Aquatic Mammals 1989, **15.2**, 64–72

The heart of some small whales (A morphological and topographical approach)

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Summary

The general gross morphological features of the isolated heart of small whales are described, as well as the location of the hearts in the thoracic cavity. The influences of lung and liver pathology on the quantitative heart data is studied and discussed.

Introduction

Morphological studies of isolated mammalian hearts have to be restricted to anatomical descriptions. Measures derived from such hearts may be influenced by the unknown pathological status of the animal concerned. Cachexia as well as obesity, in an animal influences both body and heart weights. Linear measures of the heart are under control of the following pathological findings: Lungworm infestations, pneumonia, pericarditis, abscesses and worms in the liver, kidney diseases and strictures in vessels. Internal cardiac findings may be important too i.e.: Endocarditis, myocarditis, fibrous and muscular stenosis of the aortic and pulmonary orifices, congenital anomalies and aneurisms in the coronary vessels (Smith & Johnson, 1961 and Nieberle & Cohrs, 1952).

The sex of the animal has an influence on the heart data too (Rowlatt & Gaskin, 1975).

So a quantitative investigation of isolated hearts obtained from a random sample of material will reveal data with a great standard deviation (Ellenberger & Baum, 1915).

The way of sampling of the hearts is important too. So a dilated heart derived from a healthy but exhausted animal displays different quantitative data than a heart derived from a healthy stunned, slaughtered and well bled animal (authors observation in slaughterhouses, 1954–1968).

The mentioned considerations implicate that a quantitative morphological investigation in small whale hearts is extremely difficult to carry out. Nevertheless some authors have succeeded reasonably well (Slijper, 1936; Sakata, 1959 and Bisaillon *et al.*, 1987). The most detailed study was published by Rowlatt & Gaskin (1975). They described the hearts of two groups of Harbour Porpoises *Phocoena phocoena* (20 ♂♂ and 16 ♀♀) with a mean bodylength of 126 cm in males and 145,8 cm in females, both morphologically and quantitatively.

The topography of the heart in small whales was studied by Slijper (1973) during the morphological dissection of the fresh animal and by transverse sections of the frozen whole animal. Rowlatt & Gaskin (1975) examined the location of the heart in dead harbour porpoises before dissection, with the aid of radiology and after removal of the lateral wall of each pleural cavity including the lungs. They also used transverse sections taken from frozen bodies.

The location of the heart in dead animals is dependent on the age, the pathological status of the animal, the post-mortem approach, the state of the body—fresh or frozen—decomposition and damage by mechanical insults.

The location of the heart in animals alive is dependent on the position of the body, the filling of the intestines and the pathology of the organs including the heart (Gould, 1960).

None of the authors quoted refers to the above discussed conditions in their investigation of the quantitative data of the heart.

The aim of this paper is to present a morphological and topographical study of 24 hearts (14 hearts from female Harbour porpoises and 10 hearts from Dolphins) derived from small whales, dissected in the laboratory of the Museum van Natuurlijke Historie in Leiden or elsewhere.

Materials and techniques

Fourteen hearts of female Harbour Porpoises (*Phocoena phocoena*, L. 1758); four of white-beaked Dolphins (*Lagenorhynchus albirostris*, Gray, 1864); one of white-sided Dolphin (*Lagenorhynchus acutus*, Gray, 1828); three of common Dolphins (*Dephinus delphis*, L. 1785) and two of bottle-nose Dolphins (*Tursiops truncatus*, Montagu, 1821) have been used in this study (Tables 1 and 2).

