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Postnatal growth of the dog heart

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INTRODUCTION

In 1883 Müller dissected 61 premature infant hearts and assigned 30% of the septal weight to the right ventricle and 70% to the left. On this criterion the left ventricle was heavier than the right at birth. Patten (1930) examined over 50 hearts from stillborn infants and reported that the right ventricle outweighed the left by a ratio of 8:7. Brock (1932) stated that the left ventricle outweighed the right at birth. Blackfan (1933) found that in the newborn infant the combined ventricular weight was 15 to which the right contributed 8 g and the left 7 g. Fulton, Hutchinson & Morgan Jones (1952) divided the ventricular part of the heart into a right ventricular, a septal, and a left ventricular mass. They found that in right ventricular hypertrophy the septal mass seldom exceeded its normal range of weight. However, it exceeded its normal limits in almost all cases of left ventricular hypertrophy. As a result of these observations they considered the septum to belong to the left ventricle.

Keen (1955) also considered the septum as forming a unit of the left ventricle. He found that at the time of birth in man the ventricular weights were approximately equal, though in some cases the right ventricle outweighed the left. During the first postnatal month the left ventricle became predominant, there being during this period a 20% reduction in the weight of the right ventricle from 6·0 to 4·9 g. From then until the fourth month there was no change in the mean weight of the right ventricle, and it was not until the second half of the first year that this ventricle regained its birth weight. Keen believed that the right ventricle underwent atrophy during the first month and that the left ventricle and septum subsequently hypertrophied.

Müller (1883) also showed that the most rapid change in ventricular ratio was during the first month after birth. He believed that it was not until 6 months that the left ventricle reached the degree of preponderance which it enjoys throughout the remainder of life. His explanation of the right ventricular atrophy was that immediately after birth the work of the right ventricle decreased.

Sala Panisello, Castellanos, Junco & Valladares (1958) dissected 25 premature and 8 full term infant hearts and divided the septum longitudinally. They found that the left ventricular weight was significantly higher than the right. Peñaloza *et al.* (1960) showed that at birth there was right ventricular preponderance but that by the end of the first week the left ventricle had gained the preponderance.

Emery & Mithal (1961) examined 105 infant hearts and found that the mean weight

of the left ventricle at birth was 5·7 g and that of the right 6·6 g. It was observed that the left ventricle outweighed the right within 4 weeks of birth. They found that the right ventricle did not undergo atrophy but simply gained weight at a slower rate than the left.

Recavarren & Arias-Stella (1964) showed that in man up to 7 days after birth the right ventricle weighed more than the left. Between the 16th day and the fourth month, however, the right ventricular weight decreased until it was only 37·7% of the total ventricular weight. From the fifth month to the fourth year there was a slight increase in the right ventricular weight. The right ventricle did not regain its birth weight until 7 months.

Dawes, Mott & Widdicombe (1954) measured the weight of the ventricular walls of 13 near term lambs, discarding the interventricular septum. They found little difference between the weights of the two ventricles: however, in every heart the wall of the left ventricle was thicker than that of the right. The mean weight of the right ventricle was $8{\cdot}5 \pm 3{\cdot}8$ g and that of the left $9{\cdot}1 \pm 3{\cdot}3$ g. In the newly born rabbit the left ventricle enlarged and thickened much more rapidly than the right and by 3 days of age there was a clearly visible difference in the thickness of the two ventricles (Gluck, Talner, Gardner & Kulovich, 1964).

It is clear that there are differences of opinion as to whether, at birth, the weight of the right ventricle is equal to, greater than, or less than the weight of the left ventricle; and there is also uncertainty as to the date at which the ventricular weights become equal. It is doubtful whether there is *any* method by which the separate weights of the two ventricles can be precisely determined, in view of uncertainty regarding the status of the septum, some authors believing the septum to be part of the left ventricle, with others believing that the ventricles can be divided along a natural line of cleavage in the septum. The heart of the newborn infant exhibits a practically straight septum bisecting the ventricular region with the apex of the heart usually formed by both ventricles, although occasionally by the right only. At 3 months, the apex is formed usually by the left ventricle alone (Hort, 1966).

