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INHIBITION AND NEUROMUSCULAR PARALYSIS IN *ASCARIS LUMBRICOIDES*

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The starting point for this work was the desire to develop a method for studying the mode of action of drugs on intestinal nematodes. Baldwin & Moyle (1949) recorded the movements of isolated preparations from the anterior and intermediate portions of pig *Ascaris* and exposed them to a variety of anthelmintics and pharmacodynamic drugs. They showed that *Ascaris* muscle differed from earthworm muscle in its reactions to drugs.

Norton & de Beer (1957) used 'decapitated' preparations of *Ascaris* and showed that the anthelmintic drug piperazine blocked contractions produced by acetylcholine, but did not affect responses to electrical stimulation of the muscle. They suggested that piperazine might be a neuromuscular blocking agent for *Ascaris*. The present work provides further evidence for this conclusion and also describes an inhibitory neuromuscular mechanism in the worm.

METHODS

The adult female *Ascaris lumbricoides*, an intestinal roundworm readily obtained from pigs, is about 25–30 cm long. It is invested with a cuticle, ridged like a concertina, which is relatively impermeable to many drugs, but which may have some biochemical activity of value to the worm (Hobson, 1948). Below the cuticle is the hypodermis, in which lie mucous glands and four main nerve cords running longitudinally and joining a ring of ganglia at the anterior end of the worm. There is then a layer of longitudinal muscles, whose cells are described as consisting of an outer contractile part, and an inner non-contractile part protruding into the body cavity. No circular muscle has been described. The body cavity contains coelomic fluid, the alimentary canal and the reproductive organs. There is no cardiovascular system (Chitwood & Chitwood, 1950).

The preparation normally adopted in the present work is illustrated in Fig. 1. The anterior 4 cm of the worm was cut off, and the posterior part of this was split open as far as the pharynx along the left 'lateral line', a structure clearly visible through the cuticle. The preparation was then suspended horizontally in buffered Locke's solution by two loops of fine 'arbrasilk' suture, passing through the opposite lateral line, one placed at the posterior end of the preparation, the other a few millimetres posterior to the front end of the slit. The dorsal and ventral nerve cords were left intact by this procedure, and the anterior end was free to contract without its movements' appearing on the contraction record. Two pairs of silver–silver-chloride electrodes were placed in position and connected to

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separate stimulators. One electrode of the first pair was placed in the mouth, and the other encircled the region of the ring of ganglia. The second pair was placed at the distal end, with one electrode situated axially in the body cavity, and the other encircling the body. In the experiments in which records were made with a micro-electrode, the gut was detached gently from the body wall and the layer of muscle cells was penetrated from the inside.

The apparatus, of which the most recent modification was described by Szekeres & Vaughan Williams (1962), was that previously employed for recording from cardiac muscle. The output from the RCA 5734 transducer recording contractions was monitored by a Kelvin and Hughes pen writing on a smoked drum. The stimulus was passed through a fixed resistance and the current calculated from the deflexion of an oscilloscope. The solution was as used for cardiac muscle, but was gassed with N_2 95% and CO_2 5%; *Ascaris* is an anaerobe and is poisoned by prolonged exposure to oxygen. The experiments were at first carried out at 31° C, but the temperature was subsequently raised to 34 and to 37° C. Raising the temperature did not appear to cause deterioration of the preparations, which continued to respond for many hours at 37° C. Intact worms were stored at 37° C in Locke's solution, which was changed daily. They remained active for many days, but were seldom used for experiments after the third day.

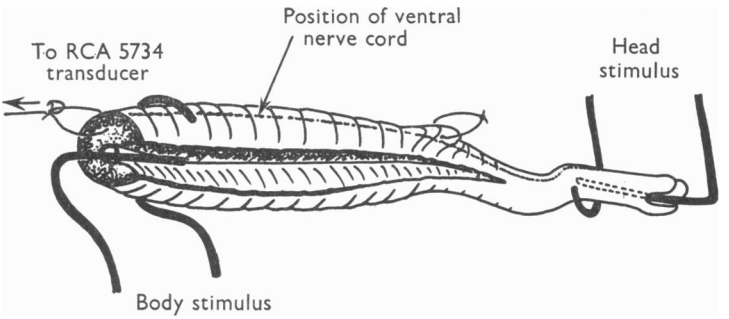

Fig. 1. Diagram of *Ascaris* preparation. The front 4 cm of the worm was cut off and suspended longitudinally in the bath so that movements of the head did not appear in records of the contractions of the body muscle.

RESULTS

Spontaneous activity

When the preparation was mounted as described, the mouth and anterior part of the worm continued 'searching' movements, circling in all directions. When an electrode was inserted into the mouth, these movements ceased, and the anterior end of the worm relaxed. Contractions of the body suspended in the recording system were characterized by small movements every few seconds, with large contractions superimposed every minute or two. Spontaneous activity varied considerably from one preparation to the next, but all the preparations exhibited spontaneous activity if left in peace. When the preparations were driven by electrical stimuli the spontaneous activity was depressed, but returned gradually if stimulation was discontinued. Spontaneous contractions from a preparation which had not

yet been stimulated, and which exhibited a particularly regular rhythm, are shown in Fig. 2*A*.

