THE INTRINSIC NERVE CELLS OF THE CARDIAC ATRIA OF MAMMALS AND MAN

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INTRODUCTION

Davies, Francis & King (1952) made a detailed study of the intrinsic ganglia of the cardiac ventricles in a number of mammals and man, and the purpose of the present work is to extend the investigation to include the atria.

Among the earliest workers, Scarpa (1794) and Lee (1849 *a* and *b*) noted with the naked eye numerous nerves covering the whole surface of the heart of various mammals and man, and considered swellings on these nerves to be ganglia. Remak (1844), Lee (1849), and Kölliker (1865) maintained that the nerves pass into the depth of the myocardium and carry the nerve cells with them, though this was challenged by Cloetta (1853) and Vignal (1881). Cloetta, who was one of the earliest to study the heart microscopically, denied the existence of nerve cells in the heart. Since the latter part of the nineteenth century, a very extensive literature has developed concerning the sites and nature of the nerve cells in the atria, and this has been reviewed by S. Michailow (1912), Perman (1924), Francillon (1928) and Stöhr, Jun. (1932).

In general, it may be said that the commonest situation among various mammals and man, in which atrial nerve cells have been noted by numerous workers, is the wall of the right atrium in the region of the opening of the right pre-caval vein (superior vena cava). Other territories include the region of the opening of the post-caval vein (inferior vena cava), the atrioventricular junction, the inter-atrial groove, the region of the openings of the pulmonary veins (including the adjacent dorsal wall of the left atrium) and the atrial septum (among the muscle fibres). For the main part these nerve cells were found to be situated beneath the epicardium, though some authors have noted nerve cells among the myocardial fibres of the atrial walls (including the atrial septum). A few workers have described ganglia at and near the origins of the aorta and pulmonary artery, though in the present work these ganglia are regarded as belonging to the ventricular series. Special attention has been devoted by several observers to the relation of nerve cells to the atrial part of the cardiac 'conducting system', namely the sinu-atrial (S.A.) and atrioventricular (A.V.) nodes and the atrioventricular (A.V.) bundle. Many detailed studies have also been made on the finer structure and types of nerve cells in the atria and of their possible functional nature.

A survey of the previous work has revealed that there is much difference of opinion concerning both the situation and the types of atrial nerve cells, so much so as to warrant the present re-investigation.

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MATERIALS AND METHODS

The hearts studied were as follows:

Ornithodelphia. Platypus (*Ornithorhynchus*) (1), Echidna (*Echidna* sp.) (1).

Didelphia. Wallaroo (*Macropus robustus rubens*) (1).

Monodelphia. Insectivora: hedgehog (*Erinaceus europaeus*) (1), mole (*Talpa europaeus*) (1).

Rodentia. Rat (*Rattus*, laboratory white rat) (2), guinea-pig (*Cavia porcellus*) (2).

Lagomorpha. Rabbit (*Oryctolagus cuniculus*) (2).

Carnivora. Cat (*Felis*) (4), dog (*Canis familiaris*) (3).

Cetacea. Porpoise (*Phocaena communis*) (1).

Artiodactyla. Ruminants: domestic ox (*Bos taurus*) (3), sheep (*Ovis aries*) (1); non-ruminants: pig (*Sus scrofa*) (2).

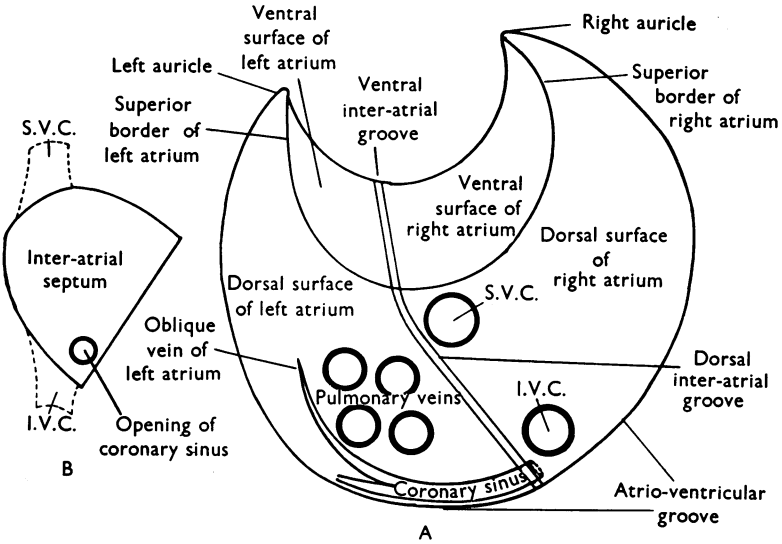
Perissodactyla. Horse (*Equus caballus*) (1).

Chiroptera. Fruit bat (*Pteropus* sp.) (1).

Menotyphla. Tree shrew (*Tupaia* sp.) (1).

Primates. Rhesus monkey (*Macacus rhesus*) (1), man (*Homo sapiens*) (3).

The numbers in parentheses indicate the numbers of specimens of each that were examined.



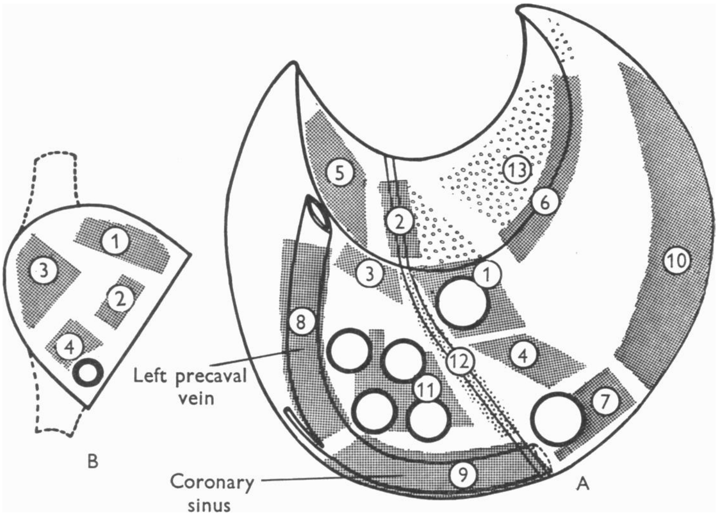
Text-fig. 1. Standardized diagram of epicardial surface of right and left atria and the inter-atrial septum.

In most cases serial transverse paraffin sections of whole hearts were prepared; in others, particularly the larger hearts, several blocks of the atrial walls were removed and paraffin or frozen sections made of each. The various staining techniques employed included haematoxylin and eosin, iron haematoxylin and picrofuchsin (van Gieson), Masson's trichrome stain (using light green), pyridine-silver (Blair & Davies, 1935), and the Bielschowski-Gros, Ranson and Smith Quigley silver methods. In the early stages of the work, graphic reconstructions from projected drawings were made to indicate the position of the nerve cells, but this proved to be exceptionally time-consuming.

Two standardized diagrams (Text-fig. 1 A, B) were therefore devised, and on them the positions of the ganglia in the various hearts were plotted as accurately as possible in their relation to well-defined cardiac structures. The first (Text-fig. 1 A) represents the atria viewed from their cranial aspect so that the ventral and dorsal surfaces are visible. The second (Text-fig. 1 B) represents the atrial septum, viewed from the right side. In some of the hearts a left pre-caval vein was present (instead of the oblique vein of the left atrium); this is depicted in Text-fig. 2, which also indicates the general disposition of the ganglion fields that were located microscopically and will be described subsequently.

The number of sections used for the reconstructions varied from every 5th in the smaller hearts to every 50th or 60th in the larger ones, the number being indicated in the Text-figures by a fraction (e.g. the fraction 1/10 in the platypus heart in Text-fig. 3).

From the totality of observations made, the following numbered ganglion fields (Text-fig. 2) were delimited, many of them being similar to those described by Eiger (1909), Schwartz (1899) and Schurawlew (1928).



Text-fig. 2. Standardized diagram of atria and inter-atrial septum with left pre-caval vein, with ganglion fields shown by shaded areas.

A. *Epicardial ganglion fields* (Text-fig. 2 A)

(1) An area surrounding the orifice of the right pre-caval vein.

(2) The anterior part of the inter-atrial groove.

(3) The upper part of the dorsal surface of the left atrium.

(4) A rather narrow area on the dorsal surface of the right atrium, close to the inter-atrial groove and extending downwards and laterally towards the post-caval vein.

(5) An irregular area occupying most of the medial half of the ventral surface of the left atrium.

(6) A narrow area on the upper border of the right atrium, extending to the junction of the atrium and the auricle.

(7) An area above and lateral to the orifice of the post-caval vein. It may extend below the vein medially to the opening of the coronary sinus.

(8) A narrow area on either side of the oblique vein of the left atrium (or the left pre-caval vein); when the latter vein is present, this area continues into area 3.

(9) An area surrounding the coronary sinus as far as its opening where it may be continuous with ganglia in the lower and dorsal part of the atrial septum.

(10) An irregular area on the lower part of the dorsal surface of the right atrium, extending to the atrioventricular sulcus and, in some hearts, far ventrally towards the right auricle.

(11) An area around and between the openings of the pulmonary veins, but mainly situated medially to the right veins.