It was the purpose of this report to determine the right and left ventricular weights in newborn pups and to assess the individual and relative growths of the ventricles until 17 days after birth.

MATERIALS AND METHODS

Hearts were obtained from 74 pups of 10 different litters. The bitches were mongrel dogs weighing between 10 and 20 kg. The pups were weighed to the nearest gram before being killed. In each litter a pup was killed every other day, starting with day 1 and continuing until day 17.

The hearts were separated from the lungs and, together with the great vessels, placed in 10% formalin for 4–5 days. After fixation the hearts were removed from the formalin and the circumference of the heart immediately below the atrio-ventricular (A-V) sulcus, and the length of the heart from ventricular apex to the topmost portion of interatrial septum were measured. The weight of the total heart mass was determined after removal of the pericardium, fat, aortic and pulmonary valves, and the great vessels where they exited from their respective ventricles. The two atria were then dissected from the ventricles at the A-V sulcus and the A-V valves removed

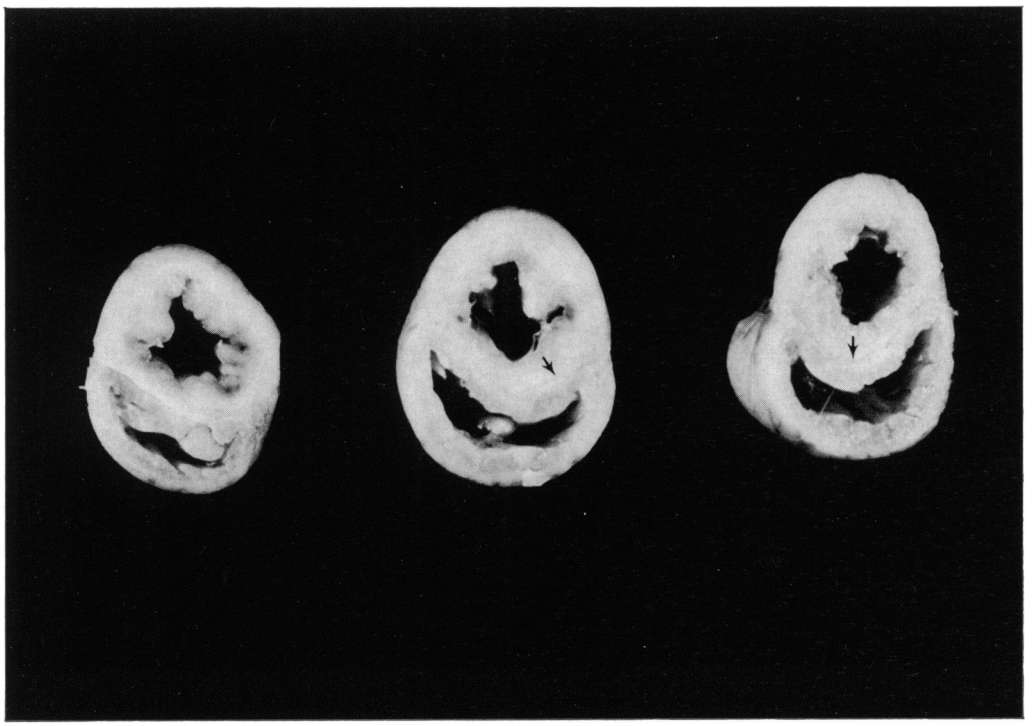

Fig. 1. Sections of the ventricles of dog heart at day 7. Arrows indicate natural line of separation used in dividing the septum.

by sharp dissection. The chordae tendineae were cut at the apex of the papillary muscles and removed. The hearts were then washed with cold water to remove blood. Excess moisture was blotted free and the ventricular mass weighed to the nearest 0·01 g.

The ventricles were cut transversely into four equal portions. The two ventricles were separated from each other by dividing the septum along what appeared to be a *natural line* of separation (Fig. 1). The right and left ventricular portions were then weighed to the nearest 0·01 g.