The hearts were obtained from stranded animals as well as from animals died in captivity. The results of the post-mortem examination were available from

Table 1. Harbour porpoises ♀♀

Nr	Body length	Heart weight	Length s.i.p.	Length s.c.	Circumf. Ao	Circumf. t.p.	Parasites Lung	Parasites Liver	Parasites Stomach	Parasites Intest.	Par. Stat.	Others
1	93	60	7.5	14.0	4.2	4.0						open f.o. & d.a.
2	110	85	7.5	16.0	4.3	4.3						cachexia
3	118	100	9.0	14.0	4.5	5.5						
4	118	125	10.0	19.0	4.8	5.9						
5	120	150	11.0	20.0	5.6	6.5						
6	128	150	9.3	17.5	5.5	6.0						
7	137	170	11.0	15.0	6.0	7.0	R+					
8	142	180	10.5	22.0	6.0	6.2						abscesses
9	147	235	12.0	26.0	7.3	6.0	R+	F+			+/−	abscesses
10	159	250	12.0	26.0	6.0	5.6	R+++	F+++	R++	R++	+	endometritis
11	166	285	12.5	28.0	7.5	8.0	R+++	F+++	R+++	R++T+++	+	pneumonia
12	167	320	13.0	30.0	7.4	5.3	R++	F++			+	pneumonia
13	167	320	15.0	25.0	6.7	7.4	R+++		R+++		+	pneumonia, ulcers
14	168	380	11.0	20.0	8.5	7.5	R++	F++	R+++		+	pneumonia

Table 2. Dolphins

Nr & sex	Body length	Heart weight	Length s.i.p.	Length s.c.	Circumf. Ao	Circumf. t.p.	Lung	Stomach	Others
1 ♀	247	2350	22.0	54.0	11.0	12.0		R+	abscesses lungs and pharynx, cachexia
2 ♂	277	2800	26.0	66.0	13.5	15.0			
3 ♂	280	2525	23.0	64.0	12.0	16.0			
4 ♀	283	2800	29.0	65.0	14.0	16.0			
5 ♂		1300	21.0	46.0	12.0	10.0			
6 ♂	217	1550	16.0	38.0	7.3	7.3	R+		ulcers stomach, hydatid in pelvis
7		550	16.0	40.0	5.2	6.7			
8 ♀	234	1800	17.0	38.0	8.7	9.4			ulcers stomach, hydatid subperit.
9 ♂		80	7.5	17.0	5.5	4.8			open ductus arteriosus
10 ♂		90	7.0	17.0	4.5	5.0			open foramen ovale

1– 4 *L. albirostris*
5 *L. acutus*
6– 8 *D. delphis*
9–10 *T. truncatus*

s.i.p.: sulcus of interventricularis paraconalis
s.c.: sulcus coronarius
Ao.: Aorta
t.p.: pulmonary trunk
f.o.: foramen ovale
d.a.: ductus arteriosus

R = round worms
F = flukes
T = tape worms
+ = light infestation
+ + = moderate infestation
+ + + = heavy infestation

14 female Harbour Porpoises dissected by the author. The post-mortem reports concerning the Dolphins were mostly incomplete and so not as useful for a detailed study of the hearts.

The following data had been collected: from the whole animal the length and the sex; from the heart the weight in grams, the length in cm of: 1. the sulcus of interventricularis paraconalis (abridged: s.i.p.); 2. the sulcus coronarius (abridged: s.c.) and 3. the external circumference of the proximal part of the Aorta and the pulmonary trunk, immediately above the ring of the semilunar valves. These limited data have been chosen, because it is assumed that they are relatively independent from the pathological status of the animal.

Special attention is given to the external and internal morphology of the heart and to the general course of the coronary arteries.

The topography of the heart was studied after removing the left thoracic and abdominal wall in fresh as well as in frozen bodies. The location of the diaphragm remained undisturbed and was left with the left lung and its lobe in the left cupula pleurae.

The isolated hearts were rinsed and cleaned in tapwater and fixed in 4% formaldehyde for at least two months. They were rinsed in 1% NH_4OH for 12–24 hours before detailed examination in order to eliminate the free formaldehyde.

The Nomina Anatomica Veterinaria (N.A.V.) third edition 1983 is used.

Table 3.

