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Anatomical Studies No. 63: An Abnormal Bovine Heart.

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THE majority of the recorded abnormalities of the heart (Schwalbe, 1909) are of relatively simple nature, e.g. patent foramen ovale and localised septal defects. The latter are usually limited to the atrial septum, occurring much less frequently in that of the ventricles. Their frequency is greater in the more basal parts than towards the apex (Bailey and Miller, 1927). Much more rare are anomalies affecting both atria and ventricles, while a search of the literature reveals but a few records of cases in which, in addition to both sets of chambers, the main arterial stems were also involved.

Subject.

The heart is that of a male calf found[1] dead in the veld on the morning of 21-12-36, apparently a few hours subsequent to birth. The calf was by an Afrikander bull (D.O.B. 4819) out of a highgrade Sussex cow (D.O.B. 3425). The foetus had been carried for 296 days, and at birth it compared favourably, as regards both weight (73 lb.) and degree of development, with other calves similarly bred under identical environmental conditions. Other than the cardiac abnormality to be described and several skin abrasions, the autopsy findings were entirely negative. It was decided that the calf had been born alive and that it had breathed.

Description of the Heart and Vessels.

In this description the heart is looked upon as being *in situ* and the animal in the normal standing posture; thus the base of the heart is dorsal, the apex ventral, the right atrium and ventricle cranial and the left chambers caudal.

(*a*) External Appearance.—As will be seen from Fig. 1, the shape of the heart differs from the normal in that it is shortened in the dorso-ventral direction; wider and more rounded at the apex.

[1] By H. P. S., who was at that time Officer in Charge of the Veterinary Research Station at Armoedsvlakte, near Vryburg, C.P.

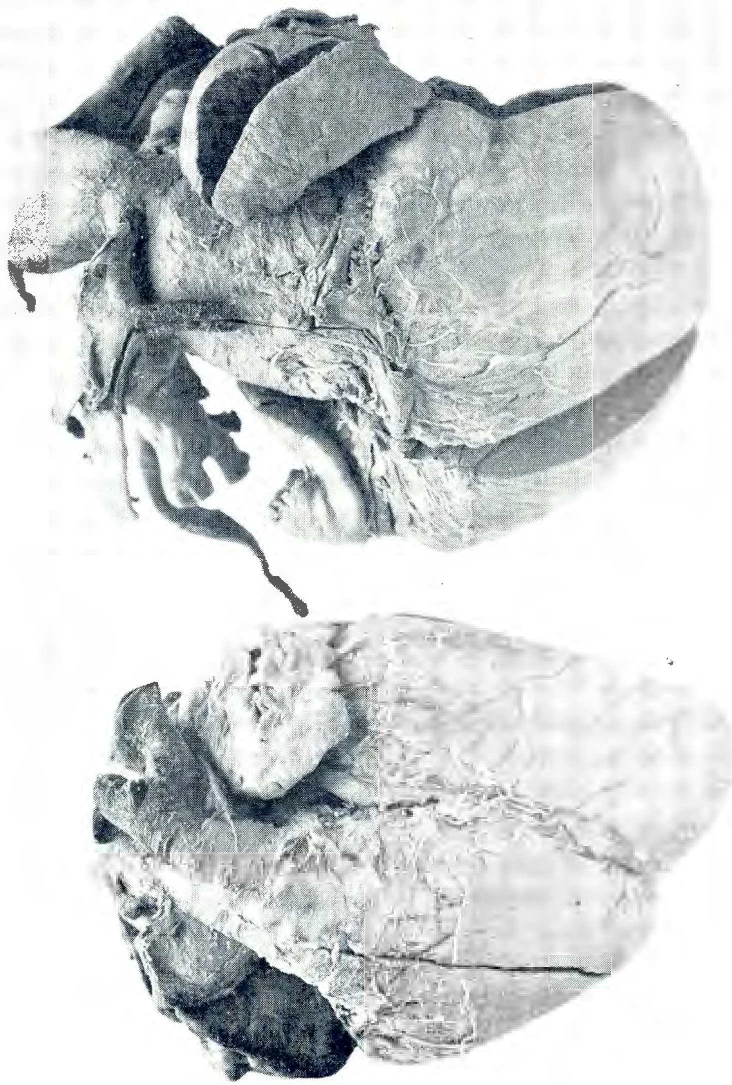

Fig. 1.—External appearance, left lateral view. On the right is the abnormal heart, while on the left is shown a normal heart of a new-born calf.