The ratio of the left ventricular to right ventricular weight (LV/RV) for each age, as well as the mean weight of both the right and left ventricles, and their standard deviations, were calculated. The mean total heart weight, as well as the mean ventricular weight, were determined for each age. The mean heart length, and the mean heart circumference below the A-V sulcus, were determined for each age. The percentage weight of the right ventricle to the total ventricular weight was determined for each age.

The data were subjected to one way analysis of variance. When the F ratio indicated that significant differences occurred among days, the least-significant-difference method was used to separate day means. Significance was assessed at $P < 0{\cdot}05$ (Snecedor, 1961).

Table 1. *Mean values (in grams) of left ventricular, right ventricular, left ventricular/right ventricular (LV/RV), total ventricular, total heart and total body weights*

Age (days)	No.	Left ventricle	Right ventricle	LV/RV	Total ventricular weight	Total heart weight	Body weight
1	10	$0{\cdot}90^{h}$ $\pm 0{\cdot}20$	$1{\cdot}14^{e}$ $\pm 0{\cdot}26$	$0{\cdot}80^{d}$ $\pm 0{\cdot}12$	$2{\cdot}10^{f}$ $\pm 0{\cdot}47$	$2{\cdot}55^{g}$ $\pm 0{\cdot}62$	$335{\cdot}80^{g}$ $\pm 66{\cdot}97$
3	10	$1{\cdot}24^{gh}$ $\pm 0{\cdot}39$	$1{\cdot}24^{e}$ $\pm 0{\cdot}30$	0.99^{d} ± 0.18	$2{\cdot}55^{e}$ $\pm 0{\cdot}67$	$3{\cdot}00^{fg}$ $\pm 0{\cdot}78$	$375{\cdot}30^{g}$ $\pm 125{\cdot}43$
5	10	$1{\cdot}62^{fg}$ $\pm 0{\cdot}30$	$1{\cdot}24^{e}$ $\pm 0{\cdot}18$	$1{\cdot}31^{c}$ $\pm 0{\cdot}22$	$2{\cdot}94^{e}$ $\pm 0{\cdot}41$	$3{\cdot}39^{f}$ $\pm 0{\cdot}52$	$475{\cdot}20^{fg}$ $\pm 119{\cdot}41$
7	10	$1{\cdot}83^{ef}$ $\pm 0{\cdot}50$	$1{\cdot}29^{e}$ $\pm 0{\cdot}20$	$1{\cdot}40^{bc}$ $\pm 0{\cdot}20$	$3{\cdot}19^{e}$ $\pm 0{\cdot}70$	$3{\cdot}73^{ef}$ $\pm 0{\cdot}80$	$619{\cdot}50^{ef}$ $\pm 183{\cdot}97$
9	9	$2{\cdot}13^{de}$ $\pm 0{\cdot}51$	$1{\cdot}43^{de}$ $\pm 0{\cdot}26$	$1{\cdot}49^{ab}$ $\pm 0{\cdot}23$	$3{\cdot}60^{de}$ $\pm 0{\cdot}66$	$4{\cdot}31^{de}$ $\pm 0{\cdot}81$	$765{\cdot}11^{e}$ $\pm 180{\cdot}70$
11	9	$2{\cdot}42^{d}$ $\pm 0{\cdot}45$	$1{\cdot}61^{d}$ $\pm 0{\cdot}30$	$1{\cdot}51^{ab}$ $\pm 0{\cdot}16$	$4{\cdot}04^{d}$ $\pm 0{\cdot}84$	$4{\cdot}88^{d}$ $\pm 1{\cdot}01$	$933{\cdot}56^{d}$ $\pm 195{\cdot}96$
13	8	$3{\cdot}08^{c}$ $\pm 0{\cdot}61$	$1{\cdot}99^{c}$ $\pm 0{\cdot}45$	$1{\cdot}57^{ab}$ $\pm 0{\cdot}22$	$5{\cdot}26^{c}$ $\pm 0{\cdot}76$	$6{\cdot}34^{c}$ $\pm 0{\cdot}93$	$1201{\cdot}25^{c}$ $\pm 216{\cdot}41$
15	6	$3{\cdot}86^{b}$ $\pm 0{\cdot}50$	$2{\cdot}37^{b}$ $\pm 0{\cdot}15$	$1{\cdot}63^{a}$ $\pm 0{\cdot}17$	$6{\cdot}43^{b}$ $\pm 0{\cdot}58$	$7{\cdot}70^{b}$ $\pm 0{\cdot}70$	$1430{\cdot}83^{b}$ $\pm 230{\cdot}57$
17	2	$4{\cdot}95^{a}$ $\pm 0{\cdot}49$	$3{\cdot}05^{a}$ $\pm 0{\cdot}21$	$1{\cdot}62^{a}$ $\pm 0{\cdot}05$	$8{\cdot}30^{a}$ $\pm 0{\cdot}71$	$9{\cdot}70^{a}$ $\pm 0{\cdot}57$	$1695{\cdot}00^{a}$ $\pm 28{\cdot}28$