Ratio width/length	oval shaped base of the heart	
Harbour porpoise	Rowlatt & Gaskin, 1975*	0.55
	v. Nie, this paper†	0.71
Dolphin	Sakata, 1959*	0.57
	v. Nie this paper†	0.71
Horse	Ellenberger & Baum, 1915**	0.61
Cattle	Montané & Bourdelle, 1917**	0.69
Pig	Montané & Bourdelle, 1920**	0.73

* Computed from the given data
** absolute values unknown, computed from the diagrams
† observed in two hearts of each species
Sakata (1959) and Rowlatt & Gaskin (1975) measured the maximum width and length of the heart; the other authors derived their data from the oval formed by the sulcus coronarius.

Results

1. General gross morphology

a. **External morphology**

The heart is conical or somewhat pyramidal in shape. The base is oval (Table 3) and formed by the atria and the origins of the great vessels. The border-line between the base and the ventricles is the sulcus coronarius. The long axis of the base lies in the cranial-caudal direction. This axis makes a sharp angle with the sagittal plane of the body (vide infra). The cranial limitation of the ventricular part of the heart is formed by the cranial wall of the right ventricle—margo ventricularis dexter—and so is the caudal limitation by a part of the wall of the left ventricle—margo ventricularis sinister.

The left side—facies auricularis—consists of the right (big) and left (small) auriculae, the left bow of the s.c., the origin of the pulmonary trunk and a triangle shaped muscular part located caudo-ventrally to the base. This muscular part is divided in two smaller parts by a deep sulcus—s.i.p. This sulcus starts caudal of the origin of the pulmonary trunk in the s.c. and ends cranially of the apex in the margo ventricularis dexter. The sulcus follows a line nearly parallel to the margo ventricularis sinister. The cranial located muscular part belongs to the wall of the right ventricle, the caudal part to that of the left one. So the apex of the muscular triangle is a part of the wall of the left ventricle.

The right side—facies atrialis—consists of the right and left atria proper with the openings of the pulmonary and caval veins, the sinus coronarius, the right bow of the s.c. and a triangle shaped muscular part located ventral to the base. Here too the muscular part is divided in two smaller parts by a sulcus—sulcus interventricularis subsinuosus. This sulcus makes a right angle with the s.c. The caudal part of the triangle including the apex belongs to the wall of the left ventricle and the cranial part to the right wall of the right ventricle.

The coronary arteries and their main branches and the veins course in the sulci, they are covered by fat tissue in animals in good condition. Myocardial bridges of the second grade have been observed in some dolphins.

Lymphatic vessels and nerves are present directly under the epicaridum.

The apex of the heart is well defined.

The coronary arteries display in all cases a right preponderance, so the right coronary artery drains the ramus interventricularis subsinuosus.

The coronary arteries are conducted by the coronary veins, the last ones open into the right atrium via the coronary sinus. Some tiny openings have been observed in the walls of the atria—openings of the venae cordis minimae.

The origin of the Aorta is located in the axis of the base, a little craniad of the origin of the pulmonary trunk.

The arcus aortae bends firstly somewhat to the right and then to the left to reach its location directly to the left of the sagittal plane of the body. a distinct bulbus aortae is not observed.

The origin of the pulmonary trunk is located to the left and somewhat caudad of that of the Aorta. The pulmonary trunk bends to the right, where it divides into its two branches. Before this partition the ligamentum arteriosum leaves the wall of the pulmonary trunk to reach the wall of the arcus aortae. This ligament is the former ductus arteriosus in prenatal and neonatal animals.

The caval veins follow, in their openings and preceding parts, those of the horse, cattle and pig. The thoracic part of the caudal caval vein is rather long.

This is caused by the topography of the heart (see location of the heart).

Four to six pulmonary veins open into the left atrium directly caudal to the atrial septum. A venous chamber is not observed.

The pericardium invests the heart and the stems of the Aorta and pulmonary trunk. It follows the general topography and histology of terrestrial mammals.

b. **Internal features of the heart**

The internal morphology of the heart of small whales follows the general characteristics of those in terrestrial mammals.

The right atrium and ventricle.

