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THE COURSE OF THE EFFERENT CARDIAC NERVES OF THE SHEEP*

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The purpose of the work to be discussed was to trace the main routes followed by the efferent nerves to the heart in the sheep. Since the thoracic autonomic nervous system of this species is nowhere described in detail, illustrations of some dissections will be presented so that sites of stimulation referred to in the text may be more precisely indicated.

METHODS

Three Dorset Horn, twelve Clun Forest and twenty-six Welsh Mountain sheep of both sexes were used. Their ages ranged from 1 month to 4 years and their weights from 14·3 to 76·1 kg. Four sheep were anaesthetized with a mixture of chloralose (Hopkins and Williams, 17·0–59·0 mg/kg body weight) and urethane (May and Baker, 170–590 mg/kg) intravenously; during the experiment anaesthesia was maintained by intravenous infusion of 2·60–7·86 mg of chloralose and 26·0–78·6 mg of urethane/kg/hr. Except for one sheep which was anaesthetized throughout with intravenous pentobarbital (Nembutal, Abbott Laboratories), the remainder, after induction with pentobarbital (16·0–36·4 mg/kg), were anaesthetized by continuous intratracheal cyclopropane (10–150 ml./min) with oxygen (50–300 ml./min) administered from a Boyle's apparatus in a closed circuit with soda-lime for CO_2 absorption. In most of the experiments an intravenous transfusion of either plasma substitute or homologous blood (50–200 ml./hr) was maintained throughout.

The cervical sympathetic and vagal nerves were first isolated and prepared for subsequent stimulation or dividing, after which one of three surgical procedures was followed: (1) The thoracic vagal trunks and their connexions were exposed by splitting the sternum along the mid line in eight experiments; or (2) parts of the thoracic sympathetic chains and their branches in twenty-five other experiments were exposed by resecting two to nine ribs on one side or both, either by a dorsal approach through the muscular attachments of the scapula or ventrally by dissection of the pectoral muscles; or (3) laminectomy of the seventh cervical to the eighth thoracic vertebrae was performed in five further experiments.

These last experiments were performed because the rami communicantes of the middle and upper thoracic sympathetic ganglia are very short and inaccessible, and it was impossible to stimulate them without danger of current spread to the ganglia themselves (see Fig. 1). When exposed the spinal cord was covered with warm liquid paraffin, and moist silk ligatures were

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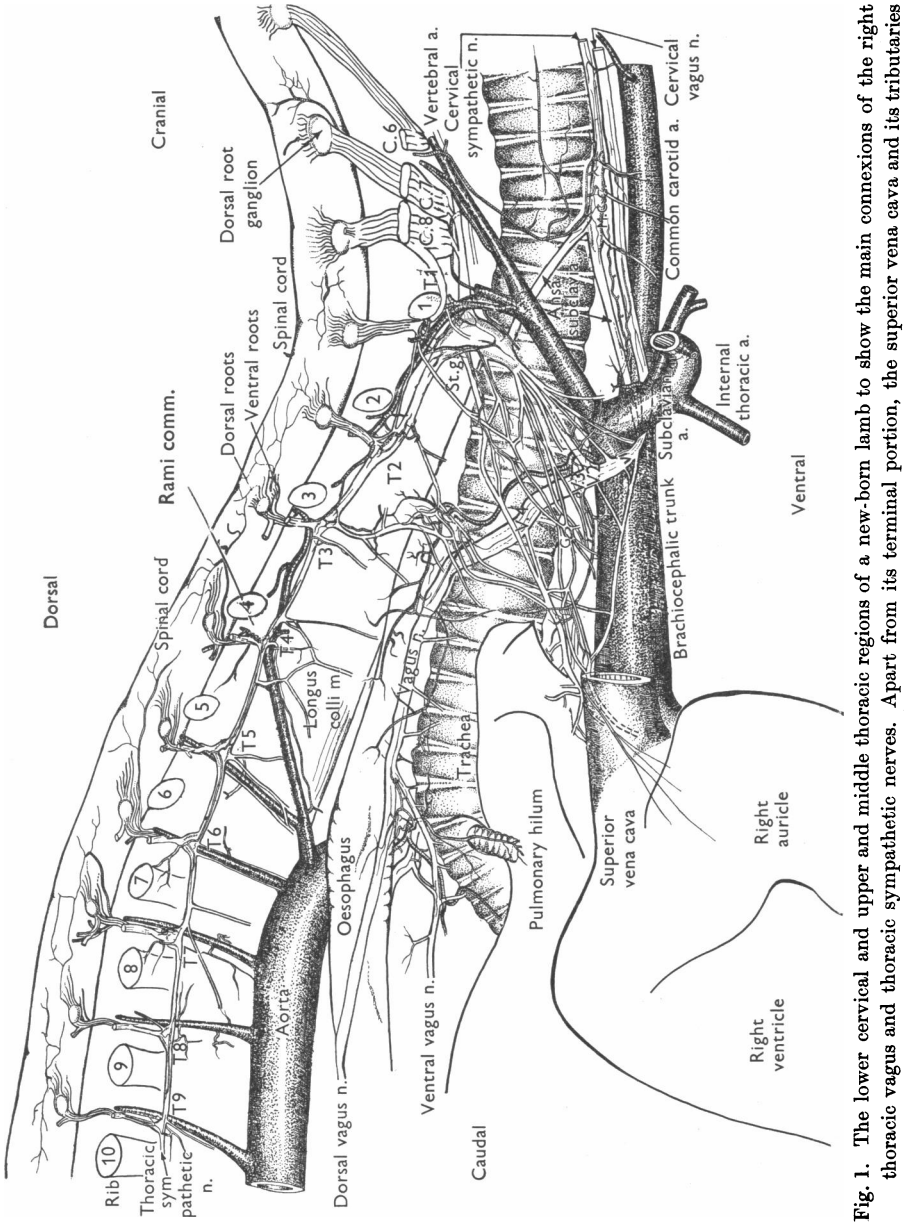

Fig. 1. The lower cervical and upper and middle thoracic regions of a new-born lamb to show the main connexions of the right thoracic vagus and thoracic sympathetic nerves. Apart from its terminal portion, the superior vena cava and its tributaries have been omitted. Abbreviations: a. = artery; G. = ganglion; m. = muscle; n. = nerve; v. = vein; Rami.comm. = rami communicantes; M.C.G. = middle cervical ganglion; St.g., T2, etc. = stellate ganglion, second thoracic sympathetic chain ganglion, etc.; V. 1–4 = cardiac branches of thoracic vagal trunk.

passed under the spinal roots at points where these emerge from the dura mater. The spinal roots were then ligated and divided nearer to the spinal cord after 15 mg tubocurarine chloride (Burroughs Wellcome) had been given intravenously in three of the experiments (50–52, Fig. 5).