A significant difference was present between right ventricular weights on days 11, 13, 15 and 17d as denoted by the superscripts d, c, b and a.

When superscripts are different within columns, statistically significant differences are present ($P < 0{\cdot}05$).

When superscripts of the samples within a column are the same, no significant differences are present.

RESULTS

The results are summarized in Table 1 and in Figs. 2 and 3. The total heart and ventricular weights increased 4 fold during the first 17 days of life. The mean left ventricular weight at day 1 was 0·90 g and the mean right ventricular weight 1·14 g (Table 1). In the present study it was observed that the left ventricle was equal to the right in weight at day 3, when both weighed 1·24 g. A total of ten non-littermate pups was used to determine the mean weights at days 1 and 3. The left ventricle increased significantly in weight between days 1 and 5, while there was no significant change in the weight of the right ventricle between days 1 and 9. The left ventricle continued to increase in weight more rapidly than the right and showed significant increases between days 5 and 9, days 9 and 13, and then between days 13 and 15, and days 15 and 17. The right ventricular weight displayed significant changes between days 9 and 13 and then between days 13 and 15 and days 15 and 17 (Table 1).

The total ventricular weight increased 7·7 % daily on average between days 1 and 17, while the total heart weight increased 7·1 % daily during the same period. The left ventricle increased in weight at a rate of 9·8 % daily between days 1 to 17. The right ventricle between days 1 and 7 increased slowly at a rate of 1·8 % daily, and