(12) An area comprising the dorsal part of the inter-atrial groove; in most hearts it is interrupted near its middle.

(13) An irregular area on the ventral surface of the right atrium; it may extend to the right auricle.

Although the above areas are fairly well defined in many hearts, in some, adjacent areas may be continuous, e.g. area 1–4; areas 4 and 7; areas 6 and 13, 6 and 12.

B. *Ganglion fields in the atrial septum* (Text-fig. 2B)

These comprise four irregular fields which are not precisely separated from each other; all are situated between the muscle bundles of the septum.

(1) The upper ventral part of the septum, extending about three-quarters of the way downwards towards the A.V. junction.

(2) An area just below the middle of the septum, immediately below the fossa ovalis.

(3) The upper dorsal part of the septum above the fossa ovalis.

(4) The lower dorsal part of the septum, just above the entrance of the coronary sinus.

OBSERVATIONS

The topography of the ganglia

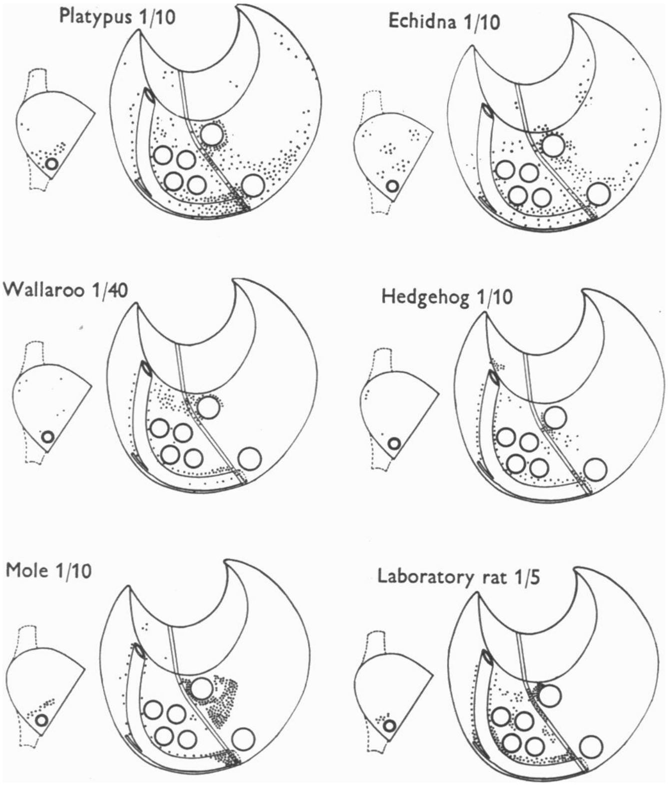
The majority of the atrial ganglia in all the specimens are situated in the subepicardial connective tissue (Pl. 1, fig. 1), an observation similar to that made in the case of the ventricular ganglia by Davies *et al.* (1952). The topography of the subepicardial ganglia and of those in the inter-atrial septum have been summarized for the different animals in the table (Table 1), in which the presence or absence of ganglia is shown in the columns under the headings of the numbered ganglion fields, for each animal of the series. The finding of very numerous ganglia in some sites is also indicated by the number of +'s. The positions of the ganglia under the epicardium and also in the septum are shown in the diagrammatic reconstructions

Table 1. *Distribution of ganglia in atria*

	Ganglion fields in epicardium													Ganglion fields in septum			
Animal	1	2	3	4	5	6	7	8	9	10	11	12	13	1	2	3	4
Platypus	++	0	+	+	+	0	+	++	++	+	+	++	+	0	+	+	+
Echidna	++	+	+	++	0	+	+	+	++	+	+	+	+	+	+	+	+
Wallaroo	+	0	+	0	0	0	0	+	+	0	+	+	0	+	+	+	+
Hedgehog	+	0	0	+	+	0	0	+	+	0	+	0	0	0	0	+	+
Mole	+++	0	0	+	+	0	0	+	+	0	+	0	0	0	+	0	+
Fruit bat	+	+	+	+	+	0	+	++	+++	0	+	++	+	0	+	+	+
Rat	++	0	+	0	0	0	0	++	++	0	+	+	0	0	0	0	+
Guinea-pig	+++	0	+	0	0	0	0	++	++	0	0	+	0	0	+	0	+
Rabbit	+	+	+	0	0	0	0	++	+	0	+	++	0	0	0	+	+
Cat	++	+	++	+	++	0	+	++	++	0	+	+	0	0	+	0	+
Dog	++++	+	+	+	+	0	+	+++	+++	+	+	+++	+	+	++	++	++
Porpoise	+++	0	+	++	+	+	+	+	++	+	+	+	++	+	+	0	+
Ox	+++	++	++	+++	++	0	++	++	+++	+	++	+	+	+	+	0	+
Sheep	+++	+	+	+	+	+	+	++	+++	+	+	+	+	+	++	++	++
Pig	++	++	++	+	0	0	+	++	++	+	+	+	+	0	+	0	+
Horse	++	+	+	+	0	0	+	+	+	0	+	+	+	0	+	0	+
Tree shrew	+	+	0	+	0	0	+	++	+++	0	+	++	0	+	++	0	++
Rhesus monkey	++++	+	++	+	+	0	+	+++	++++	++	+	++	+	+	+	++	++
Infant human	++	++	+	0	+	0	+	+	++	0	+	++	+	++	+	+	+
Adult human	++	++	++	+	+	0	+	+	++	+	++	+	+	++	+	+	+

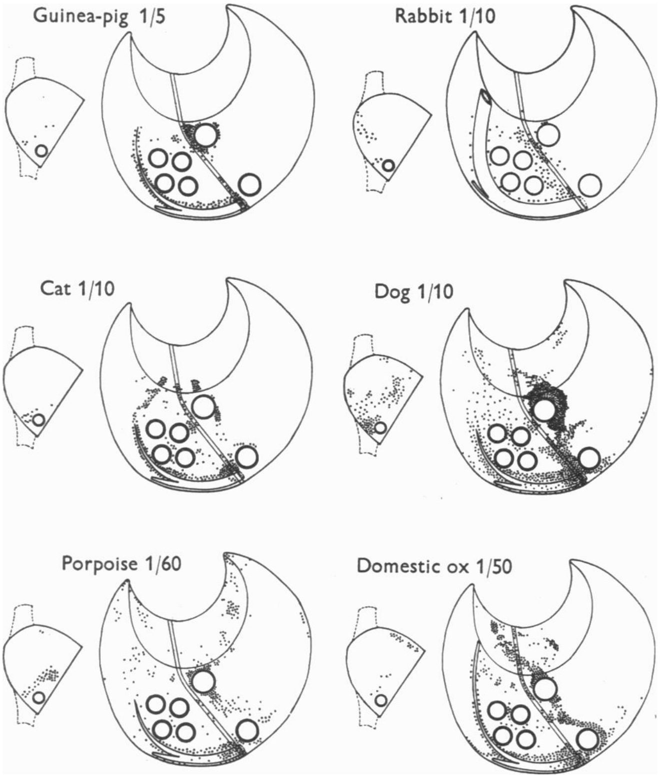
(Text-figs. 3–5) in which they are represented by dots, as already described. The pig and the horse are excluded from these diagrams because, as these hearts were examined in separate small blocks, it was impossible to give an accurate reconstruction of their ganglia, comparable to those of the other hearts of the series, which were sectioned whole.

Subendocardial ganglia are extremely rare; in most of the hearts none were found in this situation. The human infant was the exception to this (Pl. 1, fig. 2). In the myocardium, however, ganglia are frequently observed, in contrast with the findings of Davies *et al.* (1952), who saw none in the myocardium of the ventricles in any heart they examined. Intra-myocardial ganglia are present in all the hearts of this series, but, like subepicardial ones, their number varies from one Order to another. The dog is especially noteworthy in this respect, having very numerous ganglia in various places in the muscle, mainly of the right atrium (Pl. 1, fig. 7), particularly the upper part of its wall, both ventral and dorsal. Included among intra-myocardial ganglia are those of the inter-atrial septum, already mentioned.



Text-fig. 3. Standardized diagrams with the ganglia plotted in.

Ganglia are associated particularly with the nodes of the conducting system. Their presence near the sinu-atrial node is a constant feature in all the hearts, and in some species the ganglia are very numerous, as in the rhesus monkey, the dog, sheep and the calf (Text-figs. 4, 5; Pl. 1, fig. 8). In the monkey a large ganglion was observed lying on the superficial surface of the node (Pl. 1, fig. 1), and in the calf several small ones between the ordinary myocardium and the node (Pl. 1, fig. 8). Ganglia related to the S.A. node are usually close to it, often at the very edge of the nodal tissue. They are numerous near the upper end of the node in most hearts, but often extend beyond its upper and lower limits. Ganglia and isolated nerve cells are often found just above the S.A. node in relation to the superior vena cava, but they do not extend upwards in the wall of this vessel. Although ganglia at the edge of the node may be embedded in connective tissue which may pass for a very short distance between the nodal fibres, it is not very common to find ganglia actually in the substance of the node, but they do occur occasionally in this situation in man (Pl. 2, fig. 14), the calf and the porpoise.