Throughout the experiments blood pressure was recorded by either a mercury or a rubber membrane manometer connected to a common carotid, brachial or femoral artery, and heart rate was measured by a cardiometer connected to a piston recorder, a rubber membrane manometer, or a differential manometer (Daly & Schweitzer, 1950) which actuated a drop timer (Gaddum & Kwiatkowski, 1938) recording on the kymograph. When the thorax was opened artificial respiration was carried out by a modified Starling 'Ideal' pump. The peripheral nerves were stimulated with square-wave pulses of 1–10 V, 1–10 msec and 10–100 c/s; and the spinal roots were tested using stimuli of 3–20 V, 1–10 msec, 10–50 c/s, because of the thickness of the nerve trunks. Stimulations were monitored on occasions by an oscilloscope. An induction coil was also used to stimulate nerves, but was usually only applied when responses had been negative. The absence of a cardio-accelerator response was not considered to be significant when the heart rate was already high before stimulation. The average pre-stimulation heart rate of all such negative results was 100 beats/min (S.D. $\pm 9{\cdot}7$). The positive accelerator responses were obtained when the average pre-stimulation heart rate was 109 beats/min (S.D. $\pm 10{\cdot}4$).

The following drugs were used: atropine or atropine sulphate (British Drug Houses), nicotine hydrogen tartrate (British Drug Houses) and hexamethonium chloride (May and Baker, Ltd.) dissolved in sodium chloride solution 0·9% (w/v).

The anatomical illustrations were made from dissections of foetal and new-born lambs done under a dissecting microscope; the vascular system was filled with neoprene latex injected immediately after death.

RESULTS

The pathways to be described were followed by observing the cardiovascular responses to electrical stimulation, after reflex effects on the heart had been excluded by dividing the cervical vagosympathetic trunks and the rami communicantes in that part of the thoracic sympathetic chains under investigation. Whenever possible the site of stimulation given in the text will be referred to in an anatomical illustration to indicate its position more clearly.

The cervical and thoracic course of the cardio-inhibitor fibres in the vagus

The cervical vagus nerve crosses the dorsal face of the superior cervical ganglion to join the cervical sympathetic trunk with which it becomes bound in the same sheath. Although the two bundles of the vagosympathetic trunk exchange small nerves they can usually be separated by blunt dissection.

Stimulation of the caudal cut end of the larger nerve dissected from the cervical vagosympathetic trunks always caused cardiac slowing accompanied by a fall of blood pressure. In five out of ten preparations complete cardiac arrest was achieved by maximal stimulation of the right vagal trunk and in two out of ten of the left nerve. Very occasionally cardio-inhibitor fibres were found in the cervical sympathetic nerve, but usually these were present only in the larger nerve, identified as the vagus. The right cervical vagus contained cardio-accelerator fibres at its caudal end in only two out of twelve experiments. Except in these instances, the vagus and sympathetic appeared to be quite separate.

Dividing the cervical vagal trunks either alone or together with the sympathetic nerves in anaesthetized preparations did not produce the cardio-acceleration and rise of arterial blood pressure which is generally seen in some other species. A transient fall of blood pressure and slowing of the heart rate due to stimulation produced by cutting the nerve was usually observed and in most of the experiments was the only response, there being a subsequent return to the pre-vagotomy level. A small cardio-accelerator effect (average +17%) was maintained after section in only seven of the twenty experiments.

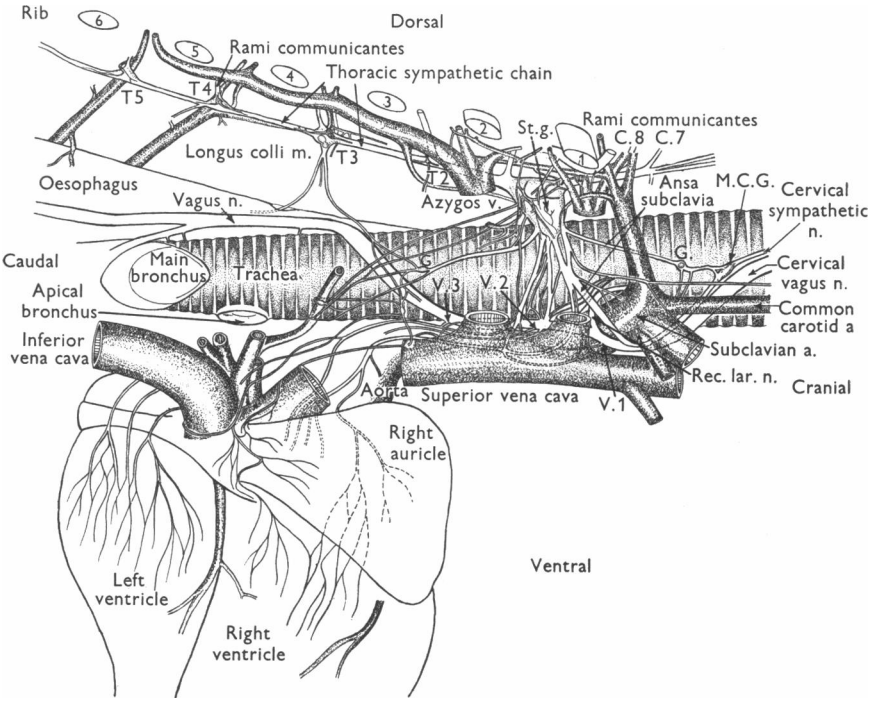

Fig. 2. The origin and course of the cardiac branches of the upper thoracic vagal trunk and the upper thoracic sympathetic chain on the right in a new-born lamb. Parts of the major veins have been omitted. Abbreviations: as for Fig. 1. Also, Rec.lar.n. = recurrent laryngeal nerve.

On the other hand, the intravenous injection of atropine sulphate (0·5–2·0 mg/kg) sufficient to inhibit the cardio-inhibitory fibres caused a substantial cardio-acceleration (+44%) in five preparations with intact cervical vagosympathetic trunks but had no constant cardiac effect in eight preparations in which the vagosympathetic trunks were previously divided. Therefore the only evidence for the presence of cardiac vagal tone in these anaesthetized sheep was this response to atropine.