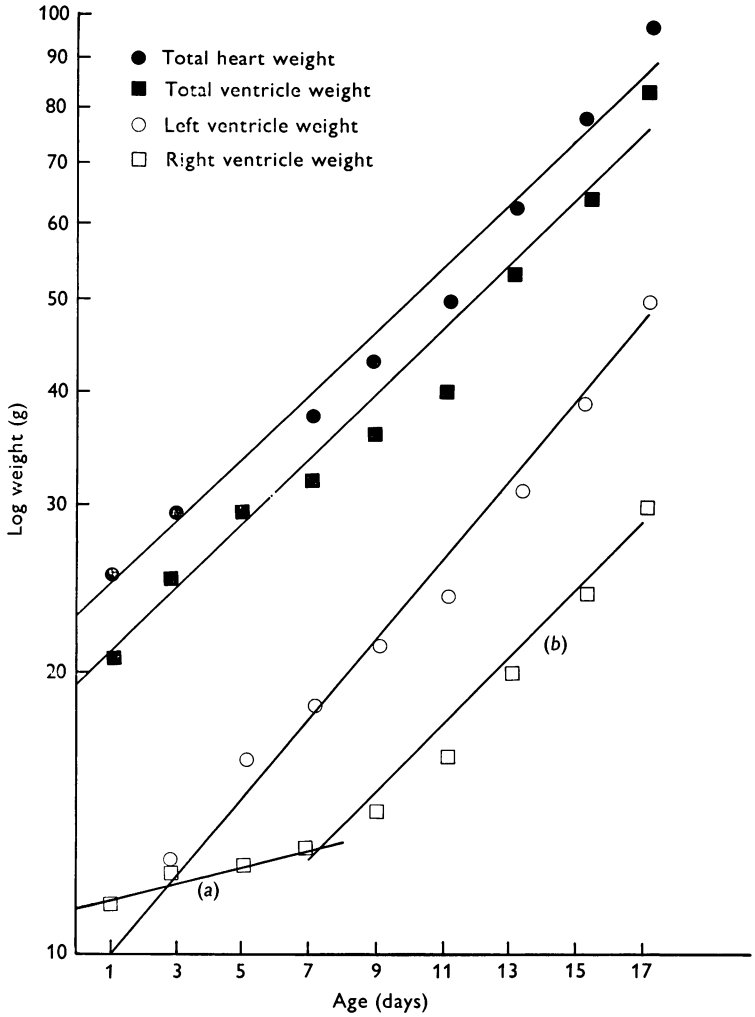

Fig. 2. Graph showing the log of total heart and total ventricular weight increases compared to the log of left and right ventricular weight increases. Total heart weight, $y = 2{\cdot}23e^{0{\cdot}071x}$ ($r = 0{\cdot}98$); total ventricle weight, $y = 1{\cdot}89e^{0{\cdot}077x}$ ($r = 0{\cdot}86$); left ventricle weight, $y = 0{\cdot}86e^{0{\cdot}098x}$ ($r = 0{\cdot}89$); right ventricle weight, (*a*) $y = 1{\cdot}14e^{0{\cdot}018x}$ ($r = 0{\cdot}95$), (*b*) $y = 1{\cdot}50e^{0{\cdot}086x}$ ($r = 0{\cdot}98$).

then at a rate of 8·6% daily between days 7 and 17, almost paralleling the left ventricular weight increase during this period (Fig. 2).

The left ventricle increased in weight from 0·90 g at day 1 to 4·95 g at 17 days. The right ventricular weight increased from 1·14 g to 3·05 g during the same period (Table 1). The left ventricle gained 0·2–0·4 g daily between days 1 and 17. The right ventricle, however, gained only 0·1–0·2 g daily during this same period. Between days 1 and 5 the right ventricle gained only 0·1 g while the left had a larger gain of 0·72 g (Fig. 2). Consequently, there was a fall in the ratio of right ventricle to total ventricular weight between days 1 and 7 (Fig. 3).

