THE RATIO BETWEEN THE HEART-WEIGHT AND BODY-WEIGHT IN VARIOUS ANIMALS.[1]

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Introduction.—In this paper are given the results of observations, which I have made, on the relation between the heart-weight and the body-weight in different animals. So far as I am aware, very little, if anything, has appeared on this subject in this country, although considerable work has been published on this and closely related subjects in Europe. For that reason I have thought it worth while to collect from previous investigators a few of the figures which seemed most interesting and have arranged them in tabular form near the end of this communication.

In the literature, we find numerous tabulations which give the weight, dimensions, etc., of the various organs of the body, and also the relation between the size of individual organs and the size of the body. These have been determined for man in the normal and in several pathological conditions. Vierordt (1) gives tables showing the weights and measurements of almost every organ of the body. Bergmann (2) gives the relation of the heart-weight to the body-weight in man and several species of animals. Parrot (3) published an extensive article upon this relation in fifty or more species of birds. Hasenfeld and Romberg, (4) W. Müller (5) and Külbs (6) may be mentioned. Many of the normal ratios were determined in order to have controls for experiments upon the effects of exercise or valvular defects of the heart upon cardiac hypertrophy and related subjects. There are some variations between the figures of these investigators for an individual species, but for the most part they are fairly constant. The use of different methods may account for many of the differences.

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The Writer's Observations.—During the past five months the relation between the heart-weight and body-weight has been studied in the animals used in this laboratory for other purposes. The animals were weighed before any operation was begun, after death the heart was removed in a uniform manner (by cutting all vessels at the point where they joined the heart), the cavities were opened and carefully washed free from clots and the heart was weighed. The animals in which this relation was studied were dogs, cats, rabbits and guinea-pigs.

By the term "ratio of heart-weight to body-weight"—a term which will be used frequently in this paper—is meant the number of grams of heart tissue for every kilogram of body-weight. For example, a ratio of 4.5 would mean four and one half grams of heart tissue per kilo of body-weight.

The ages of the animals in my series of observations were unknown. No comparison, therefore, could be attempted between the ratios of younger animals and those that were older.

The animals of each species have been grouped in two ways. *First,* they were grouped according to *sex,* in order to get a comparison between the average ratio of heart-weight to body-weight in males and females of an individual species. *Second,* they were grouped according to *sex* and *body-weight.* To do this the animals of the first grouping were arranged so that the average ratio of animals having an equal (or nearly equal) body-weight could be determined. The purpose of this was to compare the ratios of lighter animals with those of heavier animals of the same species.

Grouping According to Sex.—In the following table there is an arrangement of animals according to sex only. Column six contains the "ratios."

TABLE I.

Species.	Sex.	Number of Animals.	Average Body-Weight in Grams.	Average Heart-Weight in Grams.	Average Ratio in Grams.	Average Per Cent. of Heart-Weight to Body-Weight.
Dog	Male	58	8,029	59.23	7.43	0.743
	Female	60	6,038	45.46	7.61	0.761
Cat	Male	11	3,078	13.80	4.56	0.456
	Female	15	2,650	12.34	4.58	0.458
Rabbit	Male	38	1,606	4.31	2.67	0.267
	Female	66	1,697	4.57	2.70	0.270
Guinea-pig	Male	14	384	1.70	4.22	0.422
	Female	33	257	1.03	3.91	0.391

It will be seen from the table that the ratios for cats and guinea-pigs are almost the same, while that for dogs is much higher and that for rabbits much lower. As a possible explanation for the very low ratio of the rabbit, two factors may be mentioned. First, the inactivity of tame rabbits and probably a larger amount of body fat as a result. Second, the large size of the stomach and cæcum. Especially after a very full feeding this last factor would exert a marked influence upon the ratio. A ratio derived from rabbits with the weight of stomach and cæcum contents excluded would undoubtedly be nearer that found in the other animals.

The difference in the ratios of males and females in an individual species is so slight in my series as to be of small significance. In cats and rabbits the male and female ratio is almost identical. In dogs the table above shows a difference of only .18 gram of heart-tissue per kilogram of body-weight in favor of the female. In guinea-pigs there is a difference of .31 gram per kilogram in favor of the male.

In December a preliminary report upon the ratios of dogs and rabbits was made before the New York Pathological Society. In that report the tables contained half or less than half the number of animals which are included at present. It is interesting to note that after almost doubling the number of these animals, the ratios have scarcely been changed at all. This fact seems to indicate that the ratios given represent the true ratio for each species. It is illustrated in the following table, which contains the number of animals upon which report was made at the meeting in December and also the number in the present report, with the corresponding ratios.