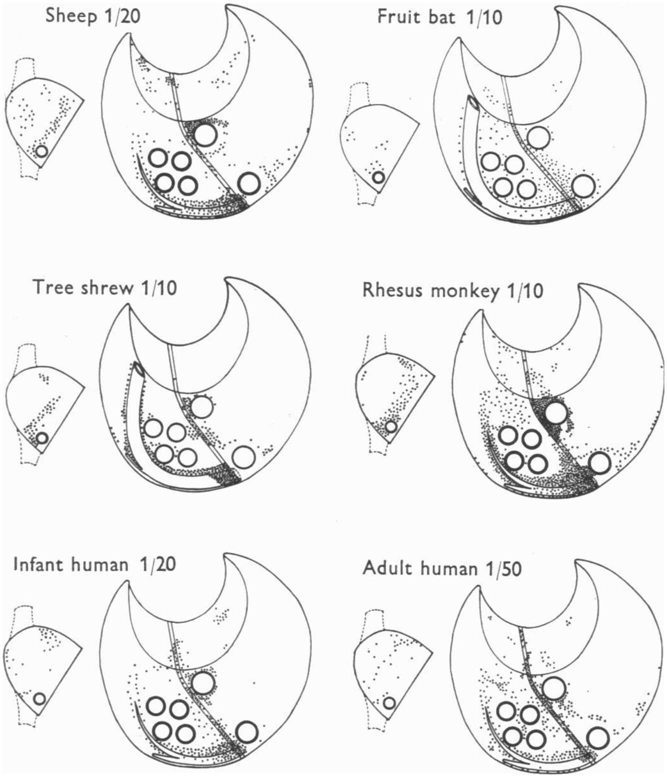
Text-fig. 4. Standardized diagrams with the ganglia plotted in.

In relation to the atrio-ventricular node (A.V. node), the commonest position of ganglia is dorsal to it, often near the opening of the coronary sinus, but they are also found alongside the node, as in the porpoise (Pl. 1, fig. 3), and very frequently above it in the lower part of the septum, in septal field 2 (Text-fig. 2). It is exceptional to find nerve cells within the A.V. node, but they were observed in this position in the rhesus monkey, the porpoise, and the calf.

Ganglia frequently accompany the atrio-ventricular bundle, being observed usually in the connective tissue close to it, and only occasionally among the bundle fibres, in which situation they were seen in calf and porpoise.

Analysis of the distribution of ganglia in the different Orders

In various animals ganglia have been observed in widely scattered parts of the atrial surface, but they are localized in the majority to certain limited areas, and the ganglion fields show the sites of their occurrence in the animals of this series.



Text-fig. 5. Standardized diagrams with the ganglia plotted in.

Ganglia are present in all the animals in four situations, namely, round the opening of the right pre-caval vein (field 1), in relation to the oblique vein of the left atrium (or left pre-caval vein) (field 8), alongside the coronary sinus (field 9), and in some parts of the inter-atrial groove (fields 2 and 12). In these positions they vary from a very large number in the dog and the domestic ox (Text-fig. 4) to only a few in the rabbit, the hedgehog, and the wallaroo. These four main ganglion positions are common to all the animals of the series, regardless of Order, the differences being only quantitative. Differences between one Order and another, and similarities in members of the same Order are observed with regard to the occurrence of ganglia in the other fields. For example, the rat and the guinea-pig have no ganglia on the ventral surfaces of either atrium (Text-figs. 3, 4) (fields 5, 13), the ventral inter-atrial groove (field 2), nor in relation to the post-caval vein (field 7), contrary to Meiklejohn (1913, 1914), who found scattered groups round the entrance of this vessel. The long chain in the external wall of the left auricle described by her is probably the chain accompanying the left pre-caval vein (field 8). A similar distribution occurs in the rabbit. The mole and the hedgehog have each a few ganglia on the upper part of the ventral surface of the left atrium (field 5) (Text-fig. 3). Of the Ornithodelphia, the platypus and the echidna resemble each other in the disposition of ganglia, with a few on the ventral surface of both atria (Text-fig. 3) (fields 5, 13), and none in the ventral inter-atrial groove (field 2). A further resemblance is that both have a chain of ganglia leading from the right pre-caval vein to the lateral side of the post-caval vein (field 4), the only other animals in which this is present in well-marked form being the ox and the porpoise. Both representatives of the Ornithodelphia also have a chain of scattered ganglia on the lower part of the dorsal surface of the right atrium (field 10), extending out to the base of the auricular appendage. In the Artiodactyla, represented by sheep and ox (Text-figs. 4, 5), a close resemblance in the ganglion distribution is observed in the occurrence of ganglia on the ventral surfaces of both atria (fields 5, 13), and in the ventral inter-atrial groove (field 2), a similar disposition being found in the porpoise, representing the Cetacea. A further point of interest is that only in these three animals are ganglia observed in the auricular appendages, the most numerous being in the porpoise, in which they are present on both appendages, whereas in sheep and ox, a few are found on the left one only. Similar points suggesting a close affinity between Artiodactyla and Cetacea were noted by Davies *et al.* (1952) in the ventricular disposition of nerve cells.

With regard to the Primates (Text-fig. 5), the rhesus monkey has an extremely dense concentration of ganglia round the pre-caval vein (field 1), the oblique vein of the left atrium, and the coronary sinus (fields 8, 9). There is a close resemblance between the distribution in monkey and that in man, in that they have scattered ganglia on the ventral surfaces of both atria (fields 5, 13), the ventral inter-atrial groove (field 2) and a few near the base of the left auricular appendage, in the region between the latter and the atrium proper.

There are also individual variations among members of the same Order, as noted by Schurawlew (1928). In the present series, in man for example, the infant heart has no ganglia between the openings of the pulmonary veins (field 11), where there is a chain in the adult (Text-fig. 5). None were observed on the ventral surface of the left atrium (field 5) in the infant, except a few to the left of the inter-atrial groove (field 2), whereas some scattered ganglia were noted in the former situation in the adult, including a few on the ventral part of the base of the auricular appendage. In the human adult, scattered ganglia were seen on the lower part of the dorsal surface of the right atrium (field 10); a chain of ganglia leads from the superior vena cava to the inferior vena cava (field 4), but these are not present in the infant.

With regard to septal ganglia, wide differences are observed in their disposition in the various Orders. It is noteworthy that ganglia bear no constant relation to the fossa ovalis. As was seen in the case of the epicardial ganglia, there are variations in distribution in individuals of the same Order in addition to variations between individuals of different Orders. For example, among the Carnivora, the dog has very numerous ganglia in all fields of the septum, whereas the cat has only a few in the lower and posterior part (field 4). In the Artiodactyla septal ganglia are very numerous in the sheep and pig, but the ox has comparatively few in this situation, and they are also sparse in the porpoise, representative of Cetacea. Among the Primates, the rhesus monkey has a large concentration of ganglia in the lower part of the septum (fields 2, 4), and in the anterior part (field 1), while the human, both infant and adult, has much fewer, mostly scattered in the upper part (fields 1, 3). The tree shrew has a septal disposition resembling that of the rhesus monkey, with ganglia in fields 1, 2 and 4, the latter having also a small group in field 3 (Text-fig. 3). In the Insectivora, mole and hedgehog, and in the Rodentia, rat and guinea-pig, only a very few ganglia are present in the septum. While the two rodents resemble each other in the septal disposition of the ganglia (Text-figs. 3, 4), the hedgehog (Text-fig. 3) has only a few in field 3, and one in field 4, whereas the mole has a group of ganglia in field 4 only. In the Ornithodelphia (Text-fig. 3), the platypus has a few ganglia in fields 3 and 4, while the echidna has groups in all septal fields. It is seen therefore that differences in the septal disposition of ganglia between members of one Order and another, and between members of the same Order, do exist, but have no constant relation to species.

Structure of ganglia

The structure of the ganglia varies in different animals, as also to some extent does the type of cell. Large ganglia, each of which passed through a large number of sections, were found to contain up to 200 cells (Pl. 2, fig. 9).

Ganglia of intermediate size, in the fatty tissue of the subepicardium, are either isolated, with several layers of connective tissue surrounding them, or else—most commonly—they are placed on the course of a nerve trunk. In this case, they appear as swellings on the course of nerves, in the form of small fusiform enlargements. Very small ganglia are attached to the sides of nerves. Such appearances were observed by Davies *et al.* (1952), in the ventricles of Artiodactyla and Cetacea. Other very small ganglia often give the appearance of being completely isolated, when they are only connected by a number of very small nerve fibres. Sometimes ganglia may be formed by only one or two nerve cells on the course of a nerve. In many cases completely isolated single nerve cells are found in the connective tissue, often between the muscle fibres (Pl. 1, fig. 4*c*). These are in the fine nerve plexuses, which run in the deeper layers of the subepicardium and between the muscle fibres.

The structure of the ganglia varies somewhat with the size. The large ones have a fairly thick connective tissue capsule, which passes into their interior, giving a supporting framework to the nerve plexus and forming delicate additional capsules to the nerve cells. Smaller ganglia have a much thinner connective tissue capsule, which in some cases appears to be completely absent. Within the ganglion, nerve cells may be scattered more or less evenly through their substance, or they may be confined to the periphery. The former arrangement is always the case with the large ganglia, but the small ones have both arrangements. The cells may be separated by a little distance from each other, or in other ganglia they are packed tightly together, either throughout the ganglion or round the periphery. In the latter case the cells are often seen to be touching so closely that sometimes two cells may be mistaken for one large one.