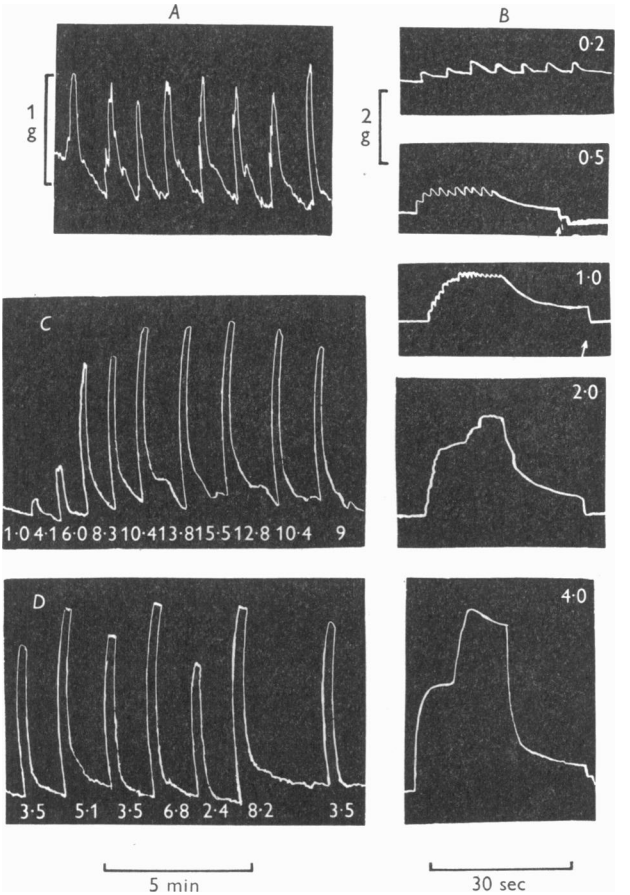

Fig. 2. Contractions of *Ascaris*. *A*, spontaneous contractions. *B*, responses to transmural stimulation of body at 0·2, 0·5, 1·0, 2·0 and 4·0 stimuli/sec with shocks of 0·6 msec, 10·4 mA. *C*, responses to shocks of 0·6 msec at 8/sec at the currents in mA as indicated. *D*, responses to shocks of 0·6 msec and 10·4 mA at the frequencies in shocks/sec as indicated.

Responses to stimulation

When the body of the worm was stimulated transmurally, responses were readily obtained to single shocks. From strength–duration curves, such as those presented in Fig. 4, it was concluded that the muscle would not be directly stimulated by shocks shorter than half a millisecond. In Fig. 2*B* a series of records shows the responses of the body muscle to stimulation at different frequencies, and indicates that fusion was complete at

frequencies as low as 4/sec. Responses to stimulation above 2/sec are shown in Fig. 2*D*, on a slower drum. The shocks were 0·6 msec in duration, and 10·4 mA, a strength shown in Fig. 2*C* to be sufficient to produce near maximal contraction at a higher frequency. The lower two records in Fig. 2*B* indicate the recruitment of a second group of fibres after a few seconds' stimulation at 2 and 4/sec. In Fig. 2*C* the frequency of stimulation was 8/sec, still at 0·6 msec, and the responses to shocks of various currents are shown.

Neuromuscular paralysis

Norton & de Beer (1957) showed that piperazine blocked contractions of *Ascaris* muscle in response to acetylcholine, but did not interfere with responses to electrical stimulation. The record shown in Fig. 3 confirms this finding. It has not yet been found practicable to dissect out a nerve-muscle preparation from *Ascaris*, and the problem remained to show that in the

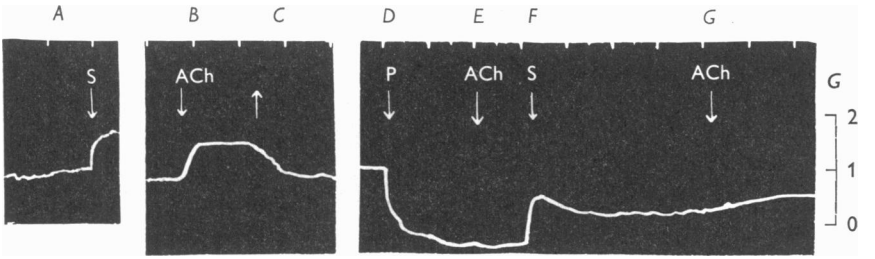

Fig. 3. Top. Time marker, minutes. At *A*, response to stimuli of 5 msec, 10·4 mA at 5/sec for 30 sec. *B*, effect of ACh 1 μg/ml. *C*, wash. *D*, piperazine 250 μg/ml. caused relaxation. *E*, ACh 2 μg/ml. was without effect. *F*, stimulus as at *A*. *G*, effect of ACh 20 μg/ml.