The right vagal trunk within the thorax gives off most of its cardiac branches (V.1–V.4, Figs. 1–3) in its upper course; the first (V.1) also sends

nerves on to the subclavian and brachiocephalic arteries, the arch of the aorta and the superior vena cava. Cardio-inhibitory fibres could be demonstrated in all these branches but the responses indicated that they were present in the largest numbers in the branches beyond the origin of the recurrent laryngeal; sometimes this also contained some of the inhibitory fibres. The majority of all such fibres were found to leave the vagal trunk above the level of the right azygos vein.

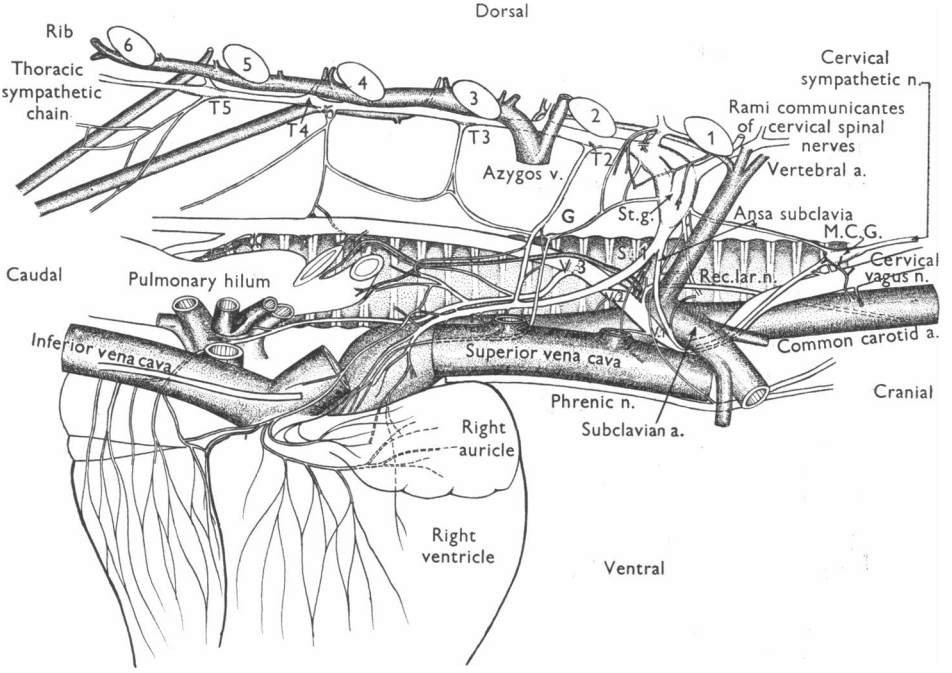

Fig. 3. The origin and course of the cardiac branches of the upper thoracic vagal trunk and the upper thoracic sympathetic chain on the right in a new-born lamb. Parts of the major veins have been omitted. Abbreviations as for Figs. 1 and 2. Also, S.1 = main cardiac branch of stellate ganglion.

On the left side the thoracic vagus takes a somewhat similar course to that of the right. Stimulation of the left recurrent laryngeal nerve usually caused marked inhibition of the heart and this nerve together with large vagal branches beyond it (V.2–V.4, Fig. 4) contained most of the inhibitory fibres of the left vagal trunk. Because of intermingling with nerves from the left sympathetic chain (Fig. 4) mixed inhibitory and accelerator responses were often observed on stimulating vagal branches at the base of the heart. Except for one out of four experiments, the first thoracic vagal branch (V.1, Fig. 10) did not contain cardio-inhibitory fibres. Its branches were mainly distributed to the arch of the aorta and the ductus arteriosus

rather than to the heart itself. As on the right, the majority of the cardio-inhibitory fibres had left the vagal trunk before it reached the level of the azygos vein.

The course of the cardio-accelerator fibres

The thoracic spinal outflow. In order to determine the limits of the cardio-accelerator outflow from the spinal cord, the spinal roots were exposed and

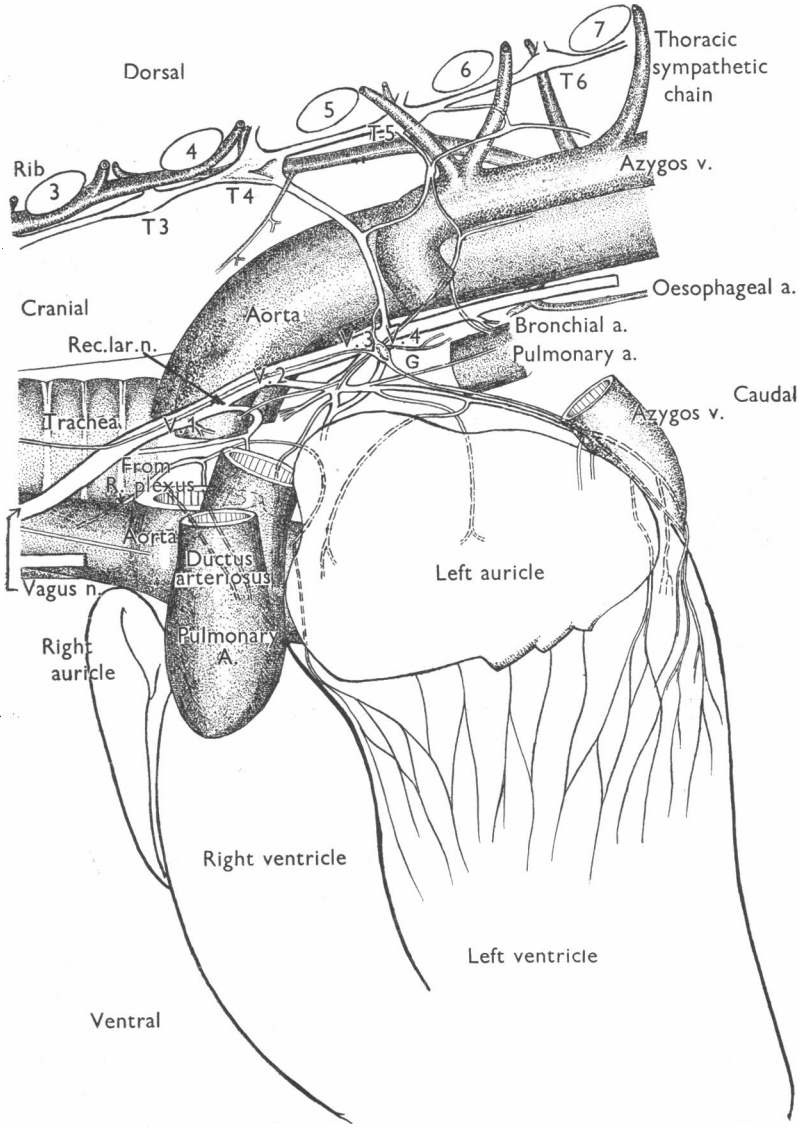

Fig. 4. The origin and intermingling of the cardiac branches of the left thoracic vagus and thoracic sympathetic nerves of a foetal lamb. Parts of the major vessels have been omitted.

