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The conducting system of the heart of the Harbour Porpoise (*Phocoena phocoena*, Linnaeus, 1758)

C. J. van Nie DVM

Vakgroep Anatomie & Biomechanica, Medische Faculteit, Vrije Universiteit, van der Boechorststraat 7, 1801 BT Amsterdam

Summary

The conducting system of the heart of the harbour porpoise (*Phocoena phocoena*, Linnaeus, 1758) is described macroscopically as well as microscopically. The topography and microscopy of this system in the harbour porpoise conforms to that of whales and hoofed animals. The proximal part of the common bundle and the basal parts of its branches lie not so deep to the endocardium as in the dolphin heart. Morphologically the relation between the system—especially the sinuatrial node—and the autonomous nervous system is striking.

Introduction

Mitchell & Patterson (1967: 383–384) define the conducting system of the heart as follows: 'This system is responsible both for the initiation of the contraction wave and for its transference from atria to ventricles. It includes: (1) the sinuatrial node, a strip of narrow, branching, transversely-striated muscle fibres, together with nerve cells and their processes, situated in the wall of the right atrium, adjacent to the orifice of the superior vena cava; (2) the atrioventricular node, of similar structure but not directly connected with (1), lying in the interatrial septum above the orifice of the coronary sinus; and (3) the atrioventricular bundle which is a slim fasciculus of specialized muscle fibres accompanied by small bundles of fine autonomous nerve fibres. It arises from the atrioventricular node and passes forwards into the interventricular septum, dividing in two branches, one for each ventricle. On reaching the ventricular walls each branch ends in an intricate subendocardial plexus of specialized 'Purkinje' muscle fibres. The contraction is started by the sinuatrial node, 'the pacemaker'.

The history, topography and microscopy of the system in the human heart is described by Schiebler & Doerr (1963), while the system in the hoofed mammals has been studied and reviewed by Meyling & Ter Borg (1957). A detailed comparative study of the system in mammalian hearts has been published by Nandy & Bourne (1963).

The conducting system of the heart in aquatic mammals has been studied by White & Kerr (1915–1917) for the sperm whale *Physeter macrocephalus* (L., 1758), by Sakata (1959) for the blue-white or striped dolphin *Stenella coeruleoalba* (Meyen, 1833), by van Nie (1983) for the common seal *Phoca vitulina* L., 1758 and by van Nie (1985) for the white-snouted dolphin *Lagenorhynchus albirostris* (Gray, 1846), while Truex & Smythe (1965) report about the Purkinje fibres in mammals in general, including the Cetacea.

The aim of this study is to describe the conducting system of the heart of the harbour porpoise *Phocoena phocoena* (L., 1758) and to compare the results of this study with those already recorded.

Materials and techniques

The hearts were obtained from ten adult harbour porpoises stranded on the Dutch beaches in the period May 1983 till June 1986.

The most important post-mortem findings were: skin-ulcers, lungworms, liverflukes, abscesses of the kidney and testis and fibrinous pleuritis.

After the dissection the hearts were rinsed first in tapwater and afterwards fixed in 4% formaldehyde for at least three months. Before the macroscopical preparation the hearts have been rinsed in 1% ammonium hydroxide (NH_4OH).

Macroscopical preparation was carried out with microsurgical instruments under a spotlight in five hearts.

From the base of the found topography of the conducting system, samples for histological processing have been taken from the other five hearts. The samples were cut in serial slices, 10 μ thick.

Since a histochemical processing of the samples was not practical due to the quality of the hearts, all slices were processed according to van Gieson and with haematoxilin-eosin.

Results

Macroscopical examination

The sinuatrial node (node of Keith-Flack) localized on the border between the right atrium and the