presence of piperazine the muscle was not capable of responding to stimulation through its nerve. Figure 4*A* shows the strength and duration of threshold shocks, at 3·5/sec, required to elicit contractions by transmural stimulation of the body. The preparation was rested for 10 min, and a regular spontaneous rhythm was exhibited. At *A* in Fig. 5 the response to 1 min stimulation at 0·7 msec, 10 mA and ·3·5/sec is shown. Piperazine citrate was then added to the bath to give a concentration of 250 μg (base)/ml. The spontaneous activity was not greatly affected but the response to the same stimulus at *B* was halved. Further piperazine was added to make the concentration 500 μg/ml.; the spontaneous activity was greatly reduced, and the response to stimulation at *C* was now less than 1/5 of the control. The concentration of piperazine was again doubled, which abolished spontaneous activity, and reduced the response to stimulation at *D* to 6 %. Between *D* and *E* the strength–duration curve was again measured, and this has been plotted in Fig. 4*B*. No response was obtained

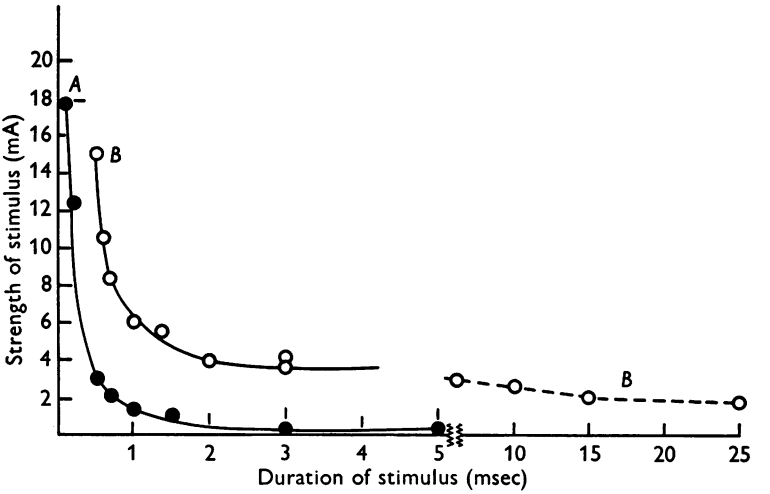

Fig. 4. Strength–duration curves. *A*, control curve. *B*, in presence of piperazine 1·0 mg/ml. Stimuli at 3·5/sec. Note change of abscissa scale on right.

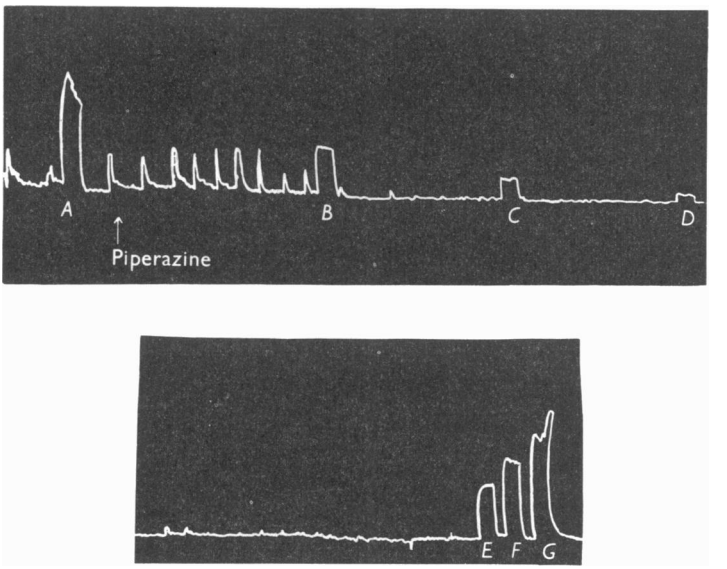

Fig. 5. Effect of piperazine. At start, spontaneous activity. At *A*, effect of shocks at 3·5/sec, 0·7 msec, 10 mA for 1 min, followed immediately by addition of piperazine 0·25 mg/ml. Spontaneous contractions continued, but the same stimulus, at *B*, produced less than half the response. The piperazine concentration was raised after *B* to 0·5 mg/ml., and after a similar stimulus at *C* to 1 mg/ml. The response to a stimulus at *D* was probably due to direct stimulation of muscle. Between *D* and *E* the contractions represent responses at threshold while the strength–duration curve of Fig. 4*B* was being measured. *E*, *F*, *G*: responses to shocks of 2·0, 3·0 and 5·0 msec respectively at 3·5/sec and 10 mA for 1 min.

to stimuli shorter than 0·5 msec, and the rheobase occurred at much longer durations, necessitating a change of scale in Fig. 4. The shift of the curve to the right would be consistent with the view that the motor nerves were paralysed or that neuromuscular transmission was blocked. Since 10 mA was just above threshold at 0·7 msec, it is probable that the small response at *D* in Fig. 5 was due to direct muscular stimulation. The muscle contraction was itself unimpaired, as was shown by responses to stimuli of the same frequency and strength, but increased duration, at *E*, *F* and *G*.