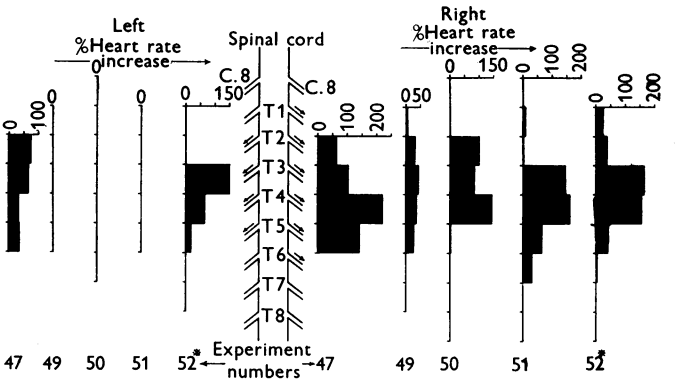

Fig. 5. The accelerator response of the heart to stimulation of some mixed spinal roots in five sheep. The arrows in the diagram indicate the roots from which accelerator responses were obtained and the direction of stimulation. The columns show the percentage heart rate increase above the pre-stimulation rate. The length of each ordinate indicates the number of roots tested in each experiment. Expts. 50–52 were curarized (15 mg tubocurarine chloride I.V.); 47 and 49 were not. * For recordings, see Fig. 6. Stimulation parameters; 3–20 V, 1–10 msec, 50 c/s for 15–30 sec.

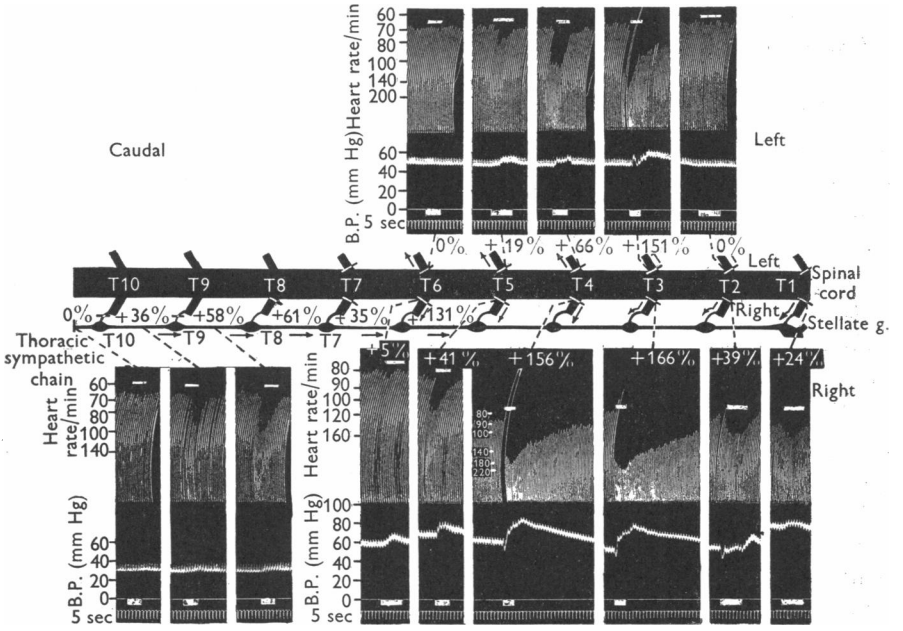

Fig. 6. Sheep, ♂, 29·0 kg; cyclopropane. The cardiovascular responses to stimulation of the upper thoracic spinal roots and three interganglionic segments of the right thoracic sympathetic chain. The diagram shows the sites of stimulation and on it are given the percentage heart rate changes obtained in response to stimulation. Heart rate (upper trace) and blood pressure (lower trace) recorded by differential and mercury manometers respectively. Stimulation parameters: 10–20 V, 1 msec, 50 c/s for 15–30 sec.

stimulated in five experiments and the results are shown in Fig. 5. Cardio-accelerator fibres were constantly found in the upper thoracic roots on the right in all five of the animals examined. They were most numerous in the roots of T3 and T4, less so in those of T2 and T5 and were present only in small numbers in T1 and T6 of some animals (Fig. 6). When present in the outflow of both sides of the thoracic spinal cord, they were apparently more numerous on the right.

Cardio-accelerator fibres were found in the spinal outflow of the left side in only two out of five animals. In one of these (Fig. 6) they were restricted to roots T3–T5, although at the same level in the left thoracic sympathetic chain the ganglia were often large with substantial branches crossing to the cardiac plexuses (see Figs. 4, 10), a point which will be referred to later.

Tubocurarine chloride was injected in the last three laminectomized preparations (50–52, Fig. 5) to prevent movements of the forelimbs and lower cervical and upper thoracic muscles, which occurred in the first two experiments during stimulation of the roots. Such movements were only marked when the last cervical and first thoracic roots were being stimulated. The majority of cardiac responses demonstrated in these experiments could not have been affected by such movements.

Pathways within the right thoracic sympathetic chain. Cardio-accelerator fibres could always be demonstrated in the right sympathetic chain. Their course within the thorax was studied in eight sheep as follows. First the cervical connexions of the chain were cut; then a test stimulus was applied to the chain to determine the most caudal point at which a cardiac response could be elicited. The chain was then cut just below this point and the spinal connexions with the length of chain above this point were divided; finally each interganglionic segment of the isolated portion of the chain was stimulated. In this way it was ensured that responses to stimulation were due only to efferent fibres acting directly on the heart and not to afferent fibres acting reflexly. When following ascending fibres in the chain the stimulations were carried out from below upwards, but in the opposite direction when descending fibres were being traced.