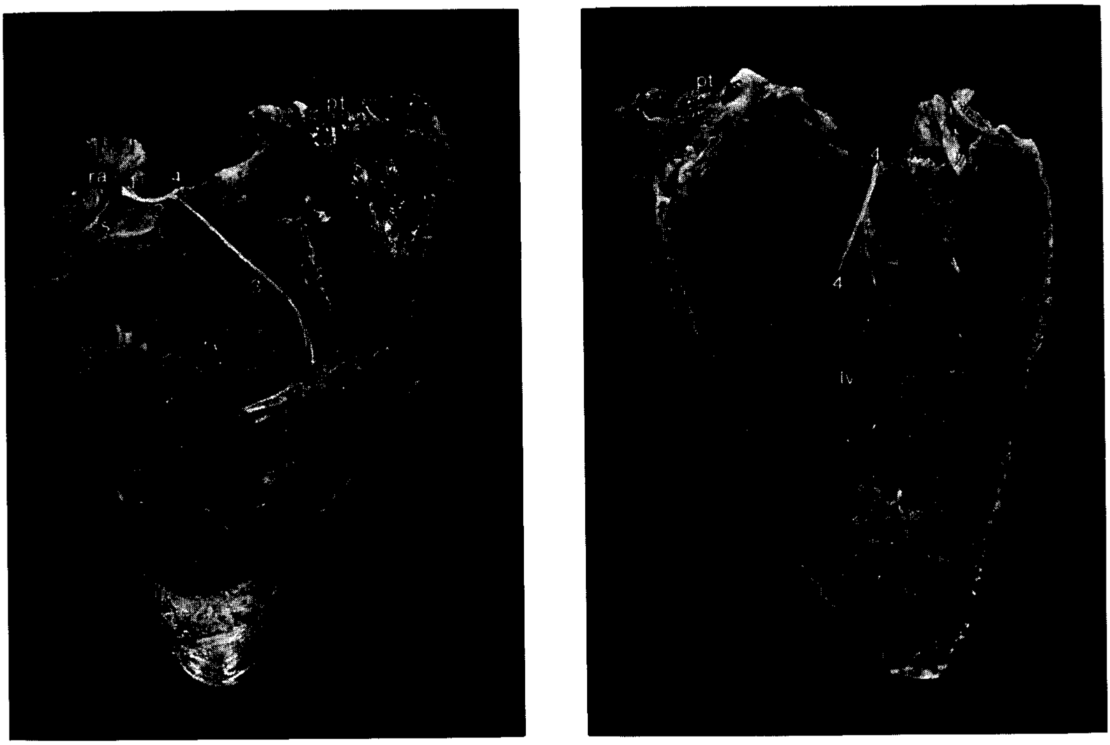

Figure 1. left (a) Photograph of the right side of the heart. right (b) Photograph of the left side of the heart. 1, Atrioventricular node. 2, Atrioventricular bundle. 3, Right bundle branch. 4, Left bundle branch. 5, Sinuatrial node fibres. 6, Ordinary atrial muscle fibres. 7, Ganglia cell. 8, Atrioventricular node fibres. 9, Ordinary ventricular muscle fibres. 10, Atrioventricular bundle fibres. 11, Loose connective tissue fibres. 12, Purkinje fibres. cs, Orifice coronary sinus. la, Left atrium. lv, Left ventricle. m, Moderator band. pt, Pulmonary trunk. ra, Right atrium. rv, Right ventricle.

cranial caval vein cannot be made visible macroscopically. Serial slices give some evidence for a crescent-shape structure of the node. A small artery and its branches—arteriolae—are present in and around the node.

The atrioventricular node (node of Tawara) (Fig. 1a) lies to the left cranial side of the coronary sinus opening, covered by a fine layer of muscle fibres. The long axis makes an oblique angle—about 45°—with the heart-skeleton. The distal part of the node is fan-shaped, while the proximal part continues in the atrioventricular bundle. The node is about 10 mm long and 0.5 mm thick.

The atrioventricular bundle (bundle of His) lies deep to the endocardium, in between the musculature of the basal part of the atrial septum. It runs in left distal direction to the fibrous heart-skeleton, in which it lies in a tunnel-like structure. At the end of the tunnel, on the basal part of the ventricular septum, the bundle divides into a left and a right branch. The bundle is 8–10 mm long, 1 mm thick and 1.8 mm wide (Fig. 1a).

The left bundle branch reaches the left side of the ventricular septum just below the non-coronary-artery cusp of the aortic ring. The proximal part lies about 1 mm sub-endocardial, covered by the sub-aortic muscle and the endocardium. It reaches the endocardium about 15 mm to its origin. The splitting up of its branches in subendocardial sub-branches and in the proximal parts of the Purkinje fibres is observable without further preparation (Fig. 1b).

The right bundle branch leaves the common bundle immediately distal to the branching-off point of the left one. This bundle is covered by a rather thick layer of muscle fibres. The bundle reaches its subendocardial position at the surface of the ventricular end of the moderator band and passes in this band to the right ventricular wall (Fig. 1a). Its splitting up into the Purkinje fibre-network in the subendocardial part of the wall can be observed.

The common bundle, its branches and the Purkinje fibre-network are enveloped in a delicate fibrous sheath.

Microscopical examination

The sinuatrial node consists of a dense network of slender, branching and light transversely-striated muscle fibres. The diameter of the central fibres

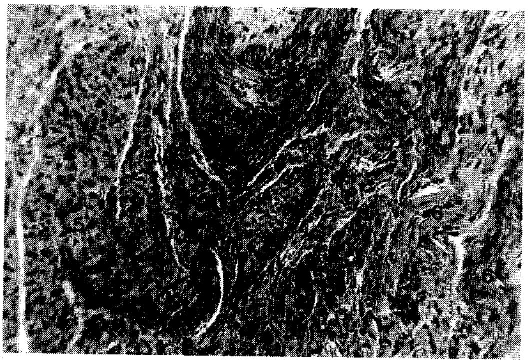

Figure 2. Sinuatrial node. Microscopical magnification × 120.