TABLE II.

Species.	Sex.	Table Referred To.	Number of Animals.	Ratios.
Dogs.	Male.	Former report.	28	7.50
		Present "	58	7.43
	Female.	Former "	25	7.64
		Present "	60	7.61
Rabbits.	Male.	Former "	21	2.70
		Present "	38	2.67
	Female.	Former "	36	2.88
		Present "	66	2.70

From this table we see first that the addition of thirty male dogs changed the ratio only .07 grm. of heart-tissue per kilogram of body-weight; second, that the addition of thirty-five female dogs changed the ratio only .03 grm. per kilo; third, for male rabbits the addition of seventeen made a change of .03 grm.; and fourth, for female rabbits, the addition of thirty made a change of .18 grm. per kilo. This last is by far the largest variation of the four, and yet even it is, for practical purposes, negligible.

In the following table are given the highest and lowest ratios found in each sex of each species. The difference between them is quite marked in some instances, especially in the cases of male dogs and male guinea-pigs. However, there were very few animals of these two species which gave such a wide variation from the average obtained for the species.

TABLE III.

Species.	Sex.	Highest Ratio Found.	Lowest Ratio Found.	Average Ratios Given in Table I.
Dog	Male	10.55	5.35	7.43
	Female	9.51	5.72	7.61
Cat	Male	5.86	3.61	4.56
	Female	5.57	3.35	4.58
Rabbit	Male	3.42	2.07	2.67
	Female	4.47	2.00	2.70
Guinea-pig	Male	7.03	2.64	4.22
	Female	5.79	2.66	3.91

Heinz (7) (Vol. I, Part 2, page 886) gives a table of nineteen dogs with an average ratio of 9.71. Among the nineteen dogs he has seven with a ratio of 10.00 or over and eight with a ratio of 9.00 or over. In my table, with a total of 118 male and female dogs, there is only one animal which goes as high as 10.00 (and that one was a very distinct case of pathological hypertrophy), and but six animals as high as 9.00. My average for dogs, it will be remembered (Table I), was about 7.50—or 2.2 grams per kilo dog less than the average given by Heinz. That is, taking a ten kilo dog, the total heart-weight, using Heinz' average, would be 97.0 grams, while a dog of the same weight, using my average, would have a heart weighing but 75.0 grams—a difference of 22 grams. This is a much greater difference in weight than could be explained by the

use of a different method of removing the heart. It would suggest a possible difference between the dogs of Germany and of the United States, or rather of New York.

Groupings According to Sex and Weight.—In the following table the dogs have been arranged in groups according to their body-weight, those having an equal, or almost equal, weight being placed in a single group.

TABLE IV.

Body-Weight.	Female Dogs.		Male Dogs.	
	Number of Animals.	Average Ratio.	Number of Animals.	Average Ratio.
3,000– 3,999	6	8.07	1	9.69
4,000– 4,999	13	7.88	4	7.58
5,000– 5,999	12	7.90	7	6.16
6,000– 6,999	10	7.28	8	7.82
7,000– 7,999	9	7.13	13	6.99
8,000– 8,999	6	7.13	7	8.18
9,000– 9,999	3	7.48	7	7.18
10,000–10,999			2	7.23
11,000–11,999			2	7.13
12,000–12,999			4	7.22
13,000–13,999			2	6.45

We see from this table that in the case of both male and female dogs, as we pass from the lighter to the heavier ones, the ratio gradually becomes less. Or, in other words, the relation of heart-weight to body-weight follows, in general, the law of an inverse proportion. It seems to me this law might be connected with the well-known observation that the smaller the animal the higher the pulse rate. We know that skeletal muscle responds to increased activity by a hypertrophy. Since a more rapid heart beat means greater activity of cardiac muscle, may it not be that this faster rate of beat in the younger animal is the cause of a physiological hypertrophy of the heart?

When the average normal relation between the heart-weight and body-weight has once been determined, it is found that, in general, this average ratio holds fairly constant for members of that species. This is illustrated by the following instance: A dog, whose body-weight had not been previously determined, was used in the laboratory. After death, the body-weight was estimated from the weight of the heart (using an average for dogs already determined) to be

12,450 grams. To test the accuracy of this estimate, the animal was then weighed and due allowance made for loss of blood during the operation. The actual weight was found to be 12,100 grams, an error of only 350 grams. There were many more instances in which a like result was obtained by a reverse of the above illustration, *i. e.*, by estimating the heart-weight from the known body-weight, then weighing the heart to find how accurate the estimate had been. It was a very common thing to predict within one to three grams the total heart-weight.