The sinus venarum cavarum is practically continuous with the right atrium proper. The tuberculum intervenosum is flattened. The walls of the caval veins are thin and membranous. The orifice of the coronary sinus is large. A valve has not been observed, in the opening of the caudal caval vein. The coronary sinus is guarded by a small crescent like valve.

The atrium proper consists of a small atrial part divided by a flat crista terminalis from a large auricula. The right side of the atrial septum is built from the septum proper and the limbus and fossa ovalis. This foramen was closed in adult animals and still open in neonatal ones.

The wall of the atrium proper displays a network of mm. pectinati, the last ones developed into heavy muscular trabeculae in the wall of the auricula. Openings of the venae cordis minimae may be observed in this wall too.

The base of the right atrium is formed by the right atrioventricular opening. This opening is oval shaped, and is guarded by the valva atrioventricularis dextra. This valve consists of three well defined triangular leaves. The septal leaf inserts along the septal bow of the orifice and so it is linked with the basal part of the moderator band. The other leaves insert along the cranial (left) bows. The leaves end in chordae tendineae, which are attached to the mm. papillares. The leaves may be subdivided into smaller ones.

The right ventricle is divided in two parts: The right ventricle proper and the right outflow tract—conus arteriosus. The parts are separated by the crista supraventricularis and the moderator band.

The wall of the right ventricle is built up by the parietal wall and the septum interventriculare. Besides the mm. papillares an intense network of trabeculae carneae is observed. This network makes the mm. papillares hardly distinguishable. Transverse coarsing fibrous strands are numerous.

The wall of the right outflow tract is smooth and nearly free from trabeculae. The conus proper is flat and basically somewhat curved. It ends in the pulmonary ring—the ostium trunci pulmonalis, which is guarded by a tricuspid semilunar valve—valva trunci pulmonalis.

The left atrium and ventricle.

The left atrium consists of the atrium proper and a relative great auricle. The septal wall is smooth except for the small part where it has fused with the valve of the foramen ovale.

Four to six pulmonary veins open directly in the atrium. The wall of these veins are fibrous and rather thin.

The opening to the auricle has a muscular aspect. The internal wall of the auricle is built up by trabeculae carneae and mm.pectinati.

The base of the left atrium consists of the left atrioventricular orifice, the oval shaped opening to the left ventricle. This opening is guarded by a bicuspid valve—valva atrioventricularis sinistra. The smaller one of the leaves is located craniad and covers the canalis aortae, it is connected with the aortic ring—ostium aortae. The other leaf finds its base in the caudal bow of the orifice. The slips of the leaves are attached via chordae tendineae to both the left and right mm. papillares.

The septal wall of the aortal ostium is smooth, a thin m. subaorticus is present. The pars membranacea is covered by this muscle.

The wall of the left ventricle is covered with a coarse network of trabeculae and free passing fibrous strands. The apical part of the ventricle is small conically shaped and here too trabeculae and fibrous strands are observed. The course of parts of the conducting system may be observed in the septal part of the left ventricular wall. The ostium aortae and its valve—valva aortae—are located in the base of the heart. The valve consists of three semilunar leaves. The commissures of the leaflets septalis and sinistra connect with those of the corresponding leaves of the valva trunci pulmonalis.

Note 1. The conducting system is described in: Lutra, 28, 106–112, 1985 for dolphins and in Aquatic Mammals, 14.2, 69–72, 1988 for harbour porpoises.

Note 2. The normal, as well as the abnormal course of the coronary arteries will be described later in this journal.

2. Data of the heart proper

a. The oval shaped base makes an angle of 30°–40° with horizontal plane through the sternum.
b. The ratio width/length of the oval base is 0.71 both in harbour porpoises and in dolphins (Table 3).
c. The height of the left ventricle is equal to the length of the s.i.p..
d. The s.i.p. makes an angle of 50° with the margo cranialis.
e. The ratio $\frac{1}{2}$ length s.c./length s.i.p. is 0.96 in harbour porpoises and 1.20 in dolphins (Table 4).