The cells show great variation in size and shape, and a number of different types have been distinguished according to their form, the number of processes and their staining reactions. As stained with haematoxylin and eosin, some cells appear very obviously dark, while others have a pale cytoplasm. The same distinction is seen with silver staining, but not so clearly with van Gieson. Such staining distinctions were observed by Blair, Bacsich & Davies (1935) in spinal ganglia. The pale stained cells may be very large, medium-sized or quite small in the same animal. In these cells the cytoplasm has a fine reticulum and is evenly filled with fine granules. The nucleus is vesicular, round or slightly ovoid, with a darkly stained, thin nuclear membrane. This membrane is slightly rough, and may have several round or pointed processes, projecting for a short distance into the surrounding cytoplasm (Pl. 3, fig. 18). Often there is a shallow groove passing transversely across the nucleus, giving the appearance, sometimes, of two separate nuclei (Pl. 3, figs. 15, 16). There is usually one darkly stained nucleolus, which may be homogeneous, or may be composed of a number of short rods, arranged like the points of a star. Sometimes there is a pale area in the centre of the nucleolus with an inner dark granule like a second nucleolus within the first (Pl. 3, fig. 18). In addition to the nucleolus there are usually a number of darkly stained chromatin granules. It is very rare to find a second nucleolus.

The shape of the large pale cells varies. They may be spherical, like posterior root ganglion cells, but most commonly they are ovoid or pear-shaped, with one rounded end slightly narrower than the other. In cells of the latter shape, the nucleus is close to the wall at the wide end, being nearer to one end in most cells. The pale cells usually have one thick process emerging from the narrow end, and a number of very slender processes arising from various points scattered over the surface, ranging from a few to a dozen or more. The large process usually divides soon after leaving the cell, and these branches may again divide soon. These fibres can, in the silver preparations, often be traced for some distance, until some of them leave the ganglion. Some branches of this process may be traced to form contact with other nerve cells in the ganglion, most commonly the dark cells, or they may become lost in the plexiform arrangement of fibres in the ganglion. The short processes either join the general plexus of the ganglion, or else they become lost in a plexus which surrounds the body of the cell, the pericellular plexus. The cells with only one process, unipolar, or pseudo-unipolar cells, which are rather rare, usually belong to the large pale cell type.

Small pale cells and those of intermediate size have appearances similar to those described for the large ones. It is possible that the small cells may really be large ones in which the section has passed through one end, that containing the nucleus, because in this type of cell the nucleus often almost fills the cell.

The dark cells are of two types, large and small. Their cytoplasm is filled with darkly stained granules, so that the nucleus is almost completely obscured. The latter is round or slightly ovoid, deeply stained with one very dark nucleolus. The dark cells have a much bigger variation in shape than the pale ones. They are practically always irregularly angular, so that they may be triangular and pointed, quadrilateral or elongated and narrow, but occasionally they may be ovoid or pear-shaped. A thick process usually rises from a sharply pointed angle of the cell body. There are also a number of slender processes arising from various points scattered over the surface of the cell. The proportion of dark cells to pale cells varies in different ganglia, from equal numbers to a majority of 2:1 pale cells to dark ones.

The nerve fibres within the ganglion form a plexus of non-myelinated nerve fibres, in which many myelinated fibres are seen in most ganglia, being more numerous in the large ones. Some of the myelinated fibres may be passing through the ganglion (Pl. 3, fig. 19), or may be ending by making contact with the cells. In a few cases it was possible to see processes of cells become myelinated, but most frequently the acquisition of a myelin sheath does not occur until some distance from the cell. In the majority of ganglia the interior is filled with a dense plexus of non-myelinated fibres with a varying number of myelinated ones, as stated above. Sometimes, however, the ganglion is so filled with tightly packed cells that any plexus present must be extremely delicate.

Capsular cells of various types are found surrounding most of the nerve cells. Some of the latter have a complete capsule of supporting cells, with dark nuclei, such cells being thick and cubical, or quite flat (Pl. 2, fig. 12*c*). In some cases it is possible to see that where the capsule is not complete, these capsular cells give off a number of processes. There seems to be no uniformity about these cells. In some ganglia the large pale cells have a complete capsule, whereas in others in the same animal similar cells may have only one or two capsular cells, some none at all. It is possible that in some cases the capsular cells are only present on one side of the cell and spread out on it forming an extremely thin layer. These cells stain well with haematoxylin but they are equally visible in the silver stained preparations. The large pale round or ovoid cells most often have complete capsules, while the darkly stained cells usually have incomplete ones. Isolated nerve cells usually have a few capsular cells, but the capsules are not complete (Pl. 1, fig. 4*c*). The fusiform cell in fig. 5, Pl. 1, has no capsular cells.

The majority of these nerve cells are multipolar and the processes pass between the capsular cells (Pl. 2, figs. 10, 11), where the capsule is more or less complete. The ganglia are well supplied with blood capillaries which are usually plainly visible among the fibres of the plexus.

There seems to be no significant difference in the structure of ganglia in the animals of the different Orders. The impression is that in smaller hearts, whether adult or infant, the nerve cells themselves are smaller and more frequently round or oval. For example, the ganglia and cells in the small puppy heart are very similar to those of the adult fruit bat and the rhesus monkey. With the larger hearts, the ganglia of the calf resemble those of the human. In the porpoise, however, there is a marked difference in shape. In this animal the majority of the nerve cells are angular and rather flattened, the round or ovoid type being rare (Pl. 1, fig. 3*g*; Pl. 3, fig. 17).

In all the animals examined the majority of cells are multipolar, a few bipolar, while recognizable pseudo-unipolar cells are extremely uncommon.

DISCUSSION

There is an astonishing disparity in the previous results of research on the topography of the cardiac atrial nerve cells. To consider first the subepicardial ganglia, a large number of the earlier authors found them scattered over the surface of both atria, and indeed, among the later authors, Glomset & Glomset (1940*a*, *b*) observed nerves and ganglion cells over the entire left atrium, but this was the case in none of the animals of the present series. Jacques (1894, 1895), Eiger (1909), Lissauer (1909), and others, stated that ganglia only occur on the subepicardial nerves. Many ganglia in this series were undoubtedly attached to the nerves, both large and small, of the subpericardial plexus but, nevertheless, numerous ganglia were observed in the subpericardium which were quite isolated and not attached to these nerves by obvious connections.

The areas of the atria described as ganglion fields by earlier workers are much less definite than those of the present authors. Krehl & Romberg's field (1892) was an area extending up to the right to the opening of the superior vena cava, downwards to the inferior vena cava, across to the opening of the left pulmonary vein, and from there up to the pericardial reflexion at the transverse sinus, and downwards almost to the A.V. groove. This would include most of the dorsal inter-atrial groove and an area on either side. The ganglion field of Schwartz (1899) was a limited region on the posterior atrial wall to the left of the inter-atrial septal groove, bounded by the posterior end of the auricular appendage and below by the transverse coronary sinus. Eiger (1909) described his field as being bounded on the left by the left pulmonary veins, on the right by the right pulmonary veins, superiorly and anteriorly by the pericardial reflexion of the transverse sinus, below and behind by the A.V. groove. Schurawlew (1928) considered that the nerve ganglia of the heart were grouped into precise regions to form ganglion fields. He had seven, of which the first two were really associated with the pulmonary artery and do not come within the classification of the present study. His field D.1 corresponds to field 4 of the present study; his D2 and B2 would be included in field 1: his field C, corresponds to field 8: and B1 includes field 6. He noted individual variations in the ganglia in the same field in different animals, even in the same species, and this agrees with the findings of the present authors.

The presence or absence of ganglion cells in the hearts of various animals was the object of much of the early research. Most later authors who studied the topographical distribution of the nerve cells in the heart came to the conclusion that their arrangement was the same in all groups of mammals and was similar in man. For example, Lim Boon Keng (1893) considered the distribution of the cardiac ganglia in the dog to be the same as in the horse and the ox, and Perman (1924) maintained that in mammals as in man, ganglia were present on the dorsal wall of the atria and on the bases of the great arteries, but with his method, many ganglia of microscopic size would escape his observation. A few authors, however, noted a difference in their findings in different animals. Woollard (1926) observed ganglia on the anterior surface of the left auricle, in which situation they were found in most of the animals of the present series, although in varying numbers, but not in wallaroo, rat, guinea-pig, rabbit or tree shrew. Woollard noted slight differences in the arrangement in the dog as compared with that of the cat. In the former, ganglia occurred, according to him, in clumps on the posterior surface of the left auricle near the inter-atrial septum, whereas in the cat he found six distinct groups of nerve cells in that situation. As can be seen in Text-fig. 4, ganglia are very numerous in the dog in all fields, and they are almost as widespread in the cat. In the dog the occurrence of ganglia in clumps was not observed by the present authors. Nonidez (1943) also noted some differences. Perinodal ganglia, according to him, which were present in calf and sheep, were absent in dog and monkey, although in the present studies such ganglia were numerous in both the latter animals also. Nonidez found ganglia in the inter-atrial septum near the node.