There are, however, several factors which tend to cause individual variations from a general average ratio determined for a species. These factors may be placed under two heads. First, those which cause changes in the size of the body, such as growth (normal or abnormal), excess of fatty tissue, pregnancy, emaciation, etc.; second, those which cause changes in the size of the heart, such as increased bodily activity or pathological cardiac conditions from which compensatory hypertrophy of the heart would result.

Vierordt has shown in his published tables that for man the relative amount of heart-tissue per kilo of body-weight decreases with the advance of age, or, in other words, that the *young* individual has a higher ratio than the older individual. It is found in other tables (my own included) that the *light* individuals have a higher ratio than heavier members of the same species. It would seem that both these factors, *i. e.*, age and size, exert a certain influence upon the ratio. Of course, we usually expect a young animal to have a smaller body-weight than an older one, and if this were invariably true, it would be unnecessary to speak of age and size as separate factors. But we know that these two factors need not, necessarily, run parallel, since we have young animals of large size and older animals of small size.

Another thing which may cause a difference between the ratios of two animals of the same species, independently of a change in the size of the heart, is the presence or absence of a normal amount of fatty tissue. For instance, an emaciated dog, because of a reduction in the body-weight, would show a high heart ratio, while for an opposite reason, a very fat dog would show a low ratio. In predicting the size of the heart in a live animal, it is sometimes nec-

essary to keep this fact in mind. Aside from the three factors already mentioned, the literature contains abundant evidence that increased bodily activity or valvular defects of the heart will bring about very great differences in the ratios of an individual species. For example, Külbs took two young dogs from the same litter and kept one of them shut up in a cage, while the other was made to exercise strenuously in a treading machine. After some time they were both killed. The body-weight of each was almost exactly the same, but the heart of the exercised animal weighed 152 grams, while that of the caged animal weighed only 99 grams. This experiment gives one a definite idea of the pronounced effect which the factor of bodily exercise may have upon the size of the heart.

Whether the amount of muscular activity can account altogether for the difference in the ratios of the *different species* of animals seems somewhat doubtful, and yet this factor undoubtedly exerts a marked influence, as is shown by the following table of ratios, collected from different sources. The animals are so arranged that

TABLE V.

Species.	Sex.	Body-Weight in Grams.	Heart-Weight in Grams.	Grams of Heart Tissue, per Kilo of Body-Weight.	Author Quoted.
Tame rabbit	Unknown	1,916	4.56	2.36	Hasenfeld und Romberg
Wild rabbit	Unknown	1,120	3.07	2.76	Grober[8]
Guinea-pig	Male	384	1.70	4.22	Joseph
	Female	257	1.03	3.91	"
Pig	Unknown	49,700	225	4.52	Bergmann
Cat	Male	3,078	13.8	4.56	Joseph
	Female	2,650	12.3	4.58	"
Cattle	Male	280,000	1,450	5.35	Bergmann
	Male (cst.)	545,000	1,410	3.86	"
	Female	398,000	1,523	3.83	"
Man	Male	58,000	340	5.88	"
	Female	50,000	273	5.47	"
Sheep	Male	20,600	127	6.17	"
	Female	20,600	118	5.85	"
Horse	Male (cst.)	493,000	3,000	6.77	"
	Unknown	417,000	2,400	5.81	"
Hare	Male	3,666	28	7.70	"
	Female	3,500	25	7.17	"
Dog (American)	Male	8,029	59.23	7.43	Joseph
	Female	6,038	45.46	7.61	"
Dog (German)	Unknown	4,706	47.3	9.71	Heinz
Deer	Male	20,600	238	11.55	Bergmann
Bird (thrush)	Unknown			25.64	Parrot

the one with the lowest ratio is at the top and that with the highest ratio at the bottom of the list, the column of ratios (Column 5) exhibiting a gradual increase as one approaches the bottom. It is also very plain that the amount of bodily activity in the various animals given follows, in a general way, the same order of increase as the ratios—the more active animals being at the bottom of the table.

One or two points shown in this table are worthy of special notice. We find the tame and wild rabbits at the top with ratios of 2.36 and 2.76 respectively. Now if we look near the bottom of the list, we will find the hare, a very near relative of the rabbit, with a ratio of almost 8.0. In this case it is very easy to see the influence of activity.

The ratio of the deer (11.55) and especially of the thrush, a very active flyer and songster (25.64)—almost twelve times as great as that of the tame rabbit—are also very interesting.

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