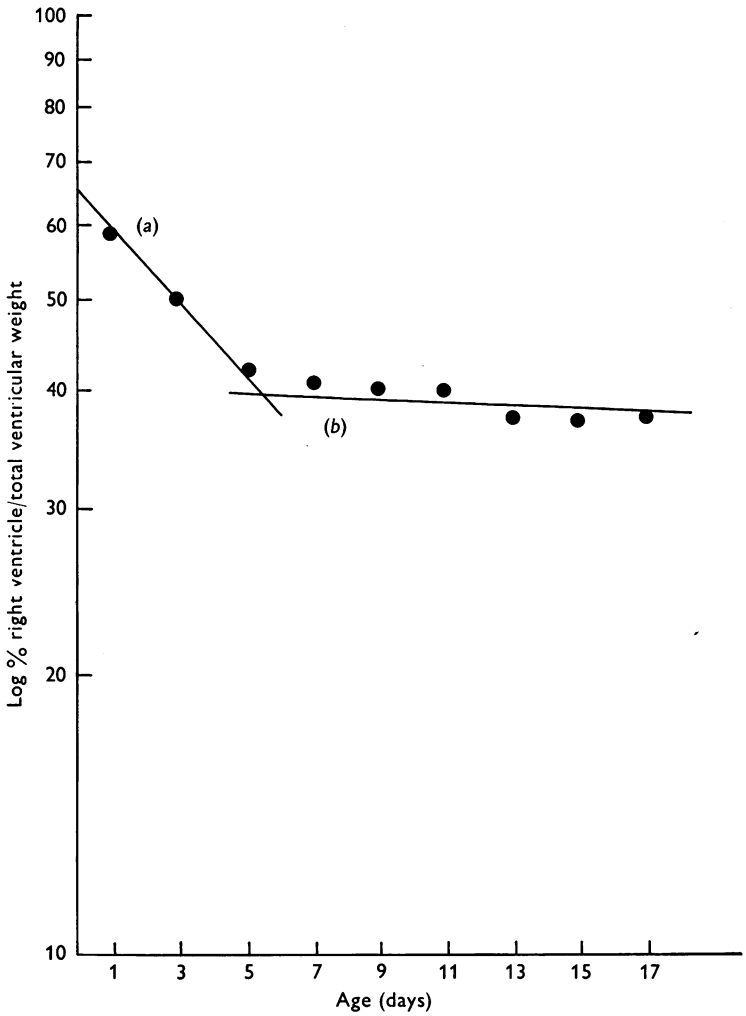

Fig. 3. Graph of the log of the percent right ventricle to the total ventricular weight. (*a*) $y = e^{-0\cdot086x}$ ($r = 0\cdot98$), (*b*) $y = 40\cdot5e^{-0\cdot001x}$ ($r = 0\cdot90$).

At day 1 the right ventricle comprised approximately 59 % of the total ventricular weight (Fig. 3). At day 3 the percentage weight of the right ventricle had decreased to 49 % of the total ventricular weight. Between days 3 and 13, the ratio of the weight of the right ventricle to that of the total ventricular weight decreased from 49 % to 37 %.

There was no significant change in the LV/RV ratio between days 1 and 3. However, there was a significant change in LV/RV ratio between days 5 and 9. There was no significant change in the LV/RV ratio ($P < 0\cdot05$) from days 9 to 17. The LV/RV weight ratio was 0·8 at day 1. A 1/1 ratio was reached at day 3, after which the ratio increased to 1·3/1 at day 5, to 1·5/1 at days 9 and 11. From days 11 to 17

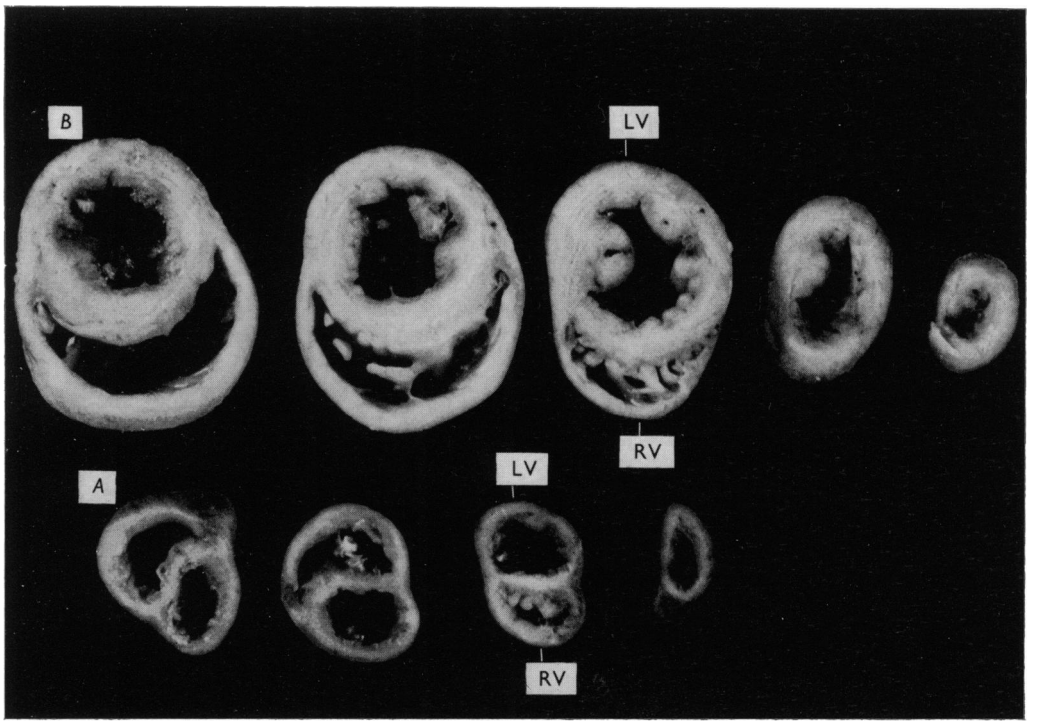

Fig. 4. Sections of the ventricles of dog hearts comparing the enlargement and thickening of the left ventricular wall (LV) to the right ventricular wall (RV) at day 1 (*A*) and day 17 (*B*).

the ratio remained at 1·6/1. The LV/RV ratios were less than 1 only at day 1, i.e. only in the least mature pups (Table 1).