Many workers have reported the presence of ganglia in the inter-atrial septum, either in the connective tissue between the right and left halves, or among the muscle bundles. The earlier workers, too numerous to mention, who have observed ganglia in this situation, include Tawara (1906) in the sheep and human, Keith & Flack (1907) in a number of mammals, and Meiklejohn (1913) in the monkey and the rat. It should be noted, however, that a number of these authors included the inter-atrial groove as part of the septum. Care has been exercised in this study to distinguish ganglia in the grooves from those actually within the muscular septum, and only these latter are regarded as being septal ganglia. Iwanowsky (1876) found ganglia on the muscle bundles surrounding the fossa ovalis in the human. Wolhynsky (1928), in the calf, observed ganglia in the superficial layer of the fasciculus limbicus inferior on the right side of the inter-atrial septum. In the present study ganglia were not seen in these situations and, in fact, the region surrounding the fossa ovalis was as a rule quite devoid of ganglia. Francillon (1928), in man, maintained that the ganglia were in the connective tissue pushed in between the muscle bundles of the inter-atrial septum. Later authors who observed ganglia in this position include Blair & Davies (1935), who noted them in the lower and back part of the septum in calf and man, whereas, in the corresponding animals in this study they were found mainly in the lower front part. Nonidez (1943) saw a few ganglia in the monkey just above the A.V. node, in which situation a large number were found in this animal by the present authors. Others who observed ganglia in the septum were Walls (1942, 1943) and Baird & Robb (1950).

Apart from ganglia in the inter-atrial septum the presence of ganglia within the myocardium, actually among the muscle fibres, has been questioned for years. In the present series of animals, as mentioned above, ganglia within the myocardium are quite numerous in the dog, in various parts of the atrial wall, mainly the upper part of the right atrium. Isolated nerve cells, as well as ganglia, both large and small, are found among the muscle fibres. In other hearts intra-myocardial ganglia are much less common. Many of the earlier workers, as noted by Francillon (1928), observed ganglion cells among the muscle fibres of the myocardium in man and a number of mammals, but this was denied by others, including Woollard (1926) and Francillon himself. However, Pannier (1935) in the cat, and King, A. B. (1939) in the rat, reaffirmed the existence of ganglion cells among the muscle fibres.

Okamura (1929) observed small cells on the perimuscular plexus among the muscle fibres, but the present authors have not been able to identify cells such as he observed. They are probably similar to the interstitial cells described by Boeke

(1933–7). Tcheng (1951) noted buried ganglia between the right lateral auricular and ventricular myocardia which were continuous with the superficial ganglia in the auriculo-ventricular sulcus.

The discovery of intra-myocardial nerve cells in the atria in this study contrasts with that of Davies *et al.* (1952), who found none within the myocardium of the ventricles of any heart they examined.

Ganglia have only rarely been reported as present in the subendocardium. Iwanowsky (1876) described nerve cells in a triangle with its apex in the fossa ovalis, and these latter may have been in the subendocardium. Lissauer (1909) described them in this position in rabbit, cat and dog. King, A. B. (1939) stated that ganglia just beneath the endocardium in the rat were common, but they were not found in this situation in those animals in the present study. No other authors have observed ganglia in the subendocardium of the atria, but Davies *et al.* (1952) found them in this position in the ventricles in Artiodactyla. Subendocardial ganglia were observed in the atria extremely rarely in this work, but a few were present in the infant human (Pl. 1, fig. 2), none in the adult human, and none in the subendocardium of the Artiodactyla, nor in that of the porpoise.

The close relation of ganglia to the conducting system, especially the S.A. node, has been noted by a number of authors who are mostly in agreement with the findings of the present study. Some disparities were observed by a few workers.

Nerve cells have been found within the S.A. node by Fahr (1909) occasionally in man, and by Oppenheimer & Oppenheimer (1912) in the sheep. Perman (1924) was unable to find them in this situation, and Francillon (1928) emphasized that in man ganglion cells were never found within the S.A. node. Copenhaver & Truex (1952), however, observed numerous ganglion cells within the connective tissue of the nodal area in the sheep, and also within the S.A. node of the human specimen, but not in the monkey. In the present study they were noted in this position in the human infant (Pl. 2, fig. 14), but not in the adult; they were also seen in the porpoise but not in other animals. Davies (1931), however, observed a number of nerve cells actually in the S.A. node of both platypus and echidna, but the present authors have not been able to confirm this. In their specimens, ganglia were limited to the edge of the nodal tissue. It is of interest that both Shaner (1929) in calf embryos, and Walls (1947) in human embryos, noted the early appearance of nerve cells in the area of the future S.A. node.

With regard to the atrioventricular node, in common with most, the present authors have found ganglia regularly near it or in its neighbourhood, but not actually among the specialized tissues, with the exception of the calf and the porpoise, in which small ganglia were observed deep within the node. In some of the other animals, ganglia were occasionally found in the connective tissue at the edge of the node. Wilson (1909) noted ganglion cells in the A.V. node in the Artiodactyla, and Fahr (1909) and Blair & Davies (1935) saw a few nerve cells buried within it in calf and man. In the present series of animals, a few ganglia were found alongside the A.V. node in some cases, while in others they were noted above the node, in the lower part of the inter-atrial septum, where they were observed by Nonidez (1943) in dog and monkey. The commonest situation, however, for ganglia related to the node, is posterior to it in the lower part of the inter-atrial groove, where numerous ganglia were found in most hearts. Stotler & McMahon (1947) observed numerous ganglia near the artery round the A.V. node in man, but this was not found to be a regular feature in the present series.

The A.V. bundle is included within the scope of this work, but not the limbs, which more properly belong to the ventricle, and were dealt with by Davies *et al.* (1952). It is noteworthy that in the Artiodactyla, e.g. the calf, and in the Cetacea, e.g. the porpoise, ganglia were found within the A.V. bundle where they were not seen in other animals. Fahr (1909) was unable to find any nerve cells in the bundle in man, but Engel (1910) saw numerous nerves and ganglion cells in this situation in Artiodactyla. According to de Witt (1909), nerve cells and fibres were numerous near the bundle in the sheep and calf, but only in the latter were they noted within its meshes. Meiklejohn (1913) described a few small ganglia in the bundle in the guinea-pig, but the present authors were not able to confirm this. Blair & Davies (1935) observed small groups of nerve cells in the A.V. bundle in the bovine heart, while Stotler & McMahon (1947) stated that no ganglia were seen near the bundle or its branches in man.

With regard to the question as to which ganglia in mammals correspond to those found in the frog, it is difficult to find any true comparison. Ludwig's ganglion (1848) was a collection of ganglion cells in the frog in the course of the nerves to the atrial septum. Remak (1844) described a group of ganglion cells on the nerves which penetrated the atrial septum, while Bidder's ganglion (1852) lay in the lower part of the atrial septum on the entrance of the nerves into the ventricular septum. According to Flack (1909) groups of ganglia were found in vertebrates often in the 'sinu-auricular junction' in the atrial septum, and in the coronary sulcus, which correspond to Remak's, Ludwig's and Bidder's ganglia respectively, while Aschoff (1909) considered that the ganglia lying on the superior vena cava corresponded to Remak's ganglion, and those which lie on the dorsal wall of the atrium and near the A.V. node to Ludwig's ganglion; and those which lay on the base of the aorta and the pulmonary artery corresponded to Bidder's ganglion. The present authors noted, as also did McFarland & Anders (1913), the small size and disseminated character of the ganglia in the human and the mammalian heart. The latter authors made numerous attempts to find the homologues of Remak's ganglion in the inter-auricular groove, and of Bidder's ganglion in the interventricular groove at the A.V. junction with little success.

The ganglia in the human and mammalian atria are much more diffusely arranged than are those of the frog, and, as Perman (1924) and others have described, the ganglia are mostly in the subpericardial nerve plexus. Francillon (1928) was more definite than Perman, and considered that they compared as follows for the human: the ganglion of Remak in the frog corresponds to the ganglia in the region of the sulcus terminalis and on the wall of the left atrium. Ludwig's ganglion consists of the ganglia in the region of the aorta and the pulmonary artery and in the commencement of the coronary plexus and in the coronary sulcus. Considering the manner in which the cardiac nerves spread out over the heart it would seem to be impossible to identify ganglia in the frog with those in the human.

As the cardiac nerves, sympathetic and vagus, form a plexus with one another, it has long been a question as to whether some ganglia might be mixed, or exclusively either vagus or sympathetic in their connections. It has often been stated that the S.A. node is innervated by the vagus, and the A.V. node by the sympathetic, following the work of Marchand & Meyer (1912), and attempts have been made by various workers to reach a decision on this point. Woollard (1926) found no change in the cells after removing the stellate ganglion and, therefore, believed that all cardiac nerve cells belong to the para-sympathetic system. Degeneration studies have also been made by Soler (1953, 1954, 1956) and from these he concluded that the ganglia of one or other side of the heart receive connexions from the vagus and sympathetic of both sides. Soler (1956) and Corzo (1956) described two types of ganglia according to the staining of the cells with silver. The darkly stained ganglia they called argentophil, while the others which were pale with silver staining they designated argentophobes. Although the difference in staining of individual cells with silver was noted by the present authors, it was usually found that the ganglia were mixed and contained both types of cell. Corzo noted after degeneration studies following unilateral and double vagectomy and stellectomy in the cat that the argentophil type of ganglia was connected with the parasympathetic system, while the argentophobe type was connected with the sympathetic. In the present work, the ganglia contained cells of different types, and it appeared to the authors that the pale staining large cells in their sections were equivalent to Corzo's argentophobe type of cell, and that they closely resembled the large cells of the posterior root ganglia. They conclude that ganglia are generally connected to both vagus and sympathetic, and that they contain both sympathetic and parasympathetic elements.