As indicated in Fig. 7, cardio-accelerator fibres were present in all segments of the right sympathetic chain as far back as T7 in the sheep examined; and in one animal they were even found between T10 and T11. As already mentioned, cardio-accelerator fibres were only present in the spinal outflow between T1 and T6. Therefore those present in the chain below this level must have descended from the upper thoracic outflow, and presumably turn back within the chain in order to reach the heart. In four experiments both the outflow of accelerator fibres in the spinal roots and their distribution within the right chain were examined in the same animal. In all four accelerator responses were obtained from a much lower level in the chain than in the roots

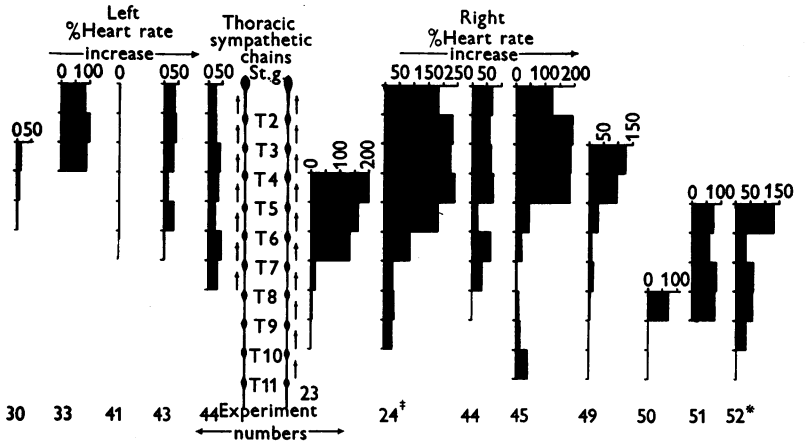

Fig. 7. The accelerator responses of the heart to stimulation between ganglia of the thoracic sympathetic chains isolated from the central nervous system in twelve sheep. The arrows in the diagram indicate the part of the chain stimulated and the direction of stimulation. The columns show the percentage heart rate increase above the pre-stimulation rate. The length of each ordinate indicates the length of chain isolated in each experiment. *‡ For recordings, see Figs. 6 and 8 respectively. Stimulation parameters: 1–10 V, 1–10 msec, 50–100 c/s for 10–30 sec.

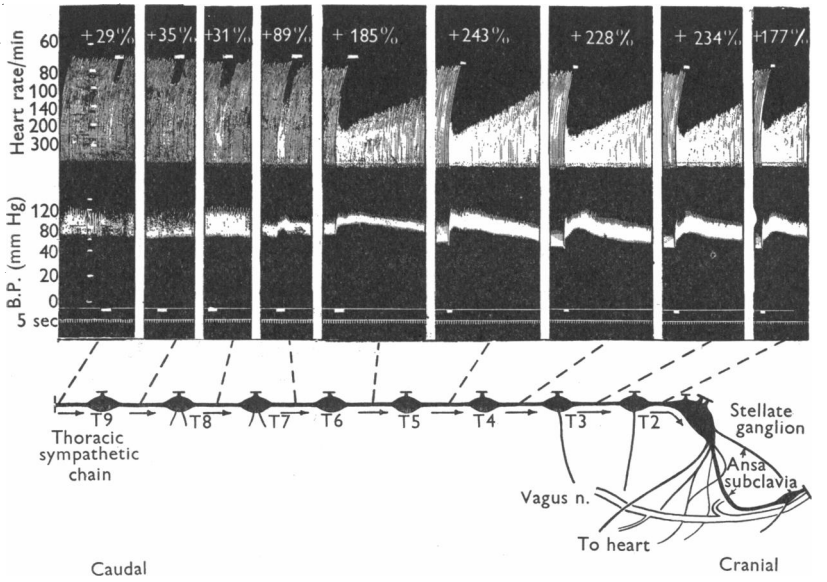

Fig. 8. Sheep, ♀, 37·4 kg; cyclopropane. The cardiovascular responses to stimulation of each interganglionic length of the middle and upper part of the right thoracic sympathetic chain (the rami communicantes of the chain and the cervical vagosympathetic trunks were previously divided). Heart rate (upper trace) and blood pressure (lower trace) recorded by differential and rubber membrane manometers respectively; diagram below to show sites of stimulation. Stimulation parameters: 2–5 V, 1 msec, 100 c/s for 10–20 sec.

(compare Expts. 49–52, Figs. 5, 7; see also Fig. 6). The results of these four experiments were therefore in agreement with the remainder in which the spinal outflow and the further thoracic course of these fibres had been studied separately (compare Figs. 5, 7; see also Fig. 8).

Relay stations of the right cardio-accelerator nerves were located by stimulating parts of the chain before and after the application of nicotine to ganglia lying between the point of stimulation and the heart. The nicotine solution (1–2%) was either dropped on to the surface of the ganglion or injected under its connective tissue capsule with a very fine hypodermic needle. In three of seven experiments, nicotine applied in either of these ways to the stellate ganglion completely abolished the cardio-accelerator response to stimulation of the cranial end of the chain divided immediately below the ganglion (the initial stimulating action of nicotine on the ganglion cells was not always demonstrable). The stellate ganglion was not the only relay station. In four experiments it was found that residual responses (average heart rate increase of 45%) remained after nicotine had been repeatedly applied to the stellate. In one such preparation this response was not abolished by intravenous injections of hexamethonium (6 mg/kg) and evidently therefore the fibres being stimulated were post-ganglionic. Whether they were also post-ganglionic in the other three experiments was not determined.

The second thoracic ganglion, like the stellate, has also been found to be a relay station both for ascending and for descending preganglionic fibres. The stellate and second ganglia were the only ganglia examined for relay points. It seems likely that ganglia T3 and T4 also contain relay points because branches which leave these ganglia to cross directly to the heart contain cardio-accelerator fibres. It seems probable therefore that these branches have their cells of origin in the ganglia from which they emerge, since that arrangement holds good for the fibres emerging from the stellate and second ganglia.

The cardio-accelerator fibres leave the chain in a number of branches arising from the portion above the fourth ganglion. As already mentioned, there are some in branches which cross directly from ganglia T2 to T4. In addition numerous branches from the stellate and ansa subclavia are present (see Figs. 1–3) and are the route by which the recurrent cardio-accelerator fibres of the right cervical sympathetic nerve reach the heart (Waites, 1957). Usually the largest of these branches was one from the upper pole of the stellate ganglion (S.1 in Fig. 3). There was considerable intermingling of cardio-accelerator fibres from the sympathetic chain with the right thoracic vagus in its upper course (Figs. 1, 2). Cardio-accelerator fibres in branches which also contained vagal cardio-inhibitory fibres were detected by stimulation after administration of atropine. In this way accelerator fibres were frequently demonstrated in the vagal trunk and also in some of the large vagal branches arising just beyond the recurrent laryngeal nerve.

