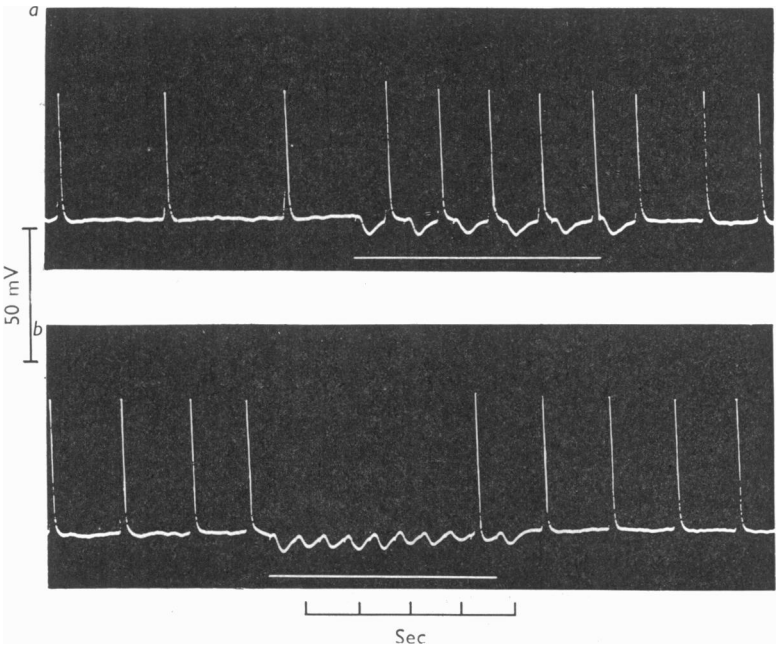

Fig. 8. Effect of stimulating the intramural nerves at low frequencies on a cell giving inhibitory responses. Frequencies of stimulation 1 and 2 c/s in *a* and *b* respectively. Period of stimulation given by the horizontal line. Pulse duration 200 μsec. Action potentials retouched. Note the rebound action potentials after successive I.J.P.s in *a*.

Spontaneous responses

In some cells which received a predominantly inhibitory innervation there were spontaneous hyperpolarizations of the cell membrane which resembled the I.J.P. whilst in other cells which received a predominantly excitatory innervation there were spontaneous depolarizations which resembled the E.J.P. In Fig. 11*a* and *b* are shown an I.J.P. due to intramural nerve stimulation and a spontaneous hyperpolarization in the same quiescent cell. Both hyperpolarizations gave rise to rebound action potentials. In another cell, which was spontaneously active, intramural nerve stimulation gave the E.J.P. shown in Fig. 11*c* during which an action potential fired, and an action potential also arose from a spontaneous depolarization (Fig. 11*d*). Such spontaneous hyperpolarizations and depolarizations may be the result of spontaneous release of the inhibitory and excitatory transmitters.

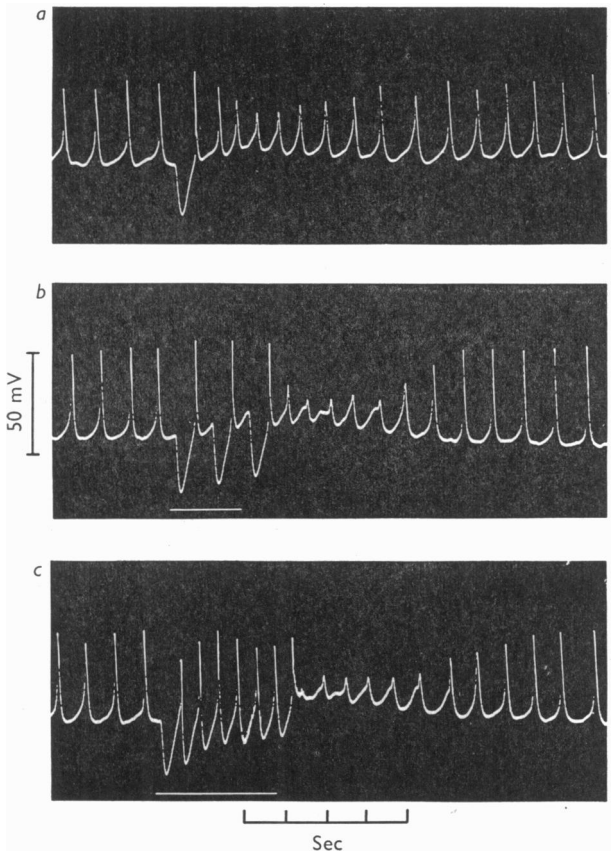

Fig. 9. Effect of stimulating the intramural nerves at low frequencies on a cell giving exceptionally large I.J.P.S. Stimulation with a single pulse in *a*. Frequencies of stimulation in *b* and *c*, 1 and 2 c/s respectively. Period of stimulation given by the horizontal line. Pulse duration 200 μsec. Action potentials retouched. Note the rebound action potentials after successive I.J.P.S and the after depolarization at the end of stimulation.

