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The closure of the foramen ovale and the ductus ateriosus in the Common Seal (*Phoca vitulina*, L. 1758). (A morphological approach)

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Summary

Ninety-four hearts and arterial stem-vessels of the Common Seal (*Phoca vitulina*, L. 1758) have been examined for the anatomical closure of the foramen ovale and the ductus arteriosus. The results corroborate Slijper's investigations (1961) in 20 seals.

The anatomical closure of the foramen ovale is completed after a heart-weight of 168 gram, those of the ductus arteriosus after a heart-weight of 120 gram. An alternation of the closure and opening of the ductus arteriosus has not been observed. In adult seals an anatomical open ductus arteriosus was not observed in 59 specimens, while the foramen ovale was anatomically open in two cases out of 54. Pathological consequences are likely in these two cases.

Introduction

This paper deals with two specific by-passes in the foetal circulation. These by-passes prevent the functional circulation through the lungs during foetal life. Both structures close during the neonatal period (Fig. 1).

The first by-pass is the foramen ovale (abridged: f.o.), an opening in the atrial septum between the right and left atrium. The f.o. can be closed by a valve localized on the left side of the septum. It's closure may be functional by a positive difference in blood pressure between the left and right atrium, or anatomically by a fibrous adhesion to the left side of the atrial septum. A patent f.o. in adult man and animals may be considered a minor pathological item. The second by-pass is the ductus arteriosus (abridged: d.a.), it connects the aortic arch with the pulmonary trunk. The d.a. may be characterized as an artery with a wall built up of smooth muscle cells and a network of elastic fibres. The post-natal functional closure of the d.a. is under control of the oxygen level in the blood—P_{02}—(Hörnblad, 1969). A high level ± 100 mmHg supports its closure. Within a few months after birth the d.a. becomes anatomically closed by growth of fibrous tissue into its lumen. The patency of the d.a. may be considered as a severe pathological entity in adult man and other mammals.

Slijper (1958, 1961, 1965 with de Vries, and 1968) reviewed the literature about the closure of the f.o. and d.a. in aquatic as well as in terrestrial mammals. In 1961 he states in his tenth conclusion in a paper concerning the f.o. and d.a. in aquatic mammals; 'Respiratory difficulties also occur in the Common Seal because the pups of these mammals are obliged to enter the water very shortly after birth. They also are immediately capable of diving and do so regularly. Consequently it may be supposed that during the period immediately after birth these respiratory difficulties cause a temporary re-opening of the ductus arteriosus. This may be regarded as the cause of the retarded closure of the ductus'.

Slijper collected 5 cases concerning the anatomical closure of the f.o. and d.a. recorded in the literature and he added 15 own observations to it. So his statement is based upon 20 cases. His main conclusion is that in comparison to other seals including Antarctic pinnipeds and terrestrial mammals the closure of the f.o. and d.a. is retarded in the Common Seal.

The aim of this investigation is to corroborate or to deny the statement of Slijper and to state some hypotheses concerning the difference in physiology of the suckling and weaned seals in the process of closure of the f.o. and d.a. Ninety-four hearts with the stem of the great arteries taken from Common Seals in all ages have been investigated for this purpose in the present paper.

Materials and methods

The 94 hearts with the stem of the arterial vessels have been derived from Common Seals presented for post-mortem examination. The viscera have been cleaned of free blood and blood clots with the aid of tapwater. Immediately after cleaning they were stored in 4% formaldehyde for at least two months. Before the examination of the structures concerned—f.o. and d.a.—the hearts with their attachments have been bathed in 1% NH_4OH for 12–24