Pathways within the left sympathetic chain. The pattern of cardiac innervation from the left sympathetic chain was very different from that of the right. In contrast to the right chain, cardio-accelerator fibres were sometimes absent from the left (see Figs. 5, 7) and, in fact, they were only found to be present in eight out of twelve sheep examined. Their course within the thorax was determined by the procedures used for the other side.

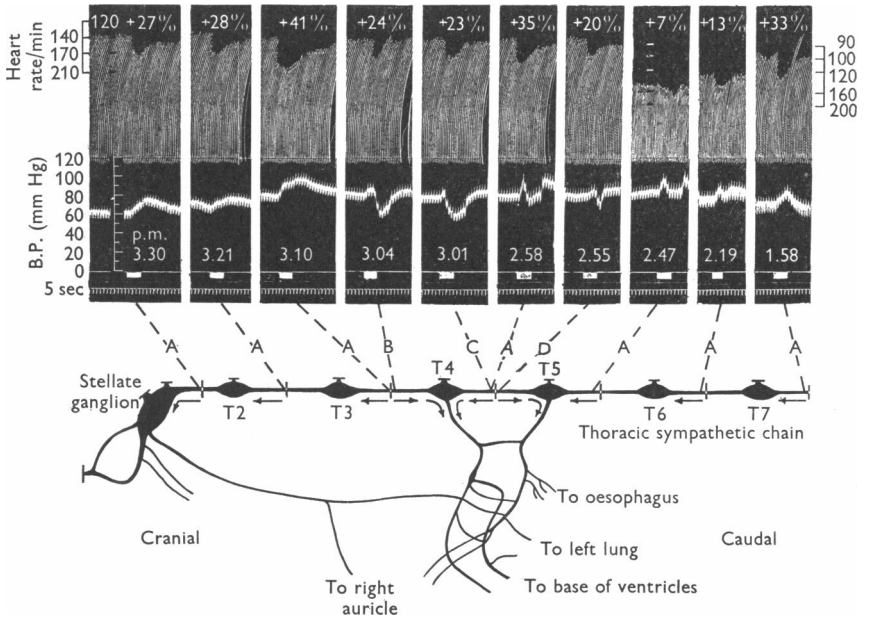

Fig. 9. Sheep, ♂, 26·2 kg; cyclopropane. The cardiovascular responses elicited by stimulation of the cranial and caudal cut ends of interganglionic parts of the left thoracic sympathetic chain (the central connexions of which were previously sectioned). Heart rate (upper trace) and blood pressure (lower trace) recorded by differential and mercury manometers respectively; diagram below to show sites and direction of stimulation and where the chain was divided at the time of stimulation. Stimulation parameters: 2–3 V, 10 msec, 50 c/s for 15–20 sec. *A*, chain above intact; *B*, chain cut below T4; *C*, chain cut above T4; *D*, chain cut below T5.

It was observed that cardio-accelerator fibres are not present over so great a length of this chain as on the right, although they may be found in the chain below the fifth thoracic ganglion (Fig. 9). On examination these were found to be ascending fibres. Since in other experiments, already mentioned, it had been found that no cardio-accelerator fibres enter the left chain from the spinal cord below root T5 (Fig. 5), the conclusion drawn was that these fibres must be recurrent. In this respect therefore the course of the left cardio-accelerator fibres resembles that of the right fibres.

A further difference between the two sides is that on the left descending cardio-accelerator fibres were found in all the segments between the second

and the fifth thoracic ganglia (on the right they were only found between the stellate and T2). Thus, within the left chain between ganglia T2 and T5 there were both ascending and descending cardiac fibres (Fig. 9). An anatomical difference exists between the right and left chain in that the branches from ganglia T3–T6 which supply the thoracic viscera are much larger on the left (Figs. 4, 10) than those seen on the right (Figs. 1–3). It was found that the size of these branches on the left was no indication of whether or not they contained cardio-accelerator fibres, for these were sometimes absent.

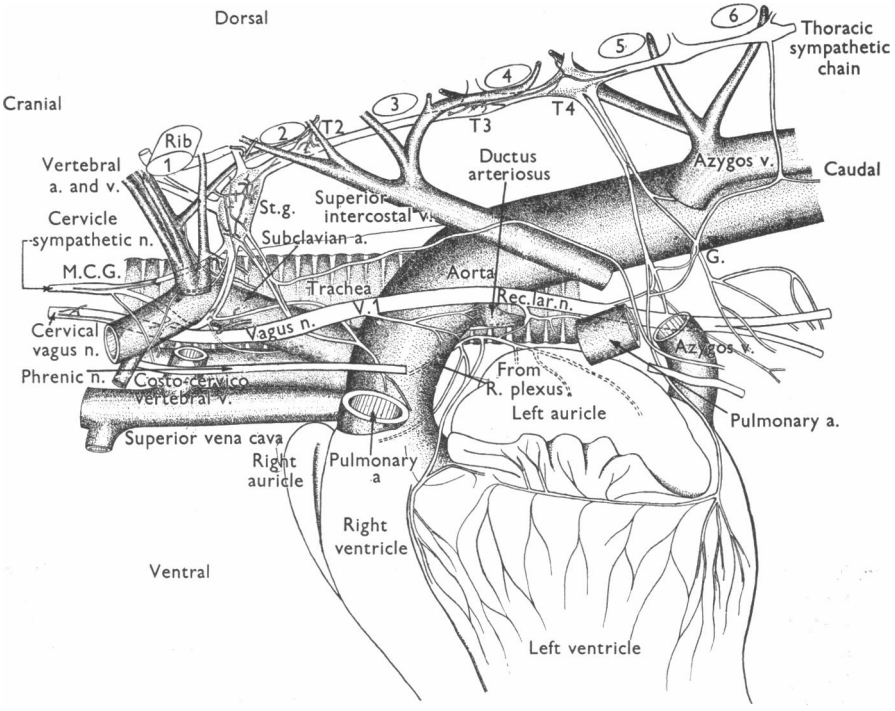

Fig. 10. The origin and course of the cardiac branches of the thoracic vagus and thoracic sympathetic chain on the left in a new-born lamb (shown also in Fig. 2). Parts of the major vessels have been omitted. The superior intercostal vein usually drained into the costo-cervico-vertebral vein.