The effect of neostigmine on intramural nerve transmission

Neostigmine in concentrations between 10^{-9} and 10^{-6} g/ml. did not reverse any responses due to intramural nerve stimulation from hyperpolarizations to depolarizations. Thus there was no increase in the number of cells giving E.J.P.S after neostigmine. I.J.P.S recorded in three cells in the presence of neostigmine (10^{-7} and 10^{-6} g/ml.) are shown in Fig. 12.

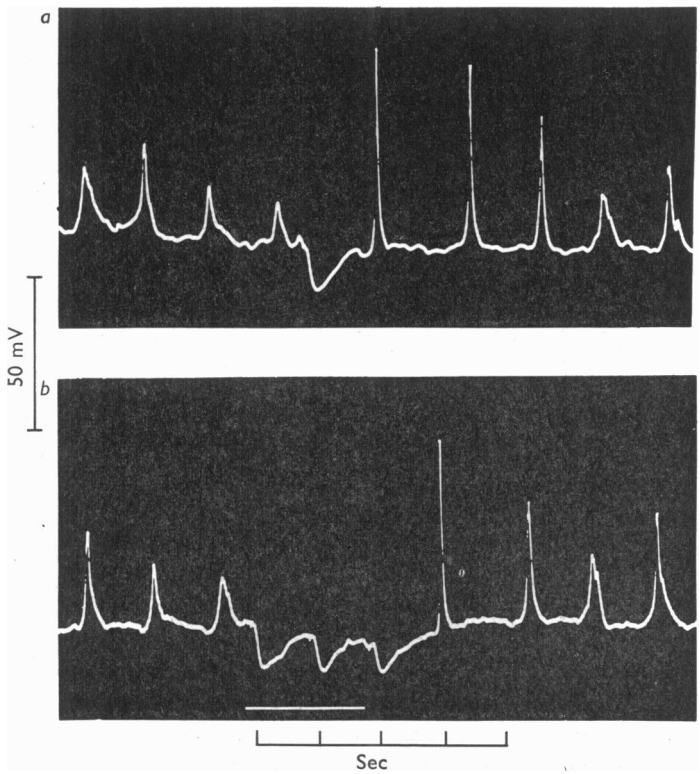

Fig. 10. Effect of stimulating the intramural nerves on a cell with small and slow spontaneous action potentials. Stimulation with a single pulse in *a*. Frequency of stimulation in *b*, 1 c/s. Period of stimulation given by the horizontal line. Pulse duration 200 μsec. Action potentials retouched. Note the large and fast rebound action potentials at the end of stimulation.

DISCUSSION

In the one preparation in which muscle cells were systematically impaled over a length of 1·5 cm, cells which gave E.J.P.s in response to intramural nerve stimulation were localized in a small area on the serosal surface of the taenia. Such areas may represent pace-maker areas in which action potentials originate after excitatory nerve transmission and then by electrotonic coupling between cells propagate throughout the rest of the tissue (Bülbring, Burnstock & Holman, 1958). However, further experiments are required to verify this localization of cells which give E.J.P. responses on intramural nerve stimulation.

Gillespie (1962) has shown that stimulation of the pelvic nerves to the distal colon with single pulses causes a transient depolarization of the

smooth muscle cell membrane. Gillespie & Mack (1964) have shown that stimulation of the intramural nerves with single pulses also gives a transient depolarization of the muscle membrane, which has the same characteristics as the E.J.P. In contrast to these studies of Gillespie the smooth muscle cells of the taenia coli generally give a hyperpolarizing response (I.J.P.) on stimulation of the intramural nerves, and only rarely give a depolarizing response (E.J.P.). There is therefore a considerable difference in the density of the excitatory innervation of smooth muscle cells in different preparations of intestinal longitudinal muscle.