Further it is distinctly flattened from side to side. The usual longitudinal grooves are absent, but there is a faint horizontal groove midway down the posterior surface of the ventricular portion. Above this groove a backward protrusion of the ventricular myocard breaks the usual straight line of the caudal border.

The left atrium is attached to the right atrium only, there being no connection between it and the ventricular portion of the heart.

At the base of the heart the usual aortic and pulmonary trunks are replaced by a single large cone-shaped vessel, clearly visible from the left side (Fig. 1). This vessel extends upwards for a distance of two inches before it divides (see Fig. 2) as follows:—

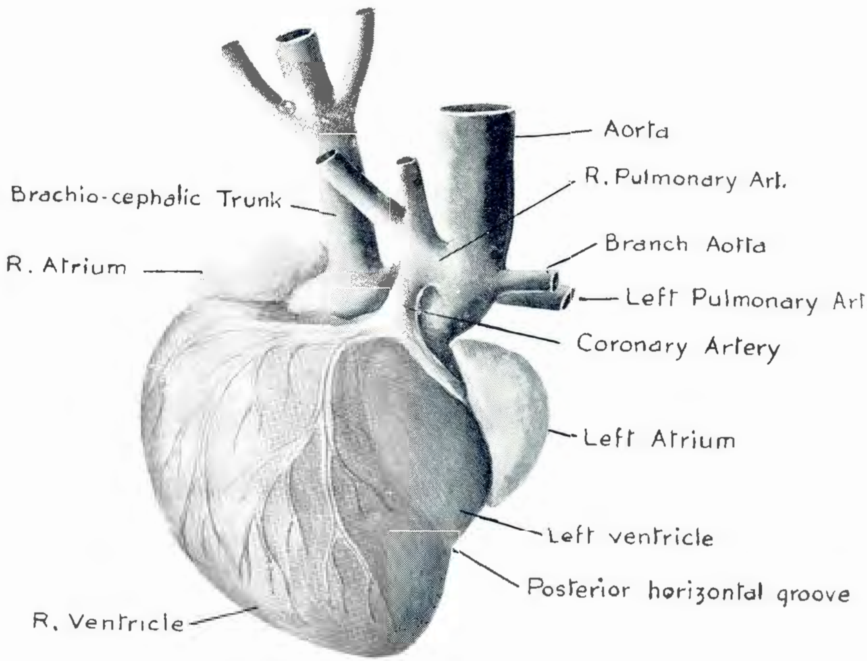

Fig. 2.—External appearance.

(i) *Aorta.*—This, the largest branch, appears to be the direct continuation of the main trunk. It curves upward and backward to reach the dorsal wall of the thoracic cavity.

(ii) *Common Brachiocephalic Trunk.*—This is second in point of size. It arises directly opposite the foregoing vessel and it passes forward towards the entrance to the thoracic cavity.

(iii) *A Fairly Large Vessel* arising at the same level as the above and to the right of it. This probably represents one of the branches of the brachiocephalic trunk. However, in the illustration it is marked as a branch of the aorta.

(iv) *The Right Pulmonary Artery.*—This originates at the left cranial aspect of the main trunk. It is of the same calibre as (iii) but at its base there is a marked constriction.

(v) *The Left Pulmonary Artery.*—Emanating from the base of the aorta, towards the caudal aspect, and having an initial constriction similar to that of the right artery.

At a distance of one inch from the point of origin of the right pulmonary artery there arises a small vessel which, lying upon the left face of the main arterial trunk, runs directly towards the base of the heart where it splits into two branches. These, coursing in opposite directions along the coronary grooves, appear to be the coronary arteries. No further coronary blood supply is detectable.

As is to be expected, neither the ductus arteriosus nor the ligamentum arteriosum is present. The vena cavae and the pulmonary veins open as usual into the right and the left atria respectively.