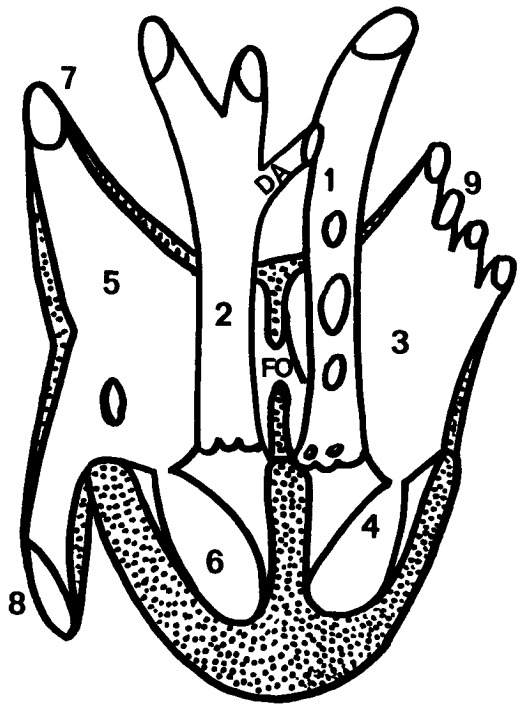

Figure 1. Neonatal heart
1, Aorta. 2, Pulmonary trunk, 3, Left atrium. 4, Left ventricle. 5, Right atrium. 6, Right ventricle. 7, Cranial caval vein. 8, Caudal caval vein. 9, Pulmonary veins. f.o. Foramen ovale. d.a., Ductus arteriosus.

hours in order to eliminate the free formaldehyde. Each heart was trimmed free from the rest of the pericardium. The stem of the arteries was cut off just distal to the semilunar valves. After this the hearts have been dried with a cotton towel and weighed on a metric balance. The vessel-stems were freed from the rest of the pericardium and from other loose fibrous tissue and so the d.a. was exposed. The patency of the f.o. and the d.a. has been determined with the aid of a small probe with a top diameter of 1.5 mm (Slijper, 1961). The structures were considered 'anatomically open' in cases of free passage of the probe through them. Neither histological examination nor physiological experiments have been carried out.

The 94 preparations have been divided into two groups. In group 1 the heart and the stem vessels have been derived from pups just born to animals just weaned. All other preparations derived from young adult to old animals are placed into group 2. While it was not practicable to fix the exact age of the seals taken up in this study, the authors used the division line between the two groups as in the next papers of Slijper (1958, 1961) and in computing from these papers the heart weights of newly weaned pups. The advantage of this computation may be found too in the possibility of comparing the material studied by Slijper with the present study.

Table 1. Pups till weaning

Nr	Heart weight gram	Foramen ovale ●	Foramen ovale ○	Ductus arteriosus ●	Ductus arteriosus ○	Ductus arteriosus ?
1	45	●		●		
2	50		○	●		
3	61		○			?
4	65	●		●		
5	68		○			?
6	70		○		○	
7	70		○		○	
8	74		○	●		
9	75		○			?
10	85		○		○	
11	85	●			○	
12	85		○		○	
13	86	●		●		
14	88		○		○	
15	90		○		○	
16	92		○		○	
17	95		○		○	
18	99		○	●		
19	100		○		○	
20	105		○		○	
21	110		○		○	
22	110		○		○	
23	115		○		○	
24	120	●			○	
25	124		○	●		
26	125		○			?
27	127		○	●		
28	129	●		●		
29	135		○		○	*
30	142	●		●		
31	148		○	●		
32	151		○		○	
33	155		○	●		
34	157	●		●		
35	168		○	●		

● = closed, ○ = open,
? = not present
* = described by v. Nie, 1982

Results

The results are listed in Tables 1 and 2.