A number of earlier authors observed differences in the nerve cells in the atrial ganglia from those in the ventricles. Vignal (1881) found unipolar cells in the ventricles and multipolar cells in the atria in the cat, dog, sheep, guinea-pig and man, whereas in the rabbit he noted ganglia in the atria with both types of cell, but in the ventricles they were exclusively unipolar cells with one nucleus.

Davies *et al.* (1952), in the ventricles of Artiodactyla and Cetacea, found that the epicardial nerve cells were mostly bipolar and unipolar. In the atria, in the present series, most of the nerve cells in the epicardial ganglia are multipolar, and this also applies to ganglia elsewhere in the atria. The same appearances of bipolar and unipolar cells observed by the above authors were noted in the present work, although in the atria these cells are rather rare, a point of distinction from the ganglia which they described in the ventricles.

Earlier workers distinguished the types of ganglion cells by their shape, number and type of processes, and the number of nuclei. In the present studies no cells with double nuclei were found, such as were described by Ranvier (1875) in his type 1, and Vignal (1881), Kasem-Beck (1884) in the rabbit, and by Kulesch (1901). Michailow, S. (1912) sometimes observed isolated ganglion cells with two nuclei in rabbits, horses and apes; he considered that nuclei are single, rounded or regularly oval in the majority of cases. Cells which appeared to be in process of division as described by Michailow, S. (1912) were not seen by the present authors.

Kasem-Beck (1884), in the rabbit, maintained that cardiac nerve cells had an oval form with only one process. His, Jr. (1891), in the hearts of embryos, observed that the nerve cells had only one process; it is to be noted however that these were young embryos and the nerve cells would be in the neuroblast stage. Berkley (1893), in the mouse and the rat, found the nerve cells to be of medium size, both bipolar and multipolar. The processes of the cell were not always limited to two, but he considered them all as bipolar cells. Jacques (1894), in rats, mice and other small mammals, was of the opinion that the majority of cells were multipolar, but some bipolar cells occurred and, rarely, a cell with one process which branched. All the cell types lay in one and the same ganglion. Schmidt (1897), in the mouse and rabbit, never saw bipolar cells, considering such appearances as simple varicosities. He found multipolar nerve cells in the myocardium of the atrium and ventricle with an axis cylinder going to the nerve stems. Noc (1899) considered that cardiac ganglia comprised a varying number of multipolar and unipolar cells, and that their structure was almost identical with the nerve cells of the spinal cord.

Lissauer (1909) described the ganglion cells as very large, round, oval or pear-shaped, with a cytoplasm which was faintly granular, and containing one or two large round clear nuclei, and dark nucleoli, of which there were usually one, and often two. He was only able to see a process in isolated cells. Cells with two nuclei were also seen by Michailow, S. (1912) and Michailow, M. (1898–9), but such cells were not found in this work although many nuclei have a shallow transverse groove, which gives the appearance of a dividing or a double nucleus. This could not be a stage in normal mitosis, because the nuclear membrane is still intact. It was possible to find only occasionally in this study fenestrated cells, as described by Michailow, S. (1912), but many nerve cells contained pigment as he observed.

With the staining technique used by the present authors, by which the shape and details of the body of the cell and the nucleus can be seen, and the processes distinguished with varying degrees of sharpness, the latter are not seen as clearly as in the studies of Dogiel (1899) and Michailow (1912) with methylene blue. On this account it is difficult to identify the former's three cell types and the latter's five types with the four types observed in this study (Pl. 2, figs. 12, 13). Both Dogiel and Michailow distinguished their cells mainly by the number and types of processes. Dogiel's type 1 cell had up to sixteen dendrons and one thick axon arising from a thick cone, which latter distinguished it from other types. The cell was round, oval or angular, and usually rather small, while Michailow's type 1, similarly round, oval or pear-shaped, had one thick axon and a number of thick dendrons. These cells resemble the types of large and small pale cells observed by the present authors (Pl. 2, figs. 12, 13), which usually have one thick process and a large and variable number of small processes, but it is not possible to identify the axon with certainty. Many cells, as in Pl. 2, fig. 11, have a number of processes all of equal diameter. Michailow's type 2 is similar, but has two kinds of dendrons, namely two to nine club-shaped ones and one to four flattened dendrons with condensed endings. Cells with dendrons of this type have not been found in this study, possibly because the processes could not be followed to their termination. Dogiel's type 2 and Michailow's type 3 are both similar to the dark cells, both large and small, and also include the dark fusiform and bipolar cells of the present study (Pl. 1, fig. 5). Both the above authors described unipolar cells in this group, but from the descriptions they appear to be pseudo-unipolar because the single process gave off the axon (described by Michailow as a thin flattened thread) and so are similar to the rather rare pseudo-unipolar cells in the present study (Pl. 2, fig. 13*a*).

Wilson (1909), in the calf and sheep, found three types of cells, unipolar, bipolar and multipolar. Woollard (1926) confirmed the findings of Dogiel (1899) and Michailow (1912). De Castro (1932), in the human heart, found cells of three types described according to the lengths of their processes, short, long and intermediate. Okamura (1929) found two types: large cells which were always multipolar; and small cells which were almost always spindle-shaped, and occurred in the plexus surrounding the muscle fibres. Blair & Davies (1935) described two types of cell in the calf and human: a larger type, with rounded form and finely stippled cytoplasm, which is pale yellow with silver; and a smaller, rather angular cell, staining darkly with silver and having a darkly staining nucleus. Similar types of cells, which were pale and dark both with silver and with haematoxylin and eosin, were noted by the present authors and form the main types seen (Pl. 2, fig. 12).

Glomset & Birge (1945) described two types of ganglia in the sulcus terminalis in man. Of these the larger groups consisted of large cells and were associated with the entering vagi, while the other groups, made up of smaller cells, were found some distance from the nerves. They observed these two types of cells in every species examined.

Walls (1942, 1943), in the hedgehog and the golden hamster, found only one type of cell, which was large and round with fine granular cytoplasm, and no cells corresponding to the second ganglion type of Kiss (1932). In the present study, however, the hedgehog heart exhibited the same types of cell as were noted in the other hearts, including cells resembling those described by Kiss in spinal ganglia. Walls (1943) also found, in association with the nerve cells in the ganglia, clumps of small dark cells which, in size and general appearance, were very similar to small lymphocytes. These cells have been observed in some of the ganglia by the present authors and it is considered that they are definitely lymphocytes, possibly indicating some focus of infection. It is interesting to note that Pančenko (1940*a*, *b*), in the lumbar ganglia, found a constant infiltration of lymphocyte cells after sympathectomy.

Many of the earlier workers made their cell descriptions from the study of embryos, and according to some recent work the discrepancies in the descriptions of cardiac nerve cells can partly be explained by age changes after birth. Walls (1947) found that at no time before birth are there two cell types in the cardiac ganglia of the human, as in the adult. The single type of the foetus corresponds to type 1 cell of Blair & Davies (1935). Lasowsky (1930) found that the cardiac nerve cells of the newborn have few processes and resemble the neuroblast type. Between the predominating mass of small, undifferentiated cells, this author observed some larger nerve cells with numerous processes. Hermann (1949) examined a series of human hearts from foetal life up to old age. He found an appearance similar to that of Lasowsky (1930) in the newborn, and observed that the change up to adult life consisted in an increase in size of the nerve cell body, and a gradually increasing complexity of the nerve processes. Conti (1948) demonstrated that the nerve ganglion cells of the heart of man are subject, during a long period of life, to a continual remodelling of their shape, which is shown visibly by an increase in volume of the pyrenophore, by a luxuriant growth of the dendritic apparatus, and also by the appearance of paraphytes. Although a similar study has not been made in mammalian hearts, it would appear likely that changes similar to the above described ones, but probably occurring at a faster rate, would be found. However, it was not observed by the present authors that the cells of the ganglia in the calf showed any marked difference from those of the adult cow. On the other hand, the ganglion cells of the infant human heart seem to be rounder, and less obviously multipolar than those of the adult human. Such growth changes must, therefore, be borne in mind in any description of the cardiac nerve cells. In the present study, in those Orders in which the main heart sections were obtained from a young animal, such as the puppy, comparisons have been made with sections from adult hearts.