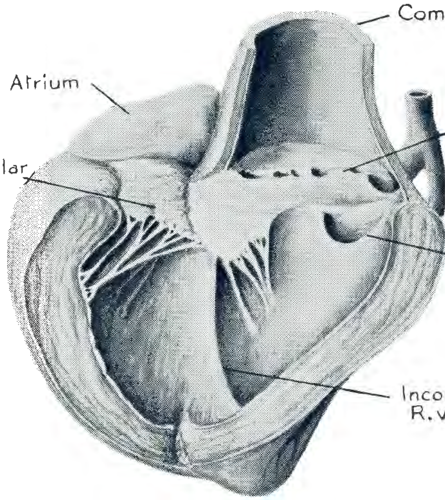

Fig. 3.—Internal appearance, left lateral view.

(*b*) Internal Appearance.—The left atrium has no ventricular communication; however, a patent foramen ovale is encountered. In the right atrium there are no unusual features. As seen in Fig. 3 the right ventricle comprises almost the entire ventricular part of the organ. By a slight longitudinal elevation of its right myocardial wall the chamber is incompletely divided into cranial and caudal compartments. The right atrium opens into the former, while the latter extends ventrally into the apex and dorsally into the main arterial trunk, from which it is demarcated by a three-cuspid semi-lunar valve. Just ventral to the posterior of these cusps a foramen, about one inch in diameter, opens through the myocardial wall into the vestigial left ventricle. The latter is contained in the posterior protrusion visible externally. It is found to consist of a simple hollow chamber with but one opening—that into the right ventricle. The muscular wall is complete and the cavity is lined by endocardium continuous with that of the larger ventricle.

Teratology.

The mammalian heart develops from a single tube, along the course of which three enlargements appear. In turn these are divided, through the appearance of septa, into paired atria, ventricles and arterial trunks—aortic and pulmonary. In the case under consideration this process has been disturbed, resulting in misplaced division of the ventricles (with consequent atrial anomalies) and total failure of division of the bulbus. The latter remains as a common arterial stem, in the sub-division of which all the main branches of both the aorta and the pulmonary artery are represented.

Foetal Circulation.

In this case a single functional ventricle and a common arterial stem maintained the entire circulation, pulmonary as well as systemic. The former being relatively unimportant in the foetus, constrictions at the bases of the pulmonary arteries served to keep the bulk of the blood-volume in the systemic vessels. For the small volume of blood returning from the lungs to the left atrium there was but one outlet, namely, into the right atrium, thus reversing the usual direction of flow through the foramen ovale.

Discussion.

The significance of this case extends far beyond its teratological rarity—it forms an important contribution to the literature on the foetal circulation.

It is known that into the right atrium are poured two streams of blood of differing quality, namely, the oxygen-poor blood from the cranial vena cava and the relatively pure blood from the caudal vena cava. The traditional belief, based on the teaching of Sabatier (1791), has been that by certain anatomical arrangements within the right atrium, these two streams are kept apart, and that subsequently the purest blood is distributed to the brachio-cephalic circulation. This purely hypothetical conception is based upon the supposed advantages that would accrue from a segregation of pure and impure blood. Save for the apparent highly unsatisfactory work of Reid (1835) there was, until recently, no attempt at experimental verification of the theory. Nevertheless this classical explanation has enjoyed immense popularity and it is to be found, faithfully reproduced, not only in the older texts, but also in works of much more recent origin (e.g. Zeitschmann, 1924; Bailey & Miller, 1927); and this despite the fact that already in 1907 Pohlmann had revived Harvey's (1628) theory of complete admixture of the two streams, and had (1907-9) furnished experimental corroboration which, although perhaps somewhat inconclusive, went far towards discrediting the Sabatier teaching. Extending this investigation, Kellogg (1929) showed that immediately after injection into either the jugular, the anterior or the posterior vena caval veins, of starch solutions or india ink, these substances were recovered in approximately equal concentrations from the two ventricles. But for the possible criticism that by artificial interference the natural mechanism is liable to be disturbed, these results would prove conclusively that in the right atrium there is definite mixing of the bloodstreams. However, Kellogg believes that all the points of criticism may be refuted. In a later study (1930) in which sensitive gaseous analyses of blood samples drawn simultaneously from various regions of the foetal system are the criteria, he records results which vindicate his earlier conclusions.