Discussion

According to Slijper (1961) a heart of 120 gram weight may be considered as derived from a seal

Table 2. Seals after weaning

Nr	Heart weight gram	Foramen ovale ●	Foramen ovale ○	Ductus arteriosus ●	Ductus arteriosus ○	Nr	Heart weight gram	Foramen ovale ●	Foramen ovale ○	Foramen ovale ?	Ductus arteriosus ●	Ductus arteriosus ○
1	172	●		●		31	275	●			●	
2	172	●		●		32	279	●			●	
3	175	●		●		33	288	●			●	
4	177	●		●		34	290	●			●	
5	177	●		●		35	301	●			●	
6	182	●		●		36	310	●			●	
7	183	●		●		37	313			?		
8	187	●		●		38	330	●			●	
9	195	●		●		39	340	●			●	
10	195	●		●		40	370	●			●	
11	200	●		●		41	400	●			●	
12	201	●		●		42	400	●			●	
13	207	●		●		43	420	●			●	
14	211	●		●		44	436	●			●	
15	213	●		●		45	450	●			●	
16	214	●		●		46	450	●			●	
17	217		○	●		47	458	●			●	
18	218	●		●		48	489	●			●	
19	225	●		●		49	490	●			●	
20	225	●		●		50	490	●			●	
21	225	●		●		51	501	●			●	
22	226	●		●		52	533	●			●	
23	230	●		●		53	540	●			●	
24	232	●		●		54	550	●			●	
25	247	●		●		56	560	●			●	
26	248	●		●		56	584	●			●	
27	250	●		●		57	660	●			●	
28	250	●		●		58	>300		○		●	
29	257	●		●		59	>300	●			●	
30	268	●		●								

● = closed, ○ = open, ? = not present.

newly weaned with a body weight of 16.4 kg maximum and an age between 6 and 9 weeks. In the case of a heart of weight 168 gram, the next data may be concluded: body weight 23 kg maximum and an age of 12 weeks.

So Table 1 concurs with the information given by Slijper concerning the f.o., however the closure of the d.a. is somewhat earlier. The difference in closure time between the f.o. and the d.a. is between 3 and 6 weeks in this paper. It is the author's opinion, that this difference is not essential (vide supra).

An alternative opening and closing of the d.a. cannot be concluded from Table 1, while the d.a. has a diameter of 8 mm in heart nr 29, weight 135 gram (v. Nie, 1982), and the probe passed without any resistance through the d.a. in heart nr 32, weight 151 gram.

The closure time of the d.a. may be considered in the range from 6 to 9 weeks. The closure time of the f.o. is fixed by heart nr 35, weight 168 gram, before the age of 12 weeks. So far the present findings corroborate these of Slijper (1961).

Table 2 presents 59 hearts in a range from 172 gram to 660 gram. These hearts have been derived from weaned young and adult seals. The d.a. is anatomically closed in all cases and an anatomically open f.o. is detected only twice.

Compared with adult terrestrial mammals these figures are striking. The incidence of an anatomically open but functionally closed f.o. and d.a. in these mammals is listed in Table 3. The special position of the adult Common Seal concerning the anatomical closure of the f.o. and d.a. is presented in Table 2. Both structures are closed in the weaned and adult seals. A continuous life in the water of diving—for food—and emerging—for breathing—is incompatible with a non-anatomical (= functional) closure of the discussed structures. A functional open d.a. does not favour a good 'windkessel' function of the bulbus

Table 3. Incidence of anatomical open foramen ovale and ductus arteriosus in some adult terrestrial mammals

Species	Author	Incidence in % f.o.	d.a.
Cattle	Chaussé 1916	16–30	—
	Cohrs 1952	16–23	—
	Steger 1927	19.5	0.38
Dog	Chaussé 1916	4.8	—
	Patterson 1967	—	0.19
Horse	Chaussé 1916	0.36	—
Man	Edwards 1960	20–25	12
Pig	Christl 1970	0.45	—
	Nie, v, 1967	10	0.6
	Slijper *et al.* 1965	18–23	—
Sheep	Chaussé 1916	0.36	—

aortae (v. Nie, 1985) and the direction of the blood may be reversed—from right to left atrium—through a functionally open f.o. during the bradycardia caused by diving (v. Nie c.s., 1970). The consequence will be a shortening of the diving time caused by mixing up O_2 rich blood with O_2 poor blood.