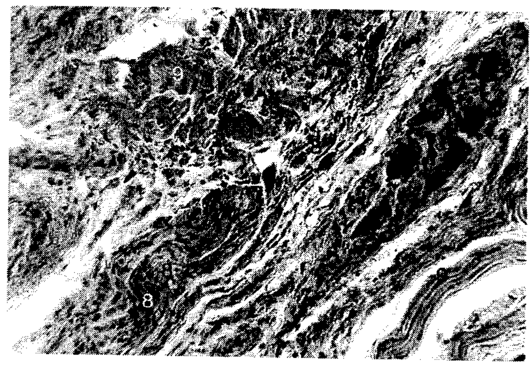

Figure 3. Atrioventricular node. Microscopical magnification × 120.

exceed not the half that of the ordinary atrial muscle fibres. Transitory fibres between sinuatrial node fibres and ordinary atrial muscle fibres are abundant. Fasciculi of nodal fibres are enveloped in a delicate fibrous sheath and so is the whole node. Autonomous nerve fibres and ganglia have been observed in the vicinity of the node (van Nie, 1986) (Fig. 2). An artery with its branches is present in the centre of the node.

The atrioventricular node consists of a loose network of nodal fibres. The diameter of these fibres is concurrent with the ordinary ventricular muscle fibres. A weak transverse striating of the nodal fibres may be observed. An intrinsic fibrous tissue network is present (Fig. 3). The fan-shaped distal end of the node displays the transitory fibres to the atrial muscle fibres, while the proximal end displays the transitory fibres to the atrioventricular bundle fibres.

The node is embedded in a loose fibrous tissue envelopment. Some autonomous ganglia and its fibres have been observed in the vicinity of the node.

Figure 4. Atrioventricular bundle. Microscopical magnification × 120.

The atrioventricular or common bundle. The fibres of this structure are elongated and display a longitudinal direction (Fig. 4). A transverse striated pattern is present. Their diameter exceeds that of the ordinary ventricular muscle fibres up to a maximum of twice. Two or three nuclei have been observed in these fibres. The bundle is enveloped in a fibrous sheath. Many nerve fibres are present in the vicinity of the bundle, while ganglia cells are absent. The atrioventricular bundle divides into a left and a right branch on top of the ventricular septum.

The microscopy of the left and right branches of the atrioventricular bundle resembles those of this structure. The size of the diameter of the fibres varies from a unit of one for the proximal ends to a factor of two for the distal ones. Transitory fibres to the Purkinje fibres have been observed too. The branch-, transitory- and Purkinje fibres are continuous and form one network of fibres. The fibrous sheath around the fibres manifests itself clearly. Accompanying autonomous nerve fibres are present too.

The Purkinje fibres consists of two or more rows of Purkinje-fibre-cells containing large sized nuclei embedded in an abundant cytoplasma, some cross-striation can be observed. The size of these cells is from twice to five times those of ordinary ventricular muscle fibres (Fig. 5). The fibres are enveloped in a delicate fibrous sheath, which is rich in autonomous nervous elements.

No bone or cartilaginous tissue has been observed in the heart-skeleton of the hearts studied.

Discussion

The observations concerning the conducting system in the heart of the harbour porpoises concur with the description by Meyling & Ter Borg (1957) in hoofed animals, by Sakata (1959) in the blue-white dolphin and by van Nie (1985) in the white-snouted dolphin.

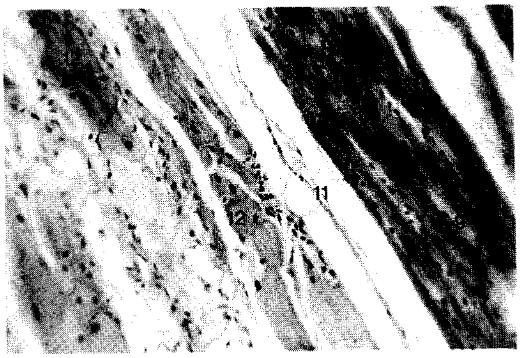

Figure 5. Purkinje fibres. Microscopical magnification ×120.

The localization of the common bundle and the proximal end of its branches is a little different to those of the dolphins, these structures lie not so deep to the endocardium in the harbour porpoises. This localization concurs with those in the common seal (van Nie, 1983).

The dense network of sinuatrial node fibres seem rather specific for the harbour porpoise. The abundance of ganglia in the vicinity of these nodes has been observed in other aquatic mammals too (van Nie, 1986).

The short common bundle in the harbour porpoise heart may be explained by the elliptical shape of the heart in contrast with round shape of the dolphin heart.

The Purkinje fibres resembles those of hoofed animals and the other whales (Truex & Smythe, 1965), however the vacuolization is not so clear.

The presence of autonomous nerve fibres in the vicinity of the nodal-, branch- and Purkinje-fibres have been observed by other mammals too (man: Mitchell & Patterson, 1967; pig: Wensing, 1964; spermwhale: White & Kerr, 1915–1917; common seal: van Nie, 1983 and dolphin: van Nie, 1985).

Conclusion

The conducting system of the heart of the harbour porpoise conforms with the same structure in the heart of hoofed animals and the whales. The abundance of ganglia and fibres of the autonomous nervous system in the vicinity of the sinuatrial node and that of fibres in the vicinity of the other parts of the conducting system is striking.

Acknowledgements

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