Table 4.

a. Ratio $\frac{\frac{1}{2}\text{ length sulcus coronarius}}{\text{length sulcus interventricularis paraconalis}}$			
Harbour porpoise	0	v. Nie this paper	0.96
Dolphin	0 & 0	v. Nie this paper	1.20
b. Ratio $\frac{\text{length heart width}}{\text{length of the heart}}$			
Harbour porpoise	0	Rowlatt & Gaskin, 1975	0.85
	0	id. id.	0.87
Dolphin	0	Sakata, 1959	1.00
	0	id.	1.06
Horse		Ellenberger & Baum, 1915	0.97
Cattle		Montané & Bourdelle, 1917	0.98
Pig		Montané & Bourdelle, 1920	1.00

f. The aortal ring is located to the right and craniad to the pulmonary ring at the crossing of both sagittal planes.
g. The vertical plane through the centres of both rings makes an angle of 55°–60° with the sagittal plane of the body.
h. The planes through the origins of the great vessels make an angle of 150° with each other.

3. Location of the heart

a. The apex of the heart is located somewhat to the left of the sagittal plane of the body and close to the cranial/ventral border of the diaphragm.
b. The sagittal plane through the long axis of the oval shaped base makes a sharp angle of 20°–25° with the sagittal plane of the body.
c. The margo cranialis follows the course of the internal surface of the sternum.

4. Some data of the heart in relation to the length of the body.

(These data are restricted to the data acquired from female harbour porpoises).

a. Ration heartweight/bodylength (Figure 1).
b. Ratio length sulcus interventricularis paraconalis/bodylength (Figure 2).
c. Ratio length sulcus coronarius/bodylength (Figure 3)
d. Ratio length external circumference aortic ring/bodylength and length external circumference truncus pulmonary ring/bodylength (Figure 4).

Comment

The general external and internal features of the hearts concerned derived from the small whales (Table 1 and 2) concur in broad outline with those of terrestrial mammals, i.e. horses, cattle, pigs and dogs. They concur too with the earlier described hearts from harbour porpoises (Slijper, 1936, 1958, 1973 and Rowlatt & Gaskin, 1975) and from dolphins (Slijper, 1936, 1958, 1973 and Sakata, 1959), while they differ from those in the Beluga whale (Bisaillon *et al.*, 1987) in the Sperm whale (White & Kerr, 1915–17 and Truex *et al.*, 1961) and in the Sei and Grey whale (Truex *et al.*, 1961).

The presented data from the harbour porpoise heart represent a group of female porpoises with a bodylength of 93 to 168 cm. The first severe infestation with lung- and liver parasites was observed in an animal with a bodylength of 159 cm. Rowlatt & Gaskin (1975) described female porpoises with bodylengths of 128.1 cm to 163.5 cm. They did not mention lung- and liver pathology, so one might expect, that they described young and young adult animals only.

The small amount of the previous described hearts without lung- and liver pathology make a statistical analysis of the presentated data unrealistic. However the ratio heart weight/bodylength in 14 female porpoises (Figure 1) give some evidence for a stable relationship between both data until a bodylength of 159 cm is reached. This bodylength concurs with the first severe infestation with lung- and liver parasites (vide supra).

The location of the heart in small whales

The descriptions of the location of the heart in the thoracic cavity in small whales seem rather controversial in the leading literature. Slijper (1973) observed a horizontal location in dissected animals as well as in frozen transversal sections, while Rowlatt & Gaskin (1975) described a somewhat vertical position observed during radiography in whole porpoises and during examination of these animals after removal of the lateral wall and the lungs and in one frozen transverse section. The present author examined the location of the heart after removal of