Inhibition

Just caudal to the mouth region of *Ascaris* there is around the pharynx a ring of ganglia from which run the nerve cords traversing the length of the worm. With the possibility in mind of finding a nerve-muscle preparation, an electrode was placed in the mouth, and another electrode was put around the 'neck' of the worm near the situation of the ring of ganglia. When stimuli were passed through these electrodes at low frequency, no effect was observed on the contractions of the body of the worm. As the frequency was raised above 10/sec, the body of the worm relaxed, and on cessation of the stimulus the body contracted violently. The phenomenon is illustrated in Fig. 6. At 1, a stimulus to the head, indicated by the short arrows labelled *H* (at 180/sec, 0·9 msec, 1·5 mA), for 30 sec caused relaxation followed by a contraction when the stimulus was discontinued. The preparation then relaxed and stayed relaxed until a stimulus to the body at 2 (long arrows, *B*) (4/sec, 1 msec, 10 mA), for 1 min caused it to contract. At 3 a similar body stimulus was followed at 4 by a further stimulus to the head. The subsequent record shows the results of several periods of stimulation of the head and body, separately and in combination, and it is apparent that in spite of continued stimulation of the body a stimulus to the head still caused relaxation.

If the stimuli to the head were 1–2 mA in strength, the 'neck' of the worm was seen to contract during the stimulus, and if the strength was increased further the relaxing effect on the body of the worm seemed to be overcome, and a motor effect supervened, the head stimuli now causing *contraction* of the body. There was still, however, a further 'rebound' contraction on cessation of the stimulus. On several (but not all, see below) occasions, when an attempt was made to observe the relaxation in response to stimuli to the head passed through an isolation transformer, there was either no effect on the body of the worm or only contractions were seen.

It was thought that there might be a direct current component in the high-frequency stimulus, through rectification or polarization, which was responsible for exciting the structures causing the relaxation of the body, and which was eliminated by the isolation transformer. This was confirmed,

both by connecting a d.c. amplifier to an electrode on the body of the worm during the high-frequency stimulation, and by stimulating the head with direct current. In both cases it could be shown that when the 'neck' contracted, the body of the worm relaxed. The suspension of the muscle was such that movements of the 'neck' region itself, whether contractions or relaxations, did not appear in the record (Fig. 1). There was no relaxation in response to d.c. however, unless currents in excess of 1 mA were employed, and unless the current was sufficient to cause contraction

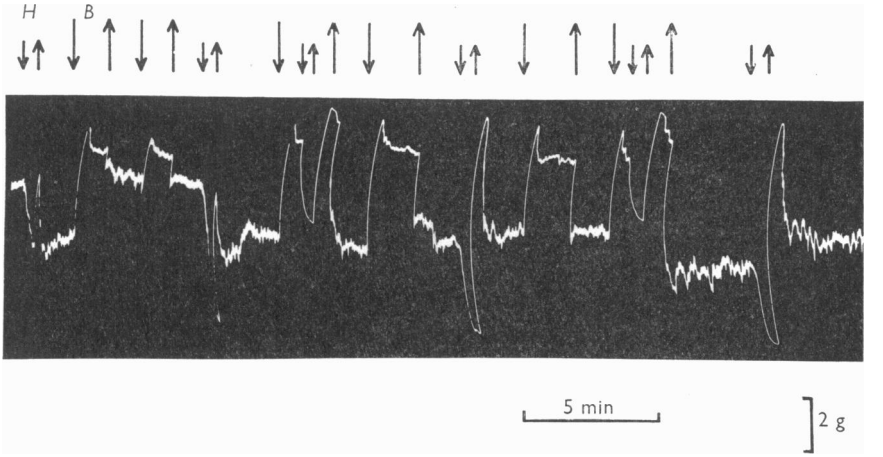

Fig. 6. Contractions and relaxations in response to body and head stimuli. Short arrows indicate stimulus to head (*H*), at 180/sec, 0·9 msec, 1·5 mA. Long arrows indicate stimulus to body at 4/sec, 1 msec and 10 mA. Down, on; up, off.

of the 'neck'. It seemed possible that there were inhibitory fibres passing from the head to the body which were being activated either directly by the d.c. or in response to contractions of the 'neck'. Further experiments described below, however, showed that neither contraction of the neck nor d.c. were essential for inhibition by the head of body movement.

It is well known that in intestinal muscle an apparent relaxation of longitudinal muscle can be observed as a result of contractions of circular muscle. There is no circular muscle in *Ascaris*, however, and close observation through a dissecting microscope during the relaxation of the body indicated either no circumferential movement at all, or a relaxation. Moreover, it was found that *spontaneous* contractions of the body could be inhibited by stimuli to the head of much lower current and of very short duration. The responses of a preparation giving large and regular spontaneous contractions are illustrated in Fig. 7. After 3 min the drum speed was increased tenfold, and two spontaneous contractions were recorded. Just before a third large spontaneous contraction reached its peak,

stimulation of the head (at 100/sec, 0·3 msec and 0·2 mA) was started at *A* and continued until the spontaneous contractions were completely inhibited. On cessation of the stimulus to the head at *B* a large rebound contraction of the body caused the recorder to hit the stop at full excursion. After a few minutes allowed for recovery of the normal rhythm, two further spontaneous contractions were recorded, and a brief burst of stimuli to the head was introduced at *C* for 3 sec during a third. After a fourth spontaneous contraction had been registered, an 8 sec train of stimuli was given to the head at *D* while the preparation was relaxed. No contraction of the neck was caused by these low-current stimuli.