In contrast with the findings on the right side, no cardiac-accelerator fibres have been found to enter the left cervical sympathetic nerve (Waites, 1957). All the accelerator outflow from the left chain is carried in branches given off to the thoracic viscera by the stellate ganglion (usually slender branches) and by ganglia T3–T5 (usually thicker branches). As on the right, however, these branches mingle with the thoracic vagus before reaching the heart. Cardio-accelerator responses were therefore sometimes obtained from the upper part of the vagus and more frequently from vagal branches arising just caudal to the origin of the recurrent laryngeal nerve.

Relay stations for the left cardio-accelerator nerves were found in the stellate and the thoracic ganglia T3–T5. The effects of application of nicotine to the ganglion T4 on the response to stimulation of the left thoracic sympathetic chain are shown in Fig. 11. The majority of fibres appeared to relay in this ganglion and also in the stellate ganglion. All ascending fibres which passed

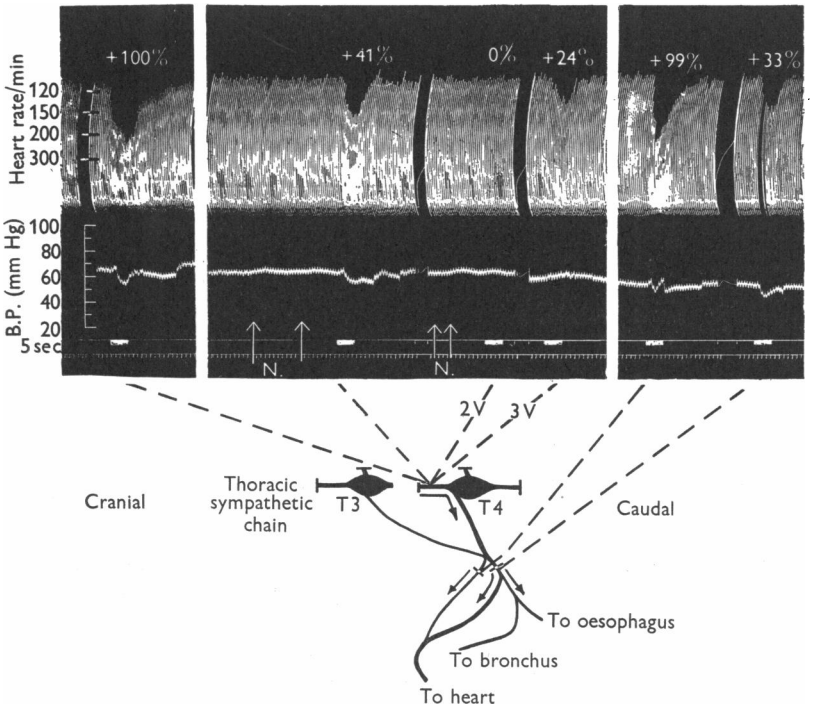

Fig. 11. Sheep, ♀, 42·5 kg; cyclopropane. The effect of the application of nicotine to the fourth thoracic ganglion on the cardiovascular responses to stimulation of the left thoracic sympathetic chain above this ganglion. Heart rate (upper trace) and blood pressure (lower trace) recorded by differential and mercury manometers respectively; diagram below to show sites of stimulation. N, application of 1 and 2% nicotine hydrogen tartrate to the fourth thoracic ganglion. Stimulation parameters: 2–4 V, 1 msec, 100 c/s for 20–25 sec.

through the stellate ganglion on their way to the heart relayed at this point. This affords another contrast with the right side in which some post-ganglionic accelerator fibres passed through the stellate ganglion. Both ascending and descending fibres of the chain were found to relay in the other ganglia examined, their post-ganglionic fibres crossed directly to the heart in branches from the chain. The results which have been described here are summarized in Fig. 12.

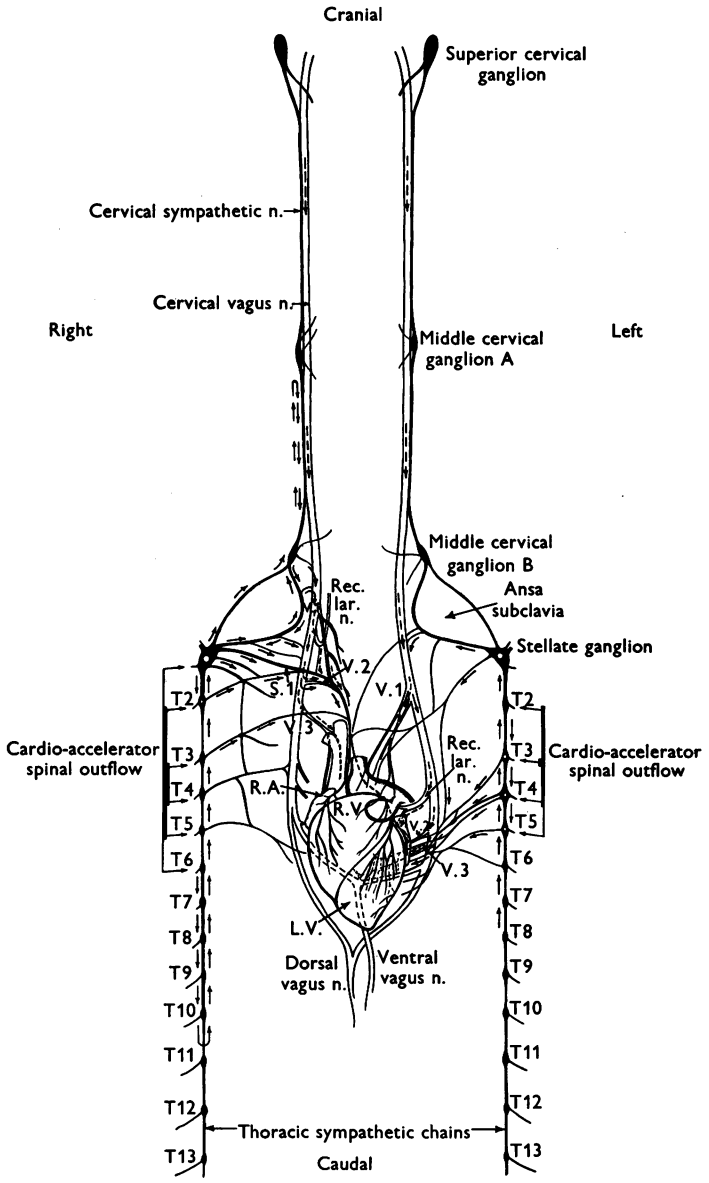

Fig. 12. Diagram to summarize the pathways of the efferent cardiac fibres of the sheep found in this investigation. Abbreviations: see figs. 1, 2. Also: R.A., R.V., L.A., L.V. = right auricle and ventricle and left auricle and ventricle. ⟶ = sympathetic accelerator fibre pathways; - - - → = parasympathetic inhibitor fibre pathways; ○ = relay sites.