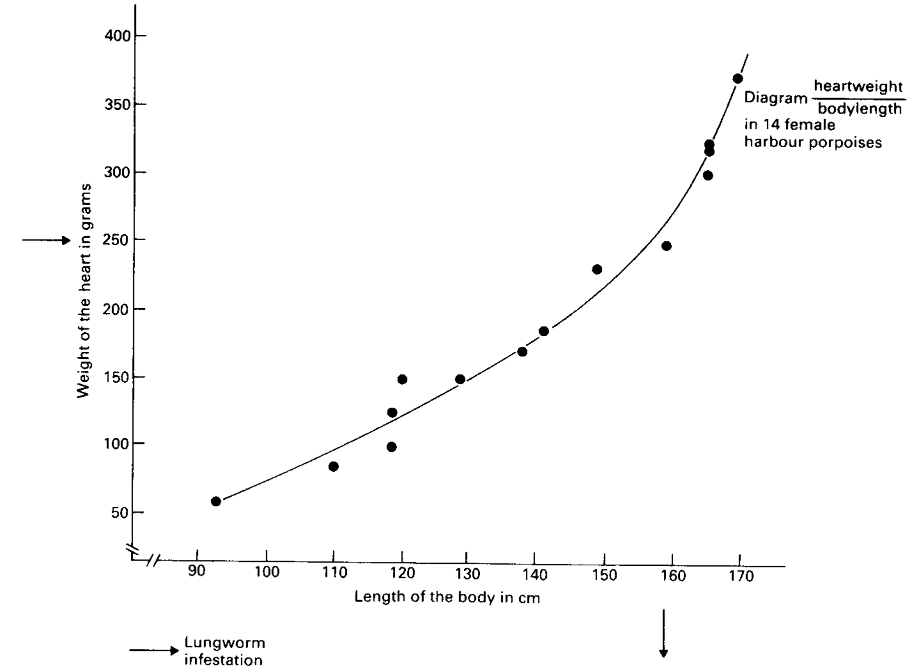

Figure 1.

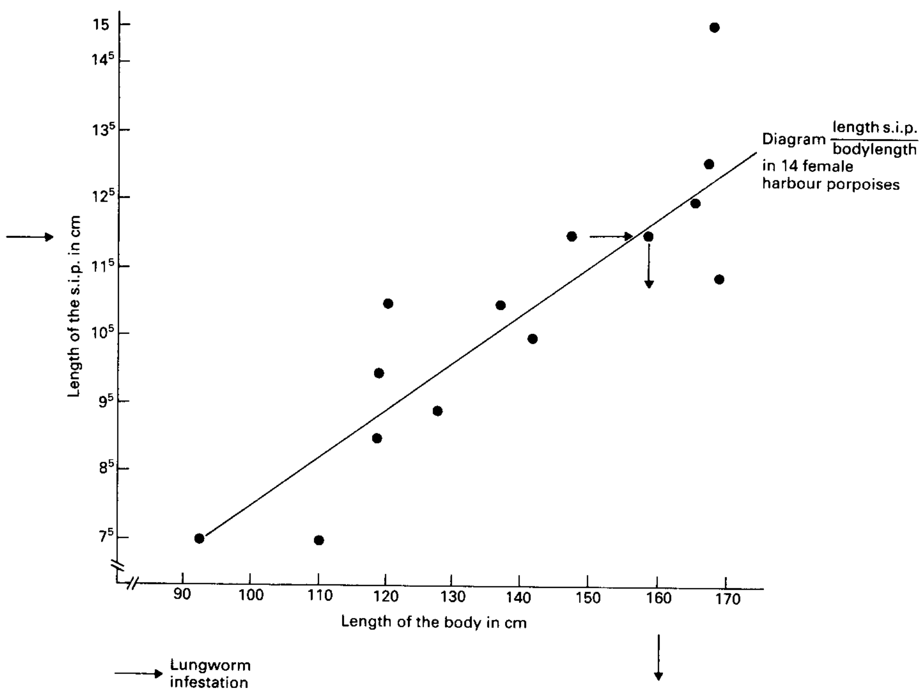

Figure 2.