At birth the right ventricle was heavier than the left. However, by day 3 the left and right ventricles were equal in weight (Fig. 2).

The total ventricular and total heart weights showed no significant increase between days 3 and 9, but did show a significant increase between days 1 and 3. After day 11, however, there was a significant increase between each sample period, i.e. between days 13 and 15 and days 15 and 17 (Table 1).

The circumference of the heart increased logarithmically between days 1 and 17 while the length of the heart increased linearly up to 17 days.

DISCUSSION

It is fortunate that, in the neonatal dog, the two ventricles can be separated along a clear plane of cleavage in the septum. The present investigation showed that, in the dog, at birth, the weight of the right ventricle was significantly greater than that of the left. In man, however, Brock (1932) reported that the left ventricle outweighed the right at birth, while Keen (1955) reported that the weights were equal at this time. There is general agreement, however, that the right ventricle is relatively

very well developed at birth and this is explained on the basis that during fetal life the right ventricle supplies both pulmonary and systemic circulations.

It was observed in the present investigation that the weight of the left ventricle became equal to that of the right ventricle within 3 days of birth. This rate of ventricular growth compares favourably with that of human ventricles, as reported by Peñaloza *et al.* (1960) and Recavarren & Arias-Stella (1964). The mean weight of the dog right ventricle at birth was 1·14 g (S.D. ± 0·26), at 7 days 1.29 g (S.D. ± 0·20) and at 15 days 2·37 g (S.D. ± 0·15) (Table 1). There are therefore no grounds for believing that the right ventricle undergoes atrophy within the first 2 weeks of life at least in the dog – the right ventricle simply gains weight at a much slower rate than the left between days 1 and 7 (Fig. 2).

Our findings are in accord with the changes in the electrocardiogram and vectorcardiograms during the first week of infant life, as described by Peñaloza *et al.* (1960). They showed there was right ventricular preponderance at birth, but at the end of the first week left ventricular preponderance was beginning to emerge. In the dog the left ventricle simply becomes the predominant ventricle at an earlier age, viz. 5 days after birth. The left ventricle thickens and enlarges more rapidly than the right in the newborn pup, as shown in Fig. 4. This agrees with the results of Gluck *et al.* (1964), who showed that the left ventricle of the rabbit increased in size much more rapidly than the right in the postnatal stage. During fetal development the dog heart develops myofibrils and mitochondria at a much faster rate in the right ventricle than in the left (Schulze, 1962). After birth the fibres in the right ventricle become distinctly thinner than those in the left (Hort, 1955; Boellard, 1952).

In the newborn infant the apex is formed by both ventricles, but at 3 months the apex is formed usually by the left ventricle only (Hort, 1966). From birth, however, the apex of the dog heart is formed solely by the left ventricle (Fig. 4). Therefore it would appear that the left ventricle in the dog at birth contributes more to the total ventricular weight than it does in man.

The LV/RV ratio showed no significant change between days 1 and 3, which might be expected since there was no significant change in either left or right ventricular weights during this time. But between days 5 and 9 there *was* a significant change in the left ventricular weight, without a significant change in the right ventricle, producing a significant increase in the LV/RV ratio during this period. From days 9 to 17 both right and left ventricles grew harmoniously, with no significant change in LV/RV ratio (Table 1).

The fall in the ratio of the weight of the right ventricle to the total ventricular weight between days 1 and 7 resulted from the slower rate of increase of the right ventricular weight as compared with the left. The fact that the increase in total ventricular and heart weights was slight up to day 9 (Table 1) was apparently largely due to the very slow growth of the right ventricle during the first 9 days after birth.

SUMMARY

We have found that, in the dog at birth, the right ventricle weighed significantly more than the left. At 3 days the left ventricle weighed the same as the right ventricle. No evidence for postnatal atrophy of the right ventricle was found – the right

ventricle simply gained weight at a much slower rate than the left. The left ventricle weighed significantly more than the right at 7, 9, 11, 13, 15 and 17 days.

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