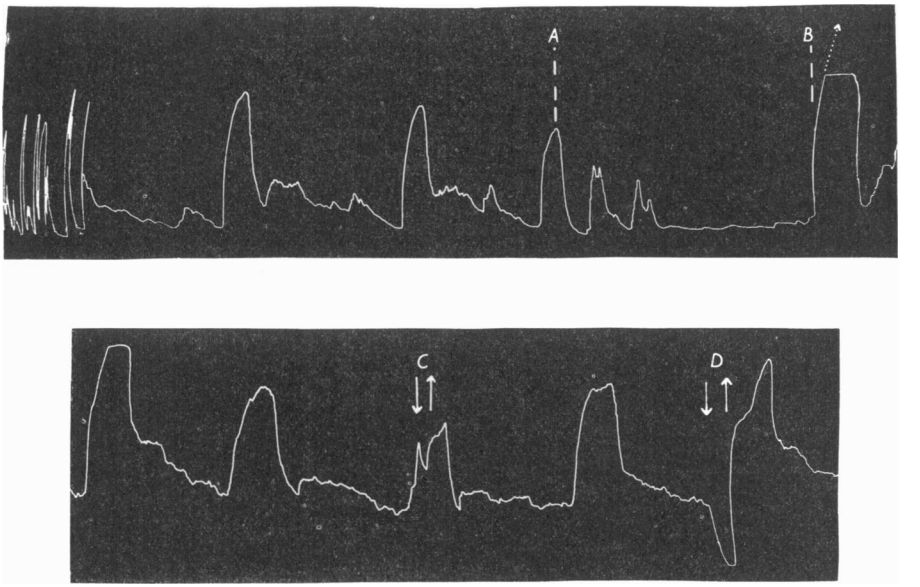

Fig. 7. Inhibition of spontaneous contractions. After 3 min the drum speed was increased 10 times. A stimulus to the head (100/sec, 0·3 msec, 0·2 mA) was begun just before the peak of a spontaneous contraction at *A*, and was continued to *B*, when the rebound contraction on cessation of the stimulus went off scale. At *C* a 3 sec train of stimuli was given to the head during a spontaneous contraction of the body. At *D* an 8 sec train was given while the worm was relaxed.

By introducing stimuli to the head during spontaneous contractions of the body, a strength–duration curve was constructed showing the threshold stimulation of the head which would just reverse a spontaneous contraction, and this is illustrated in Fig. 8. Since inhibition of spontaneous contractions of the body was observed with stimuli to the head of duration less than 0·1 msec, and the rheobase was found at 1·3 msec, it is unlikely that any direct stimulation of muscle was involved.

Stimuli to the head not only inhibited spontaneous contractions of the

body but also, as seen in Fig. 5, those occurring in response to transmural stimulation of the body. The optimal frequency for the stimulus to the head was well over 150/sec, and no inhibition could be seen at frequencies below 5/sec, although there was often a small rebound contraction when the stimulus was turned off. Responses are shown in Fig. 9 to a series of 14 successive bursts of stimulation to the body of a worm at 4/sec, each burst lasting 105 sec. In all but the seventh, after 45 sec from the beginning of the body stimulus, the head was stimulated for 30 sec at various

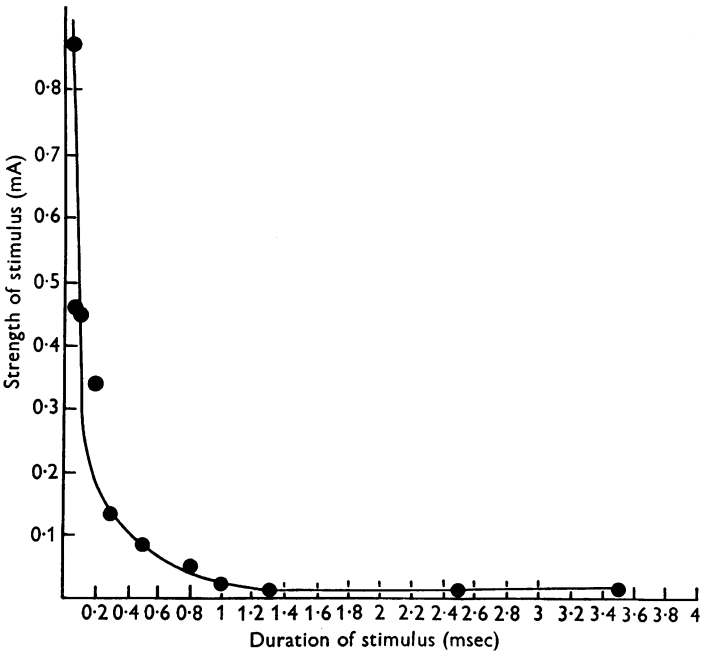

Fig. 8. Strength–duration curve. Frequency: 100/sec. Plot of threshold shocks to head required to inhibit spontaneous contractions of the body.

frequencies, each shock being of 0·5 msec, 1 mA. Although no relaxation was observed when the head was stimulated at 4·4/sec (Fig. 9 (6)), there was a rebound contraction when the stimulus was turned off, as can be deduced from a comparison with Fig. 9 (7), when no stimulus was given to the head.