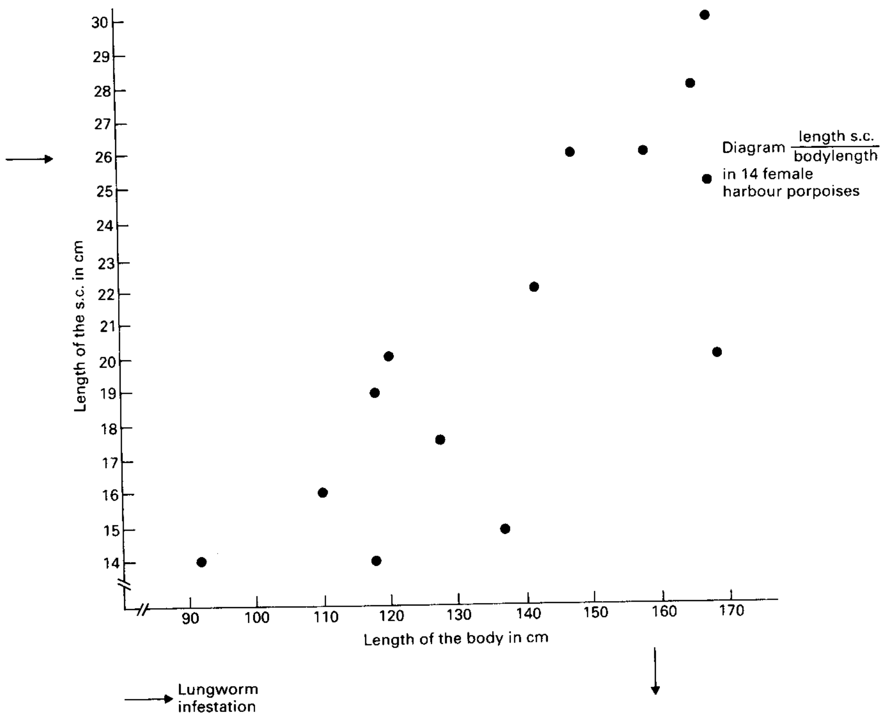

Figure 3.

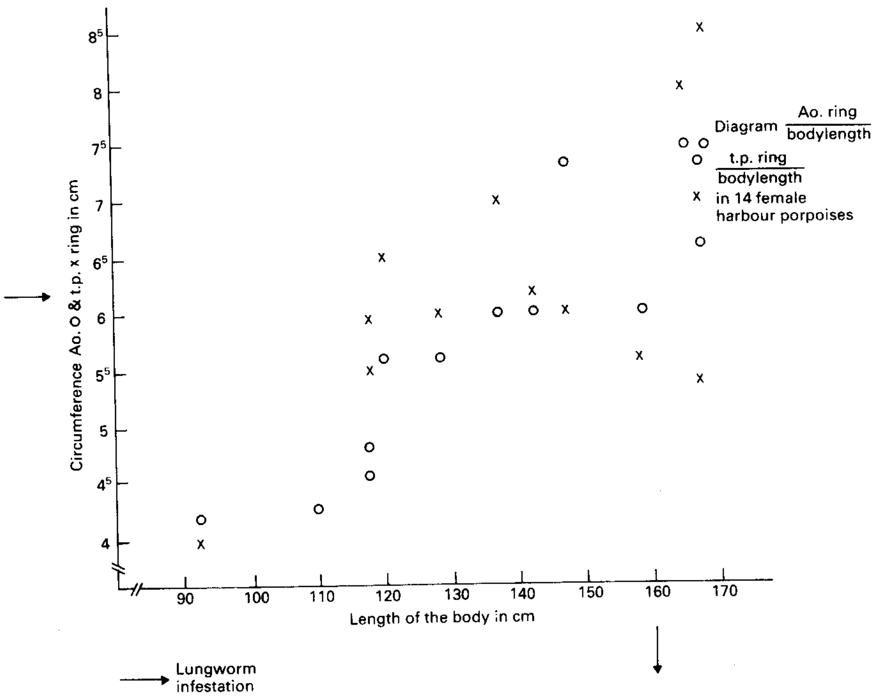

Figure 4.

the left thoracic and abdominal wall in fresh and defrosted bodies. His observations concur broadly with those recorded in the mentioned literature. The cranial border of the heart (margo cranialis) lies parallel with the thoracic side of the sternum.