The functions of the cardiac ganglia have naturally aroused considerable speculation among various workers. Soler (1953, 1954, 1956), for example, from his degeneration studies has concluded that the ganglia have both afferent and efferent connexions with the vagus and sympathetic. The functions of the different types of cardiac nerve cells have been thoroughly discussed by Davies *et al.* (1952), who on purely morphological grounds suggested that the multipolar ventricular nerve cells might be efferent, and the bipolar and unipolar cells afferent in function. They noted similar types of nerve cells in the atria and made the same suggestion for them. From observations in the present study it would appear that these authors noted a larger proportion of unipolar and bipolar cells in the ventricular ganglia than were seen in the atria in this series. However, it was only in Artiodactyla and Cetacea that they saw numerous ganglia in the ventricles. Other animals, not having these ventricular ganglia, must supply their ventricles from ganglia in the atria, and it is felt, therefore, that many of these, observed by the present authors in the atrio-ventricular groove would have this function, as also would many of the large number accompanying the coronary sinus. It would be expected, therefore, that in animals without ventricular ganglia, those in the lower part of the atrium would have the composition observed by Davies *et al.* in ventricular ganglia in Artiodactyla, that is, a greater proportion of unipolar and bipolar cells. It was not possible, however, for the present authors to confirm any such difference in constitution of the lower, as compared with that of the upper atrial ganglia. In any case, as the cardiac ganglia are mainly concerned with a nerve supply either afferent or efferent to the cardiac muscle and its blood vessels, the much larger volume of these tissues in the ventricles would necessarily demand a much greater proportion of the total available nerve supply. Probably, therefore, many of the atrial ganglia must supply the ventricles, others would be expected to supply the conducting system and the nodes, and the atrial muscle, while, of the remainder, some must be distributed to the venae cavae and the coronary blood system, including the sinus. To elucidate the problem of the connexions and distribution of the ganglia it would be necessary to trace all the nerve fibres from them to their destination. This presents great technical difficulties, but with a more accurate knowledge of the topography of the nerve ganglia such work may be possible in the future, especially with improvements in surgical techniques.

SUMMARY

1. Hearts from animals of a large number of Orders of mammals have been examined by histological methods, the hearts being sectioned as a whole transversely. A number of different staining methods have been used.

2. The positions of the intrinsic ganglia were plotted on to a standardized diagram for each heart, and a number of ganglion fields described.

3. The ganglia in the epicardium are found regularly in certain situations, namely, round the opening of the superior vena cava (right pre-caval vein) in the inter-atrial groove, mainly the dorsal part; the upper part of the left atrium; and a continuous chain accompanying the oblique vein of the left atrium or left pre-caval vein and the whole length of the coronary sinus. A few ganglia are found near the pulmonary veins and the inferior vena cava, on the ventral surface of the left atrium, and occasional ones on the ventral and dorsal surfaces of the right atrium. With few exceptions ganglia are never found on the auricular appendages. Ganglia are also found regularly in varying numbers within the interatrial septum, in most hearts among the myocardial fibres, and very rarely in the subendocardium.

4. Ganglia are associated with the conducting system. In all hearts they are found near both nodes and the bundle. Nerve cells have only rarely been observed within the specialized tissue of either the sinu-atrial or the atrioventricular nodes.

5. Differences in the distribution of ganglia between members of one Order and another, and individual variation within the same Order are noted.

6. The structure of the ganglia is described, and a number of different cell types have been distinguished. These are pale and dark cells, both large and small, and fusiform cells. The majority of cells are multipolar, but some bipolar cells are found and a few recognizable pseudo-unipolar cells.

7. The discrepancies in the earlier results have been discussed. An identification of the ganglia of Remak, Ludwig and Bidder with those in the mammal and man is considered to be practically impossible owing to their diffuse arrangement in these groups of animals.

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EXPLANATION OF PLATES

Plate 1

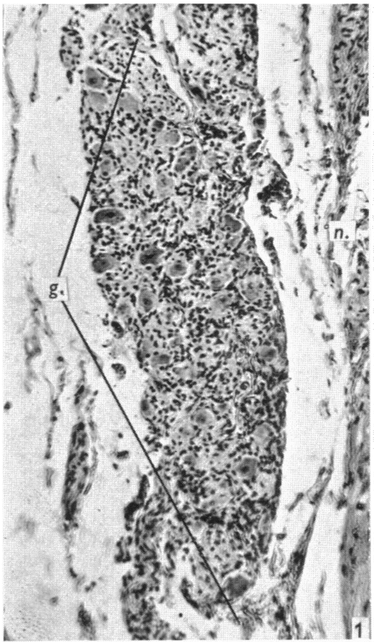
Fig. 1. Subepicardial ganglion (*g.*) beside sinu-atrial node (*n.*), in rhesus monkey. H. & E., ×88.
Fig. 2. Subendocardial ganglion (*a.*). Infant human. Silver, ×200. *end.* = endocardium.
Fig. 3. Ganglion (*g.*) at edge of atrio-ventricular node (*n.*) in porpoise. Van Gieson, ×120.
Fig. 4. Two single isolated nerve cells (*c.*). *Pteropus.* H. & E., ×510.
Fig. 5. Bipolar cell. Human. Silver, ×510.
Fig. 6. Pseudo-unipolar cell (*d.*) in calf. Silver, × 325.
Fig. 7. Intra-myocardial ganglion (*b.*) in dog. H. & E., ×220. *m.* = myocardial fibres.
Fig. 8. Ganglion (*g.*) beside sinu-atrial node (*n.*) in calf. Silver, ×132. *m* = ordinary atrial muscle.

Plate 2

Fig. 9. Part of very large ganglion in rhesus monkey. H. & E., ×120.
Fig. 10. Multipolar cell. Cat. Silver, ×510.
Fig. 11. Multipolar cell. Adult human. Silver, ×510.
Fig. 12. Ganglion showing dark staining and pale staining cells. *Pteropus.* (*c.*) capsular cells; (*d.*) large pale staining cell, (*e.*) dark angular cell; (*f.*) dark round cell; (*g.*) dark flattened cell. H. & E., ×510.
Fig. 13. Pseudo-unipolar cell (*a.*). Human. Silver, ×570. *b.* = small pale cell.
Fig. 14. Ganglion in sinu-atrial node (*n*). Human infant. Silver, ×510.

Plate 3

Fig. 15. Part of atrial ganglion of talpa. Cell (*a.*) gives the appearance of having two nuclei. H. & E., ×650.
Fig. 16. The same cell as in fig. 15 under oil immersion showing a single nucleus with a shallow groove at (*b.*). ×1400.
Fig. 17. Atrial ganglion of porpoise, showing narrow angular cells. Van Gieson, ×280.
Fig. 18. Cell from atrial ganglion of rhesus monkey showing nucleus with pointed processes (*c.*). A dark granule is seen in the centre of the nucleolus (*d.*). H. & E., ×1400.
Fig. 19. Atrial ganglion of rat, showing myelinated fibres (*e.*). Osmic preparation, ×570.



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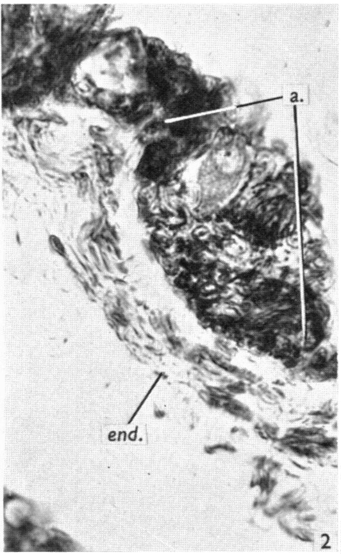

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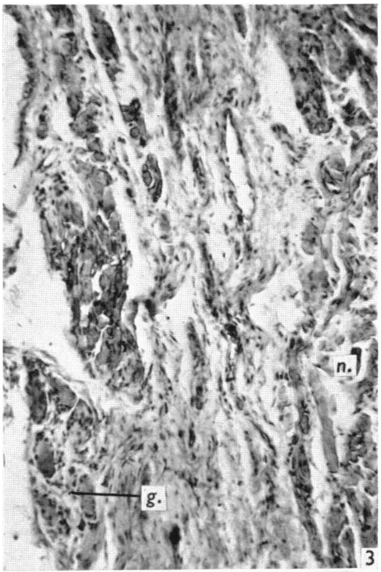

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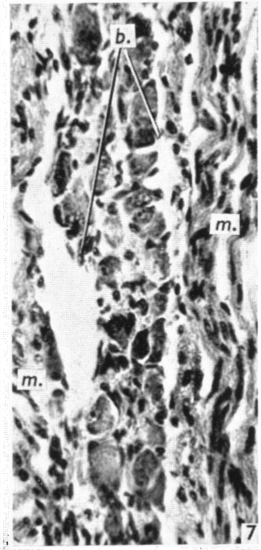

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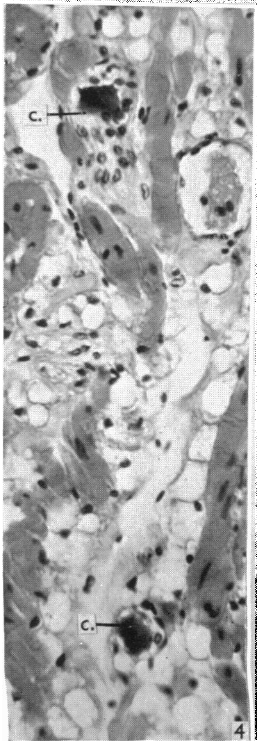