A d.c. component in the stimulus to the head was not essential to stimulate the structures causing relaxation in the body of the worm. In Fig. 10*A* is shown a contraction in response to body stimulation at 4/sec (1·0 msec, 2 mA), with an intercalated stimulus to the head for 30 sec (at 98/sec, 0·5 msec, 1·0 mA). Between *A* and *B* the leads from the stimulator to the head were disconnected and replaced in series with an isolation

transformer, to eliminate any d.c. flow of current along the worm. The response shown in Fig. 10*B* was very similar to the control.

In one experiment the dorsal nerve cord was cut, at a site between the head electrodes and the thread suspending the head end of the worm, to avoid interference with the contraction record. The inhibitory effect of a stimulus to the head was then reduced by about 20 %. When the ventral

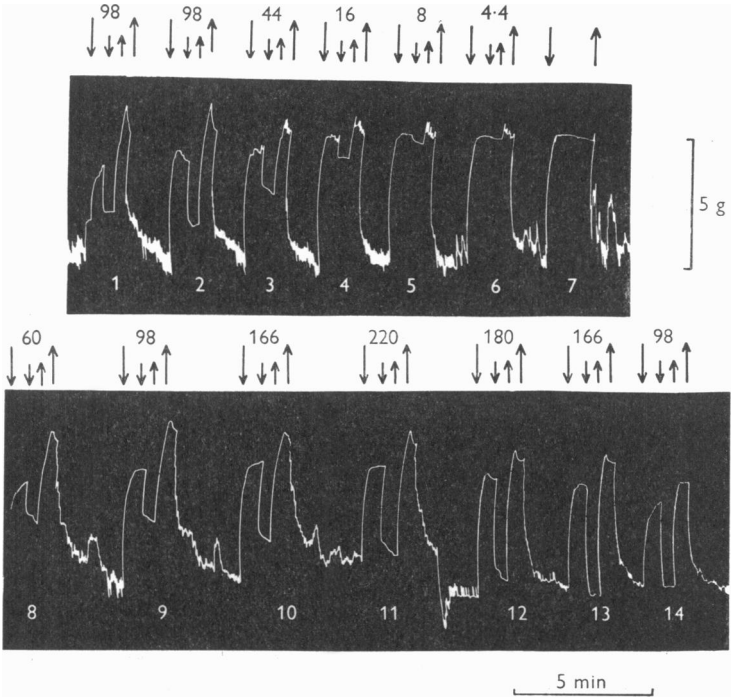

Fig. 9. Frequency of stimuli to head necessary to inhibit contractions of body. Long arrows: stimulus to body, at 4/sec, 0·6 msec, 1·5 mA. Short arrows: stimulus to head; shocks of 0·5 msec, 1 mA at the frequency indicated. Down, on; up, off. In 6, at a frequency of the stimulus to the head of 4·4/sec, there was no relaxation of the body, but there was a rebound contraction at the cessation of the stimulus, absent from 7, when there was no stimulus to the head.

cord was subsequently cut, the inhibitory effect was reduced by 80 %. In another experiment, cutting the dorsal cord reduced the inhibitory effect by 25 %, and cutting the ventral cord by 95 %. In Fig. 11*A* the effect of a stimulus to the head (180/sec, 0·8 msec, 1·3 mA) for 1 min is shown. This was then repeated on a fast drum (Fig. 11*B*). Between *B* and *C* the ventral nerve cord was cut, causing a reduction of the inhibitory effect of a repeated head stimulus by 80 % (Fig. 11*C*). When the dorsal cord was cut, the response was reduced by a further 7 %. In all three experiments a cut

was subsequently made transversely through all the remaining tissue with the exception of a band of cuticle connecting the neck to the body (in order to retain approximately the original anatomical relation between the head and the body). This would have permitted any current which might have been spreading from the head electrodes to the body to continue its effect, but abolished all conduction through nerves or muscle. In all three experiments the inhibitory effect of the head stimulus was completely abolished.