Seal sucklings enter the water within $8\frac{1}{2}$ hours after birth (Slijper, 1961). Their diet is restricted to the mothers-milk. A long diving time is not necessary before weaning, in the mean time an anatomical open f.o. and d.a. favours a short diving time during the period of life, in which the visual contact with the mother is most important.

The present author states that the alternative opening and closure of the d.a. in sucklings as mentioned by Slijper (1961) may be explained with the given arguments, however the alternative closure and opening of the d.a. cannot be concluded from the present findings (vide supra).

Conclusions

The examination of 94 hearts with arterial stem vessels derived from Common Seals, for the anatomical closure of the foramen ovale and ductus arteriosus leads to the following conclusions:

1. The closure time in sucklings and young unweaned Common Seals is retarded in comparison with antarctic and other pinnipeds and terrestrial mammals. This conclusion corroborates Slijpers statements.
2. The anatomical closure of the f.o.—52 cases—and the d.a.—59 cases—after weaning gives evidence for a special adaptation for routine diving in the Common Seal.
3. Patho-physiological consequences of the two open foramen ovale in adult Common Seals are likely.

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References

Chaussé, M. P. (1916). Recherches sur la persistance du trou de Botal chez quelques animaux domestiques. *Comptes Rendus Acad. Sciences Paris* **162,** 480–481.

Christl, H. (1970). Kongenitale Miszbildungen der Vorscheidewand bei Schweine. *Die Blauen Heften,* 10–14.

Edwards, J. E. (1960). Malformations of the Aortic arch. Pathology of the Heart, ed. S. E. Gould. C. C. Thomas, Springfield, Illinois, USA.

Hörnblad, P. Y. (1969). Effect of oxygen and umbilical cord clamping on closure of the ductus arteriosus in the guinea pig and the rat. Studies on the closure of the ductus arteriosus, VI. *Acta physiol. scand.* **76,** 58–66.

Nie, C. J. van (1967). Unpublished data.

Nie, C. J. van (1982) De morphologie en de congenitale pathologie van het hart van de gewone zeehond (Phoca vitulina vitulina). *Tijdschr. Diergeneesk.* **107,** 368–374.

Nie, C. J. van, (1985). The bulbus aortae (Aorta ascendens) in the growing Common Seal (Phoca vitulina vitulina) (a morphological approach). *Aquatic Mammals* **11,** 71–74.

Nie, C. J. van, Versprille, A., Giesberts, M. A. H., Riedstra, J. W., Beneken, J. E. W. and Rohmer, J. (1970). Functional behaviour of the foramen ovale in the newborn piglet. *Pflügers Arch.* **314,** 154.

Nieberle, K. (1952). Kreislauforgane, Lehrbuch der Speziellen Pathologischen Anatomie der Haustiere. P. Cohrs (ed.), 3e Auflage, Gustav Fisher Verlag, Jena.

Patterson, D. F. & Detweiler, D. K. (1967). Hereditary transmission of patent ductus arteriosus in the dog. *American Heart J.* **74,** 289–290.

Slijper, E. J. (1958). Organ weights and symmetry problems in porpoises and seals. *Arch. Néerl. Zool.* **13,** 97–113.

Slijper, E. J. (1961). Foramen ovale and ductus arteriosus Botalli in aquatic mammals. *Mammalia* **25,** 528–575.

Slijper, E. J. (1968). On the heart of temporary aquatic mammals with special reference to the embryonic pathways. *Bijdr. Dierk.* **38,** 75–84.

Slijper, E. J. & Vries, R. J. de (1965). The closure of the foramen ovale and the ductus arteriosus Botalli in the domestic pig. *Mammalia* **29,** 602–609.

Steger, W. (1927). Variabilität und Miszbildung im Schweine-Herzen. *Anat. Anz.* **63,** 145–164.