However, in spite of their acceptance by Arey (1934), who, judging from Kellogg's acknowledgement, appears to have been in a position to appreciate their merit, these findings have not resulted in a settlement of the controversy. Barcroft (1936) points out that in all Kellogg's (1930) results the figures for oxygen content are extremely low. Like Huggett (1927), he finds that in the small ruminant foetus the percentage oxygen saturation varies in decreasing sequence in samples of blood drawn from the posterior vena cava, the carotid and the umbilical artery. Statistical analysis of Barcroft's data shows that the difference between groups two and three (carotid and umbilical artery) is just significant at the five per cent. level of probability, whereas between numbers one and three (posterior vena cava and umbilical artery) there is a difference highly significant even at $P = 0 \cdot 01$. Thus, as far as these results are concerned, Barcroft is justified in concluding that " there is on the whole a difference " between samples of blood from the anterior and the posterior systemic arteries. However, in view of the fact that the two significant differences just mentioned are of widely varying order, we consider the qualification, " there is evidence of *some* crossing of the two streams ", to be of equal importance.

Moreover, it must be borne in mind that in the collection of these blood samples the foetuses were probably all held in the same fixed position; this position may have been favourable to an increased flow of blood through the foramen ovale. From anatomical considerations it is not difficult to conceive of such positions; on the other hand it is equally easy to picture positions which might predispose towards thorough mixing of the streams within the right atrium.

The further use, however reservedly, of these highly variable data for the purpose of apportioning the extent of crossing of the streams is questionable. Here exception is taken not so much to the possible inaccuracy of the result as to the implication that there is in existence a mechanism through which only a limited and definitely determinable amount of mixing of the two streams is allowed; again the basis of this idea is the supposedly preferential treatment, in the matter of oxygen supply, of the more cranial part of the foetal body. The limit to which this theory may be stretched is well indicated in Barnard's (1938) discussion of an aneurism of the left ventricle, the result of the left coronary artery taking origin from the pulmonary artery. He maintains that the process had already been instigated in the foetal period by the deprivation of this part of the myocard of " pure blood " from the aorta.

The entire theory is based mainly on the observed relatively large size of the foetal head. Rightly Kellogg (1928) has pointed out that the dominance of this region is limited to the earlier part of prenatal life, and that later the abdominal and pelvic regions undergo rapid growth and differentiation. Statistically it has been shown by one of us[2] that in regions such as the limbs, from early in

[2] J. H. L. C. in an as yet unpublished study of foetal growth and development in the Merino sheep.

prenatal life, the true growth-rate of the caudal member is always higher than that of the cranial one. However, in the latter the inception of growth occurs earlier (chronologically) and hence this member obtains a " start " which ensures that for a long time it will be relatively larger than the faster growing caudal member. On this basis the reason for the disproportionate size of the foetal head is its early entry into the growth process; hence the fallacy of hypotheses based upon the supposed accelerated growth, and consequent increased oxygen requirements, of the brachiocephalic region.

For these reasons we incline towards a modified Harvey-Pohlmann theory which, while admitting the absence of constant, thorough and complete mixing of the two caval streams, regards any difference in the quality of blood in the upper and the lower systemic arteries as " accidental " and physiologically meaningless. Such a modification seems to have been implied by Kellogg, for his contention, after a considerable and varied number of tests, is not that the blood in the two ventricles is always identical (his results prove otherwise), but that such differences as do appear are inconstant, variable and of no moment.

" To those who obtain mental satisfaction from fitting supposedly advantageous mechanisms to physiological ideals, the Harvey-Pohlmann theory may be disappointing. Yet it is by no means certain that there is any necessity in maintaining a difference in the quality of blood distributed to various parts of the body. Circulatory efficiency in the mammalian embryo doubtless depends jointly on the relatively large quantity of swiftly moving blood, and on the large factor of safety in the oxygen supply." In these words Kellogg appears to lay upon those who still persist with the Sabatier conception the onus of definite proof of the necessity for separation. However, in addition to facts already advanced, the case recorded in this article is a natural experiment which has proved effectively that such segregation is not an essential factor in foetal growth and development. Thus the balance has been weighted against the discharge of this onus.

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