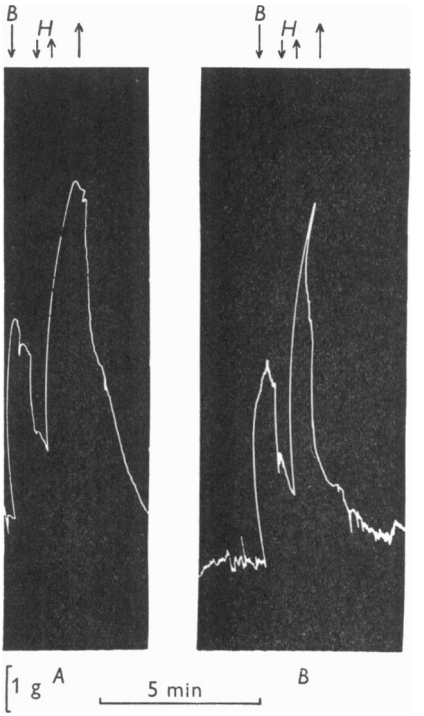

Fig. 10. Isolation of stimulus to head. *A*, contraction in response to body stimulus for 105 sec at 4/sec, 1 msec, 2 mA, with a stimulus to the head at 98/sec, 0·5 msec, 1·0 mA, starting after 45 sec and continuing for 30 sec. *B*, As for *A*, but with the stimulus to the head passing through an isolation transformer.

Intracellular records

The cells of *Ascaris* described as muscle cells are extremely large ($> 100\,\mu$ diameter), and it is a simple matter to introduce micro-electrodes (Jarman, 1959). There is some difficulty in interpreting the records in a manner consistent with published histological work on *Ascaris* (Chitwood & Chitwood, 1950; Lee, 1962). The resting potentials obtained from these large 'muscle' cells were only 20–30 mV. On penetration of the layers nearer the cuticle, which contain structures resembling muscle fibres, resting potentials of

40–60 mV were observed, and it is possible that the large inner cell bodies are not really parts of the muscle cells.

No reliable intracellular records have yet been obtained during stimulation of the body and head because apparatus at present available is inadequate to eliminate stimulus artifacts satisfactorily.

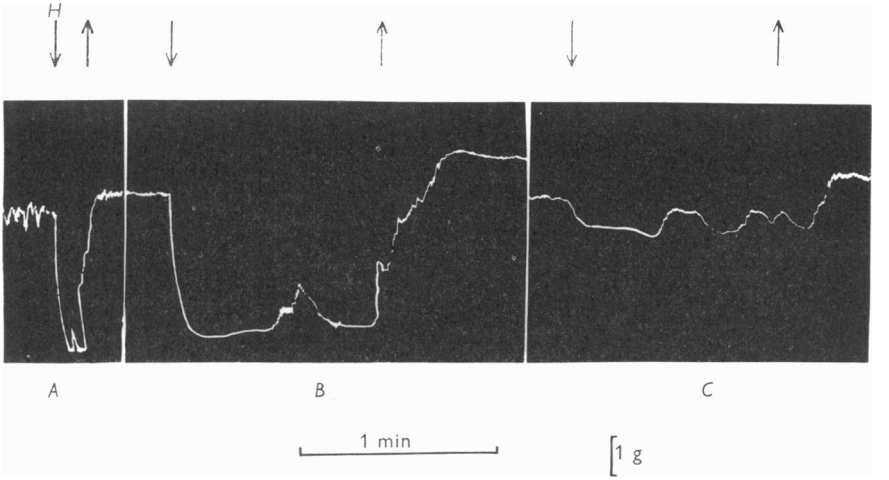

Fig. 11. Effect of cutting ventral nerve cord. At *A*, a stimulus to the head for 1 min at 180/sec, 0·8 msec and 1·3 mA caused relaxation of the body. The drum speed was increased 10 times, and the stimulus repeated at *B*. The ventral cord was then cut, and the stimulus repeated a third time at *C*.

DISCUSSION

The population of intestinal parasites harboured unwillingly or unknowingly by man greatly exceeds the human world population. Infestation may lead directly or indirectly to a variety of disabilities, and also reduces effectively the value of food consumed by man and domestic animals, especially in underdeveloped countries where it can least be spared. A need exists, therefore, for laboratory methods for studying the action of compounds which might prove useful against parasites, but the physiology of the parasites themselves has attracted little attention (see Broome (1962) for a review of chemical and therapeutic studies).

The muscle of the body of *Ascaris* was found to respond readily to single shocks administered transmurally through an interior axial and exterior circumferential electrode. Measurements of the strength and duration of the shocks at threshold implied that excitation was via motor nerves. Fusion of individual responses into a maintained tetanus was complete at a frequency of only 4/sec at 37° C. Norton & de Beer (1957) had shown that

Ascaris muscle would still respond to electrical stimulation in the presence of piperazine, which blocked contractions in response to acetylcholine. This finding has been confirmed, and it has further been shown that in the presence of piperazine the strength–duration curve for electrical stimuli at threshold was shifted to the right, as would be consistent with a failure to respond to stimulation through the motor nerves. In the absence of any precise knowledge of the mechanism of neuromuscular transmission in *Ascaris*, however, it would be premature to conclude that piperazine produced neuromuscular block in a manner analogous to curare or decamethonium in vertebrates. The authors of publications presenting histological illustrations of ascarine muscle (Chitwood & Chitwood, 1950; Lee 1962) have suggested that the muscle cells are complex structures consisting of a large ($> 100\ \mu$) globular 'non-contractile' portion with an 'innervation process' and a contractile part nearer the cuticle. Observation of these cells during contractions in response to electrical stimulation has confirmed the existence of longitudinally contracting muscle fibres, upon which the globular structures rest passively. On puncture of the globular structure a resting potential of only 20–30 mV was observed, whereas the contractile muscle fibres gave potentials of 40–60 mV, so that it would seem possible that there are two separate kinds of cell. Much work remains to be done to elucidate the relation of the resting potential to ionic concentrations and to examine the effects of stimulated activity, but the latter has not been possible with available apparatus.

