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Biometric Analysis of Splancnic and Somatic Weight in Infancy

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Summary. During 712 consecutive autopsies on liveborn infants, body weight and the weight of single organs were systematically recorded. These data have provided the material for a statistical investigation.

Tables and graphs have been prepared to allow a statistical estimate of the normal value of the weight of organs in the first year of life, as a function of body weight and/or the subject's age.

It has been shown that in this period, the weight of an organ varies as a linear function of these two independent variables, whose action is sometimes synergic and, more rarely, in conflict in determining the weight of the organ.

Key words: Organ weight – Body weight – Normal values – Biometry – Regression analysis.

Introduction

It has been known for some time that the weight of the human organs is a basic datum in the anthropometric sciences and in interpreting physiopathological or clinical findings (Berry, 1969). The persistent interest taken in the measurement of weight in the past has increased greatly with the appearance of biomedical techniques based on morphological criteria such as computerized tomography (Heymsfield et al., 1979), echography (Sapira and Williamson, 1979; Worburton et al., 1979), scintigraphy, etc.

In the past, many weight analyses on adults have been published, especially in anthropological texts (Martin and Saller, 1962), whereas data dealing with subjects under one year old refer to rather small samples, which are, in any case, not very recent (Coppoletta and Wolbach, 1933; Giordano, 1938; Gruenwald and Minh, 1960; Schulz et al., 1962).

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The first year of life is, however, the period when increases in weight are most rapid, and thus the period in which constant reference to normal values is most useful in assessing pathological cases. It need hardly be said that weights measured in normal subjects in the first year of life are of interest to students of pure and applied morphological sciences as well as paediatricians (Gilchrist et al., 1978).

Since the Authors had the opportunity of measuring body weight and the weight of organs examined during the autopsies performed in a large children's hospital between May 1974 and November 1978, it seemed useful to pool data from the 712 cases in which the weight of normal organs was available for a statistical analysis based on the linear regression method. The aim was to obtain graphs which would make it possible to immediately determine whether the weight of an organ in a patient falls within normal limits.

Material

The material for this study has been gathered from the records of 712 postmortem examinations carried out at the 'Bambino Gesù' Children's Hospital, Rome.

All the data refer to liveborn infants which had died before the age of one.

The sample examined comprises 407 male (57.2%) and 305 female (42.8%) infants. Distribution according to age and sex is given in Table 1. The division of cases into male and female is a traditional practice but, since preliminary calculations revealed no statistically significant differences, no breakdown according to sex was adopted in determining body weight and the weight of organs. This allowed the standard error to be calculated from a higher number of observations than would otherwise have been the case. In any event, if sex-dependent differences do exist, they are proportional to body weight, which, in the present study, has been chosen as one of the independent variables for the calculation of the expected value of the weight of single organs.

All the cases examined at autopsy were Italian, and they made up a fairly homogeneous population, as they all came from the central and southern regions of Italy.

In preparing this study, the diagnostic examination included the measurement of body weight, and of the weight of the heart, lung, liver, spleen, kidney, adrenal and thymus while still wet. The brain was weighed whenever it had to be examined. The two kidneys were weighed together

Table 1. Number of cases by age and sex

Age	Number of cases		
	Male	Female	Total
Birth – 1 month	297	215	512
> 1 m. ≦ 2 m.	31	24	55
> 2 m. ≦ 3 m.	19	14	33
> 3 m. ≦ 4 m.	22	11	33
> 4 m. ≦ 5 m.	8	11	19
> 5 m. ≦ 6 m.	10	8	18
> 6 m. ≦ 7 m.	6	3	9
> 7 m. ≦ 8 m.	5	3	8
> 8 m. ≦ 9 m.	0	4	4
> 9 m. ≦ 10 m.	2	1	3
> 10 m. ≦ 11 m.	1	2	3
> 11 m. ≦ 12 m.	6	9	15
Total	407	305	712

and the weight of a single organ was assumed to be half the total weight. The same is true of the adrenals. All weights were measured by the same staff using the same scale.

In any case, body weight, which was calculated immediately before the examination, was compared with the last value obtained intra vitam, usually on the day when death occurred. As already reported (Gruenwald and Minh, 1960) there is an actual fall in body weight soon after death. This may be attributed to the evaporation of the body in the interval between death and autopsy; the Italian health laws do not allow autopsy to be carried out less than 24 h after death. It has been found that this fall in weight, whose mean value is 50 g, is surprisingly constant.

Statistical Methods

As may be seen from Table 2, and, still more clearly, by comparing this with Table 1, the numbers of observations (n) shown for the weights of various organs within a single age group are not constant. Since the aim has been to obtain values representative of a normal population, it has, in fact, been decided to utilize only the weights of those organs which showed no appreciable lesions in each case. This criterion has already been adopted in the literature (Coppoletta and Wolbach, 1933; Gruenwald and Minh, 1960; Schulz et al., 1962), and leaves open the question of how far an organ examined at autopsy can be considered normal (Gruenwald and Minh, 1960).