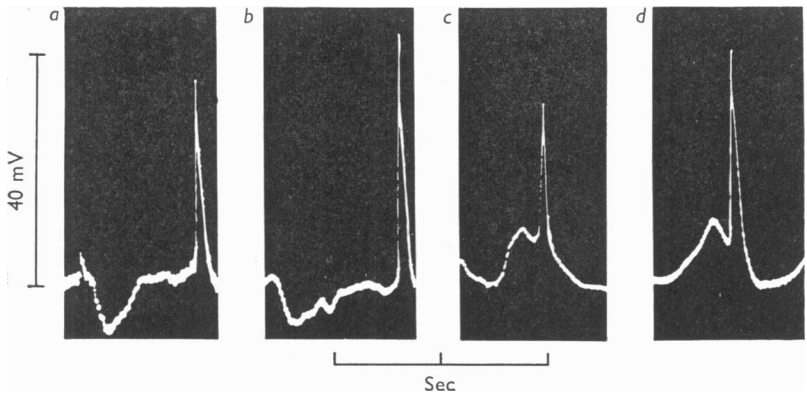

Fig. 11. Spontaneous hyperpolarizations and depolarizations of the cell membrane similar to the responses to intramural nerve stimulation. Stimulation with single pulses in *a* and *c*. Spontaneous responses in *b* and *d*. Pulse duration 200 μsec. Action potentials retouched.

Although the time course of the E.J.P. was similar to that of the E.J.P recorded in the smooth muscle cells of the distal colon on stimulating its intramural nerves with single pulses (Gillespie & Mack, 1964), the characteristics of the E.J.P. in the taenia during repetitive stimulation were very different. Action potentials were initiated by each E.J.P. when the nerves were stimulated at 1 c/s. However, at higher frequencies the membrane depolarized, firing a single action potential, and this depolarization was not maintained during stimulation. Gillespie (1962) found that action potentials would only follow a frequency of stimulation of the nerves of about 1 c/s; however, at higher frequencies the membrane was depolarized and this depolarization was maintained for the duration of stimulation. The difference between these results and those observed in the taenia coli can possibly be accounted for by the hyperpolarizing action of intramural inhibitory nerves predominating over that of the excitatory nerves after a few seconds of stimulation. This interpretation is supported by the small hyperpolarization of the membrane sometimes observed

after an initial depolarization during repetitive stimulation of the intramural nerves.

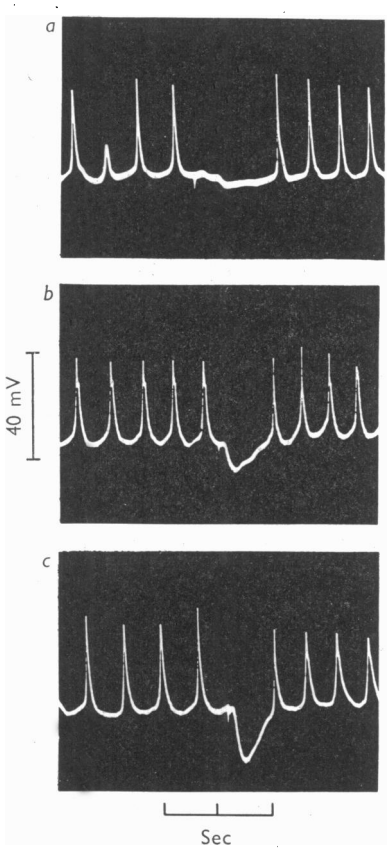

Fig. 12. The effect of neostigmine on the inhibitory response due to stimulation of the intramural nerves with single pulses. Neostigmine 10^{-7} g/ml. in *a* and 10^{-6} g/ml. in *b* and *c*. Pulse duration 200 μsec. *a* retouched.

In most cells the hyperpolarization during the I.J.P. was smaller than that recorded in atropinized preparations, and therefore it is probable that these cells receive some excitatory innervation. Recently Bennett (1966*b*) has shown that the studies of Bülbring & Kuriyama (1963*a*) on the membrane potential changes in the smooth muscle cells of the taenia coli in the presence of ACh or adrenaline may be interpreted quantitatively by a model in which there is an increase in membrane permeability to sodium or potassium ions in the presence of these transmitters. The predictions of this model were that the equilibrium potential for inhibition is the potassium electrode and that for excitation intermediate between the

potassium and sodium electrodes. Hence the membrane potential changes recorded in the present study on simultaneous stimulation of inhibitory and excitatory nerves may be interpreted as resulting from the antagonistic inhibitory and excitatory junctional currents.

In these experiments the intramural nerves have been stimulated with pulses of sufficient strength to give the maximal response, whether a hyperpolarization or depolarization of the muscle membrane. Since it is likely that every cell receives an innervation from several inhibitory and excitatory nerves, the stimulation of all these nerves at once probably does not represent a likely physiological event. Recently Granit, Kellerth & Williams (1964) examined the physiological stimulation of motoneurones by stretching either synergistic or antagonistic muscles. They found that the membrane potential changes of the motoneurone soma consisted of small wavelets of depolarization or hyperpolarization which were very different from the excitatory post-synaptic and inhibitory post-synaptic potentials (E.P.S.P.S and I.P.S.P.S) produced by synchronous maximal stimulation of muscle afferents (Eccles, 1964). Thus even though most of the cells in the taenia coli gave a hyperpolarizing response on maximal stimulation of the intramural nerves, under physiological conditions these cells may be either depolarized or hyperpolarized, depending on the number of each type of nerve activated.