When the head of the worm was stimulated by an axial electrode in the mouth and an external circumferential electrode, the body of the worm relaxed. Such relaxations were only obtained if the frequency of stimulation was greater than 5/sec, and the optimal frequency was in the region of 150–200/sec. Direct current of sufficient strength to cause contraction of the 'neck' of the worm also caused relaxation of the body. Neither d.c. nor contraction of the neck was essential, however, for this effect. Spontaneous contractions, and the responses to transmural stimulation of the body, could be inhibited by stimuli to the head at 0·3 msec and 0·2 mA, which were well below threshold for eliciting contractions of the neck region. Also, on several occasions, relaxations of the body were obtained when stimuli to the head were passed through an isolation transformer, which eliminated any possibility of direct current passing down the worm. On other occasions no relaxation was found when the isolation transformer was used for the head stimuli, but as the strength of the stimulus was increased, the *body* of the worm contracted. It is possible that both inhibitory and motor fibres pass from the head to the body, and that to excite the first without the second requires a precise selection of strength and duration of stimuli which is not always possible with the distortion

introduced by the transformer. It was certain, however, that spontaneous contractions of the body could be inhibited by stimuli to the head with pulses of duration less than 0·1 msec, which implied that the effect was mediated by nerves. Most of the inhibitory 'traffic' passed through the ventral nerve cord, because, when this was cut, 80 % of the inhibitory effect was abolished. Cutting all tissue except a strip of cuticle abolished it altogether.

It remains to speculate what role such an inhibitory system may play in the normal function of the worm. Roundworms are not in any way attached to the intestinal mucosa of their hosts. They maintain their position in the gut by active movements 'against the tide' of intestinal propulsion. The ridges in the cuticle enable them to brace themselves on the mucosa and to move forward sinuously against the peristaltic waves.

In the course of studies of the effects of drugs on intact *Ascaris*, a method was devised in which the whole worm was enclosed in a nylon stocking and the movements recorded on a smoked drum (Goodwin, 1958). Slow arching movements of the body in the dorsiventral plane occurred regularly at intervals of 2–3 min and sinuous waves appeared to run forwards along the worm, decreasing in wave-length and amplitude as they approached the anterior end. The 'head' of the worm was very active and carried out independent searching movements. If a hole in the stocking was encountered which was large enough to admit the extreme anterior tip of the worm, vigorous muscular movement of the body thrust it through; powerful activity continued until the whole worm had emerged from the stocking. It was suggested that in its natural habitat the searching anterior end of the worm finds and penetrates the central lumen in advancing peristaltic constrictions of the gut, and that the vigorous muscular movements which follow the stimulus to the anterior end enable the parasite to thrust itself through the constriction and so keep its station in the alimentary tract.

The roundworm has no skeleton. It maintains its shape by the tension exerted by the cuticular and muscular layers on the liquid contents of the body cavity. Its volume is constant during movement and therefore any decrease in diameter is necessarily accompanied by an increase in length. When the anterior end encounters a peristaltic wave it is clearly to the worm's advantage to become thinner and longer to allow penetration. Once the head was through the constriction, contraction of the anterior end would make it thicker and wedge it firmly in place, while relaxation posteriorly would facilitate the pulling up of a relaxed and thin body through the descending peristaltic wave. The anterior tip of *Ascaris* is provided with sensory papillae and amphids which have rich connexions with the pharyngeal ring of ganglia. Sensory stimuli could assist

coordination of contraction and relaxation in different parts of the worm, to permit it to become thin and passive at a point of constriction, and fat and vigorous elsewhere.

SUMMARY

1. The anterior 4 cm. of *Ascaris lumbricoides* was suspended in a bath, and contractions of the posterior 2½ cm of the preparation were recorded. Responses were obtained to single transmural shocks, and stimulation at 4/sec produced a fused tetanic contraction.

2. Strength–duration curves at threshold implied that stimulation was through motor nerves. Piperazine, a paralysing anthelmintic, shifted the curve to the right, implying nervous or neuromuscular block. The muscle responded normally to shocks of long duration.

3. Coaxial stimulation of the head in the region of the circumpharyngeal nerve ganglia at frequencies above 5/sec caused inhibition of both spontaneous and electrically-stimulated contractions of the body of the worm. Inhibition was obtained in responses to shocks shorter than 0·1 msec, implying mediation of the effect through nerves.

4. Section of the ventral nerve cord abolished 80% of the inhibitory effect on body contractions of stimuli to the head. Section of the dorsal cord reduced the inhibitory effect further, and section of all tissue except cuticle abolished it altogether.

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