The difference in the observations of the leading authors can be reduced to a difference in the definition of the horizontal plane in the animal.

Slijper (1973) considers the straight line through the sternum as the horizontal bodyline, while Rowlatt & Gaskin (1975) relate the location of the heart to a horizontal plane, which makes a right angle with the sagittal plane of the body. So the presented data concerning the location of the heart and those recorded in the literature mentioned don't differ importantly. The controversial descriptions may be due to a different approach of the morphology and its terminology. And so it is with some other data mentioned in this paper (vide supra) which seems not concurring with those of Rowlatt & Gaskin (1975). The last ones used the terminology introduced by Walmsley, 1929.

The ratio length sulcus interventricularis paraconalis/bodylength is within small limits rather stable, so the length of the sulcus seems independent from lung- and liver pathology (Figure 2).

The ratio's length sulcus coronarius/bodylength (Figure 3) and length of the external circumference of the Aorta and pulmonary trunk/bodylength (Figure 4) display great variation. An influence from lung- and liver pathology could not be concluded, nor a relationship with the bodylength in young animals.

The ratio half the length of the sulcus coronarius/ length of the sulcus interventricularis paraconalis (Table 4) varies too, however there is a tendency, that this ratio follows the ratio heartweight/bodylength (combination Figures 2 and 3). The length of the sulcus coronarius increases by the progressing of the lung- and liver pathology and so the axis of the facies auricularis decreases from long in young animals to short in adult infected animals.

The mentioned ratios make it reasonable to accept the influence of lung- and liver pathology on the quatitative morphological data of the heart of small whales. General observations concerning these influences in terrestrial mammals have been recorded already (see introduction).

The physiological implications of the observed morphology and location of the heart of small whales are rather difficult to trace. The arguments concerning the different quantitative functions of the right and left ventricles given by Rowlatt and Gaskin (1975) are disputable, while after the closure of the foramen ovale and the ductus arteriosus the lung- and body circulation is reconstructed in one closed circulation. So the same amount of blood courses in the same time interval through both parts of the circulation. The observations of these authors may be right in young animals with an open foramen ovale and open ductus arteriosus and in cases with great anterio-venal anastomes (up till now this has not been observed in healthy mammals). In terrestrial young mammals the thickness of the wall of the right ventricle approximates that of the left one.

A comparative quantitative study of the moment of closure of the foramen ovale and ductus arteriosus and the development of the wall of the ventricles will inform the interested student further about this subject.

Note: Rowlatt & Gaskin (1975) (pg 480 & 481, Table 1 and 2) recorded data concerning the *diameter* of the aortal and pulmonary ring and those of both atrioventricular openings. The mean values of these data are extremely high. The values are like those of the circumferences of these structures—the aortal pulmonary trunk orifices—in the present paper. It seems, that they had been using the diameter instead of the circumference.

Conclusion

The general gross morphological features of the isolated heart of small whales don't differ widely from those of terrestrial mammals.

The horizontal location of the cranial margin of the heart of small whales is related to the topography of the sternum.

Quantitative data as heartweight and thickness of the ventricular walls are dependent on the occurrence of lung- and liver pathology. Other data as length of the sulcus interventricularis paraconalis have a more or less independent character.

Acknowledgements

The author is grateful to Dr C. Smeenk and his technical staff of the Museum van Natuurlijke Historie in Leiden for providing the animals and supporting the examinations; to Prof. Dr J. Hoorens, veterinary pathologist, Veterinary Faculty, Gent and Ir. R. Duyndam and his fellow members of the Vlaamse Vereniging voor Bestudering van Zeezoogdieren, Puurs-Ruisbroeck and to Prof. P. Zwart, veterinary pathologist, Veterinary Faculty Utrecht; they provided some of the isolated hearts.

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