As the amplitude of the I.J.P.S was generally smaller in preparations not treated with atropine, low frequencies of stimulation of the intramural nerves gave rise to rebound action potentials which occurred on the recovery phase of each I.J.P. The rebound action potentials were not suppressed until higher frequencies of stimulation were used. This result is similar to that recorded by Andersen, Eccles & Sears (1964) during stimulation of inhibitory nerves to thalamic-cortical relay cells (see their Fig. 11). Since the tension developed by the taenia is correlated with the frequency of action potential firing (Bülbring & Kuriyama, 1963*b*) it is possible to obtain contractions due to this rebound excitation (Bennett, 1966*a*) during low frequencies of stimulation and to obtain relaxations at higher frequencies of stimulation.

In previous experiments (Bennett *et al.* 1966*b*) no excitatory responses were recorded in over 100 cells in the taenia coli on stimulation of the intramural nerves of atropinized preparations. As excitatory responses have now been recorded in normal preparations, the excitatory nerves are presumably cholinergic. Campbell (1966) has come to a similar conclusion. These cholinergic nerves are presumably comparable to those in other intestinal preparations, the evidence for which was reviewed by Kosterlitz & Lees (1964).

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REFERENCES

ANDERSEN, P., ECCLES, J. C. & SEARS, T. A. (1964). The ventrobasal complex of the thalamus: types of cells, their responses and their functional organization. *J. Physiol.* **174**, 370–399.

BENNETT, M. R. (1966*a*). Rebound excitation of the smooth muscle cells of the guinea-pig taenia coli after stimulation of intramural inhibitory nerves. *J. Physiol.* **185**, 124–131.

BENNETT, M. R. (1966*b*). A model of the membrane of smooth muscle cells of the guinea-pig taenia coli during transmission from inhibitory and excitatory nerves. *Nature, Lond.* (In the Press).

BENNETT, M. R., BURNSTOCK, G. & HOLMAN, M. E. (1966*a*). Transmission from perivascular inhibitory nerves to the smooth muscle cells of the guinea-pig taenia coli. *J. Physiol.* **182**, 527–540.

BENNETT, M. R., BURNSTOCK, G. & HOLMAN, M. E. (1966*b*). Transmission from intramural inhibitory nerves to the smooth muscle cells of the guinea-pig taenia coli. *J. Physiol.* **182**, 541–558.

BÜLBRING, E., BURNSTOCK, G. & HOLMAN, M. E. (1958). Excitation and conduction in the smooth muscle of the isolated taenia coli of the guinea-pig. *J. Physiol.* **142**, 420–437.

BÜLBRING, E. & KURIYAMA, H. (1963*a*). Effects of changes in ionic environment on the action of acetylcholine and adrenaline on the smooth muscle cells of guinea-pig taenia coli. *J. Physiol.* **166**, 59–74.

BÜLBRING, E. & KURIYAMA, H. (1963*b*). The effect of adrenaline on the smooth muscle of the guinea-pig taenia coli in relation to the degree of stretch. *J. Physiol.* **169**, 198–212.

BURNSTOCK, G. (1958). The effects of acetylcholine on membrane potential spike frequency conduction velocity and excitability in the taenia coli of the guinea-pig. *J. Physiol.* **143**, 165–182.

BURNSTOCK, G., CAMPBELL, G. & RAND, M. (1966). The inhibitory innervation of the taenia of the guinea-pig caecum. *J. Physiol.* **182**, 504–526.

CAMPBELL, G. (1966). Nerve-mediated excitation of the taenia of the guinea-pig caecum. *J. Physiol.* **185**, 148–159.

ECCLES, J. C. (1964). *The Physiology of Synapses.* Springer-Verlag.

GILLESPIE, J. S. (1962). The electrical and mechanical responses of intestinal smooth muscle cells to stimulation of their extrinsic parasympathetic nerves. *J. Physiol.* **162**, 76–92.

GILLESPIE, J. S. & MACK, A. J. (1964). The electrical response of intestinal smooth muscle to stimulation of the extrinsic or intrinsic motor nerves. *J. Physiol.* **170**, 19*P*.

GRANIT, R., KELLERTH, J. O. & WILLIAMS, T. P. (1964). Intracellular aspects of stimulating motoneurones by muscle stretch. *J. Physiol.* **174**, 435–452.

KOSTERLITZ, H. W. & LEES, G. M. (1964). Pharmacological analysis of intrinsic intestinal reflexes. *Pharmac. Rev.* **16**, 301–339.