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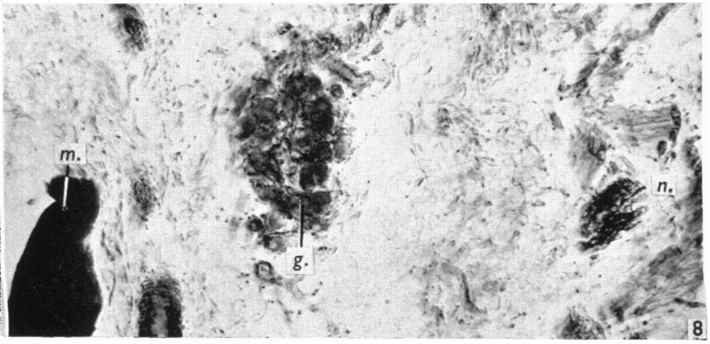

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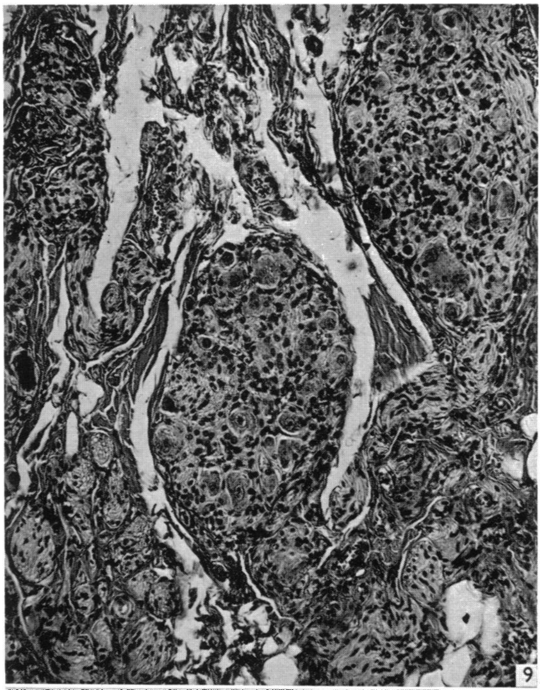
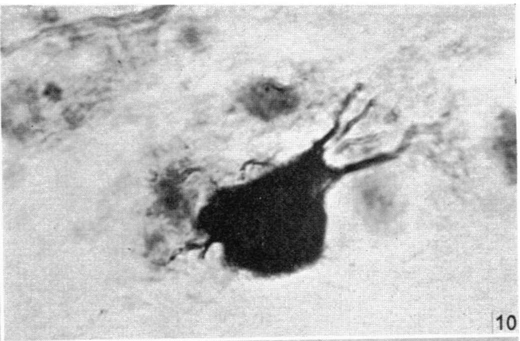
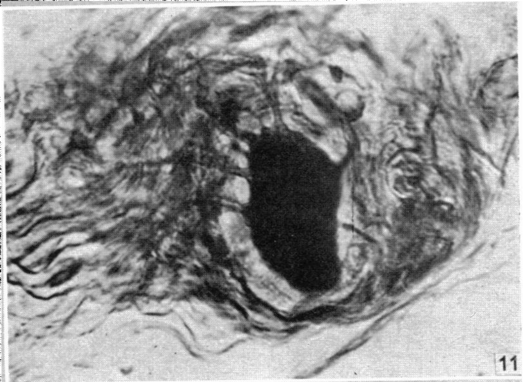
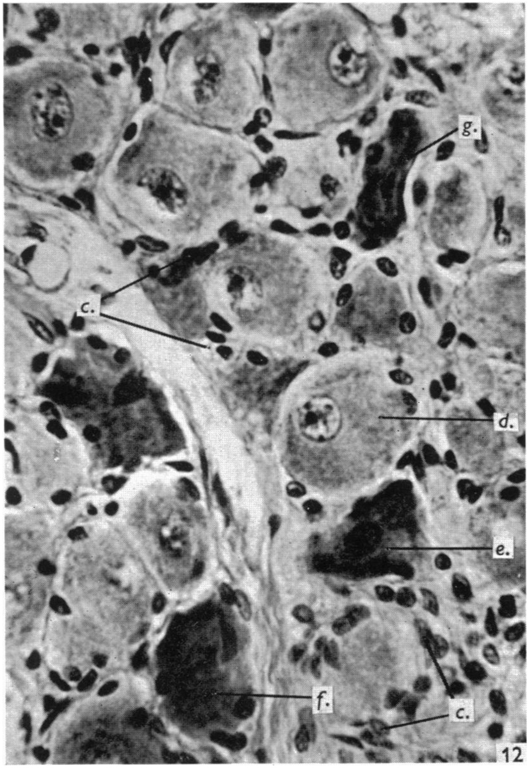
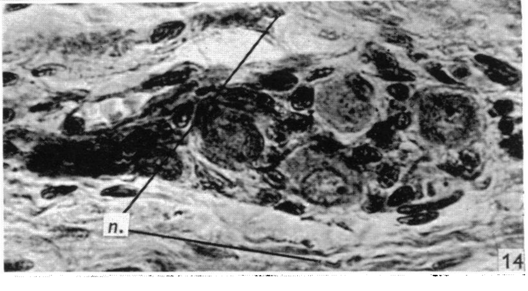
SUMMERFIELD KING AND COAKLEY—INTRINSIC NERVE CELLS OF CARDIAC ATRIA OF MAMMALS AND MAN











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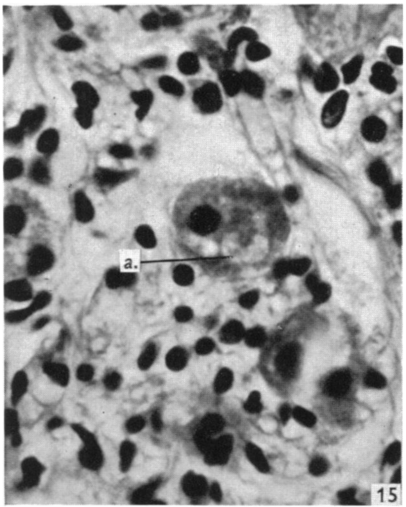

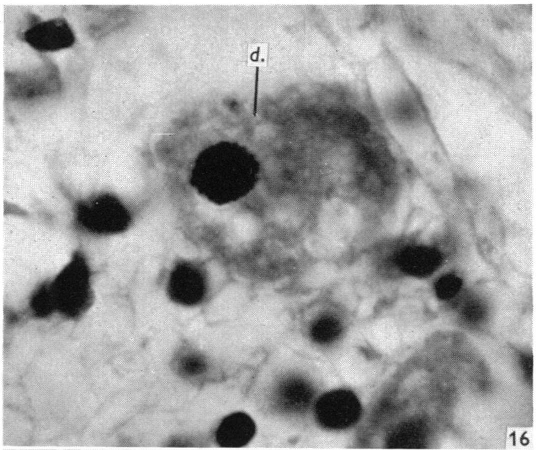

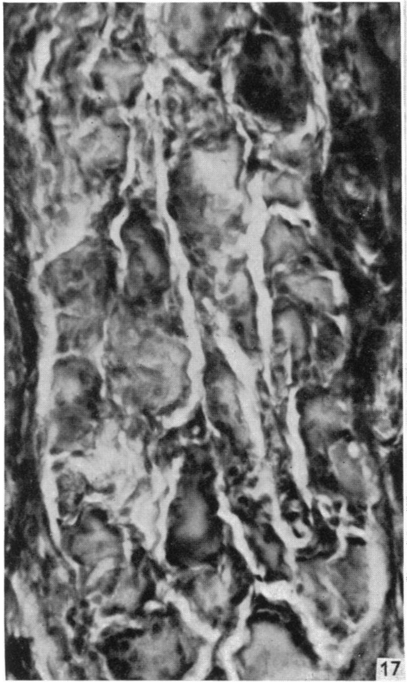

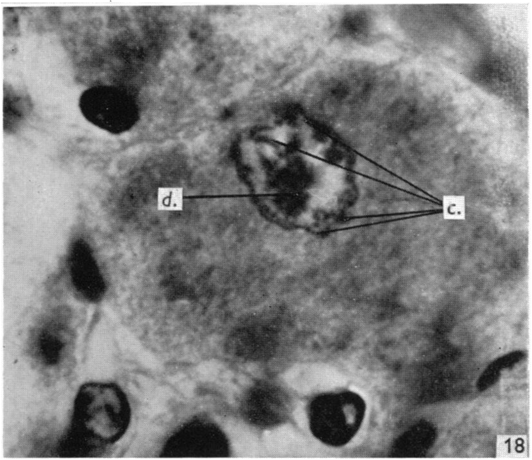

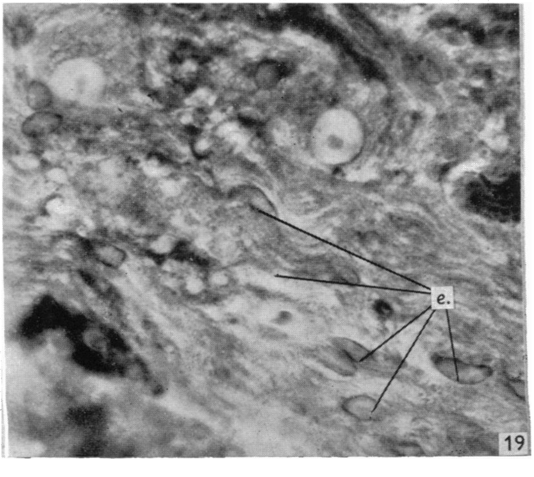

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