DISCUSSION

The main cervical and thoracic pathways carrying the cardiac fibres of sheep have been mapped out by electrical stimulation in anaesthetized preparations. The inhibitor fibres have been shown to follow much the same course as in other species, but the accelerator fibres follow routes to the heart which have not hitherto been described (Fig. 12). Cardio-accelerator fibres originating from the spinal cord in the first five or six ventral roots ascend into the right cervical sympathetic nerve before returning to the heart. Furthermore, cardio-accelerator fibres arising from the same ventral roots turn down into the lower part of both thoracic sympathetic chains, loop and then ascend in the chain before reaching the heart. On the right side these recurrent cardiac fibres must be of considerable length since they are sometimes found as far caudal as the tenth thoracic ganglion.

It is difficult to suggest why the peripheral course of the accelerator fibres should be so circuitous. It has been observed (Waites, 1957) that the upper level which these recurrent fibres reach in the right cervical sympathetic nerve is always caudal to the upper portion of the middle cervical ganglion (middle cervical ganglion A, Fig. 12); their growth may therefore be related to factors determining the occurrence and position of this ganglion. The problem has also been considered in embryological terms, but so far all attempts to explain it appear to be inadequate (J. D. Boyd, personal communication).

It has been shown that more profound changes of heart rate occur when the ventral roots and the thoracic sympathetic chain on the right as opposed to the left are stimulated. Indeed, cardio-accelerator fibres are sometimes absent from the left roots and chain. There is therefore a numerical as well as a topographical difference between the accelerator fibres of the two sides. Moreover, a difference in the synaptic sites of preganglionic neurones has been observed between the two sides. The majority in the right chain ascend to form synapses in the stellate ganglion, their post-ganglionics crossing from the upper part of the chain. This is in agreement with Goodall (1951) and Goodall & Kirshner (1956), who suggested from pharmacological evidence that the right sympathetic ganglia from the stellate to the fifth thoracic contained most of the relay points for sympathetic cardiac fibres in the sheep. On the left, however, it has been found that the preganglionic fibres, when present, either ascend to form synapses in the stellate or descend to cell stations in the third to the fifth thoracic ganglia. As a consequence the post-ganglionics are found in the ventral limb of the ansa subclavia, the usually slender branches of the stellate, and the more substantial branches of the third to the fifth thoracic ganglia.

Ionescu, Teitel-Bernard, Iliescu & Enachescu (1928) have shown that the left thoracic cardiac nerves of the calf contain accelerator fibres and there is also abundant evidence from non-ruminant species that accelerator pathways

cross to the heart from the upper thoracic ganglia (White, Garrey & Atkins, 1933; Chapman, Kinsey, Chapman & Smithwick, 1948). A number of authors have suggested from experiments on dogs that amplification of ventricular contraction might be the predominant function of the left thoracic cardiac nerves (Fogelson, 1929; Saccomanno, Utterback & Klemme, 1947; Randall & Rohse, 1956). It is here apparent that apart from branches which pass to the oesophagus and lung, the nerves which form a plexus around the left azygos vein mainly innervate the ventricular muscle rather than the sino-auricular or auriculo-ventricular nodal regions (Figs. 4, 10). Although no attempts have been made to demonstrate cardio-augmentor activity in the sheep, it might be that the sympathetic cardiac fibres on the left are mostly inotropic to the ventricular muscle rather than chronotropic to the nodal tissue.

Although fibres which accelerate the heart have been observed in the cervical and thoracic vagosympathetic trunks of several mammalian species after prior vagal degenerative section high in the neck and after the administration of atropine, there has been some controversy about the origin of such nerves (reviewed by McDowall, 1956). The evidence from experiments on sheep leaves no doubt that cardio-accelerator fibres occurring in the right cervical vagus nerve and in the upper course of both thoracic vagal trunks originate from the thoracic sympathetic outflow and are not descending from more cranial segments. This conforms with the classical concept of the thoracico-lumbar sympathetic outflow of the autonomic nervous system formulated by Gaskell (1916) and Langley (1921). The intermingling of sympathetic with vagal fibres at the upper thoracic level means therefore that the nerves of the cardiac plexuses contain fibres of both types, a feature emphasized by Lim Boon Keng (1893) in a study of the cardiac nerves of the dog.

In these experiments the presence of cardiac fibres has depended upon the demonstration of changes in heart rate on electrical stimulation of nerves and the magnitude of such changes. As previously emphasized by Cannon & Lewis (1927) any such effect may depend upon the pre-stimulation heart rate, which in turn is partially determined by artificially imposed factors such as anaesthesia and surgical shock. It has to be remembered therefore that negative results do not necessarily mean that cardiac fibres are absent from a given nerve. The pre-stimulation heart rate may already be so high that a small fibre component when stimulated is unable to accelerate it further. All negative responses to stimulation have been evaluated with these considerations in mind and precautions have been taken to avoid or reduce errors of the kind mentioned. However, it remains a possibility that some efferent cardiac nerve pathways have escaped detection because of some factor such as anaesthesia. In experiments now in progress it is hoped to assess such effects as anaesthesia in the responses of the cardiovascular system and in the light of these it may be necessary to modify some of the conclusions reached here.

SUMMARY

1. Efferent cardiac fibres in the sheep have been traced by measuring responses of the heart to electrical stimulation of the cervical and thoracic vagosympathetic nerves.

2. Cardio-inhibitory fibres descend in both cervical vagal trunks and only rarely are any found to join with the cervical sympathetic nerves. They pass to the heart from the upper part of the right thoracic vagus and on the left from the recurrent laryngeal and from the vagal trunk just below the origin of this nerve; the majority leave the vagal trunks above the level of the terminal portions of the azygos veins.

3. Cardio-accelerator fibres are consistently found in the right sympathetic outflow but are present in fewer numbers or are absent from the left. They enter the thoracic sympathetic chain through the spinal roots T1–T6 on the right side, and T2–T5 on the left. On both sides they are found in the chain well below these points and there is evidence therefore that they turn back within the chain. Other differences in the distribution on the two sides are described.

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