The difficulty of obtaining normal values is particularly hard in the case of the lung, which,

Table 2. Weights of organs by age

Organ		Age												
		Birth –7 d.	2–4w.	2 m.	3 m.	4 m.	5 m.	6 m.	7 m.	8 m.	9 m.	10 m.	11 m.	12 m.
Brain	$\bar{Y}$	248.3	291.7	455.0	525.0	543.5	–	717.0	–	–	–	–	–	963.7
	s	95.9	401.4	85.8	120.2	60.0		24.0						175.4
	n	33	11	4	2	4		2						4
Heart	$\bar{Y}$	14.9	19.4	23.4	29.6	35.8	36.0	35.8	43.6	35.0	30.0	–	43.0	51.8
	s	5.3	6.7	8.1	6.9	17.0	13.5	8.8	11.8	11.9	14.1		15.5	17.7
	n	282	115	39	25	24	8	13	6	6	2		2	10
Liver	$\bar{Y}$	91.6	134.8	165.2	212.8	190.1	222.6	237.9	347.3	–	190.0	–	–	275.0
	s	209.1	138.1	50.4	39.0	40.2	63.8	39.7	133.8		90.5			67.3
	n	302	83	22	13	16	13	9	6		2			6
Spleen	$\bar{Y}$	7.5	9.9	12.1	15.3	18.2	17.1	19.0	34.9	16.0	13.0	–	–	25.3
	s	4.4	3.8	6.1	11.1	7.4	10.6	9.4	23.1	5.2	12.8			16.4
	n	320	127	37	21	23	14	12	7	6	4			11
Kidney	$\bar{Y}$	22.7	32.4	36.6	50.0	43.3	50.9	65.0	36.5	–	22.5	32.5	–	32.2
	s	11.7	13.6	13.1	11.6	12.6	18.6	17.2	13.6		10.6	33.7		12.1
	n	292	85	23	11	18	13	10	4		2	2		6
Adrenal	$\bar{Y}$	5.9	5.7	5.5	5.9	6.7	7.2	5.9	4.3	2.3	3.0	3.5	–	6.5
	s	2.9	2.6	2.8	1.7	4.4	2.1	2.1	0.9	0.5	1.7	0.7		9.5
	n	284	119	31	20	16	8	8	4	4	3	2		8
Thymus	$\bar{Y}$	7.1	5.3	6.1	10.4	14.8	9.2	6.0	8.9	2.6	7.5	–	3.5	12.9
	s	4.7	3.9	5.9	10.2	8.2	5.8	5.3	4.1	2.9	9.2		3.5	9.2
	n	322	117	36	19	14	9	11	6	3	2		2	9

$\bar{Y}$ = mean of Y (weight of the organ)
s = standard deviation
n = number of cases

as regards the measurement of weight, can be considered a hollow organ. The decision to exclude pathological organs from the analysis led to such a large reduction in the number of observations which could be used to evaluate the weight of the lung that no statistical processing of the few data referring to definitively normal lungs was carried out.

In processing data, mean weight ($\bar{Y}$), deviance (Σy^2), variance (s^2) and standard deviation (s) have been calculated for each organ and each age group. The values of $\bar{Y}$, s and n are shown in Table 2. These data have yielded the standard error of the mean (S_m), which allows comparison with other series and the evaluation of differences due to racial factors (Schulz et al., 1962). Weights for which only one observation was available for any given age group have been omitted from Table 2.

Further statistical analysis of data has aimed to determine whether there is any relationship between the weight of an organ (assumed to be a dependent variable and called Y) on the one hand, and body weight and age of subject (assumed to be independent variables, and called X and Z), on the other.

In elaborating data, body weight has been allocated to classes whose range is 200 g, and the mean value has been calculated for each. Similarly, age at death has been allocated to one of 24 classes whose range is half a month each.

The weight of single wet organs, on the other hand, has not been allocated to classes, even during the statistical processing of data.

Graphs were then drawn in which the experimental data appeared as the points at the intersection between two coordinates – the weight of the organ, Y, as ordinate, and body weight, X, as abscissa. As analysis of the graphs appeared to involve difficulties yielding no practical advantage, it was decided to determine the regression line only. By allowing interpolation between data, this method makes it possible to obtain continuous functions from discontinuous observations, to construct graphs from data and to measure the fiducial interval on the graph.

The demonstration that the weight of an organ is a function both of body weight and of the age of a subject does not, however, make it possible to determine whether the two independent variables analysed have a synergic or conflicting effect in determining the dependent variable, or to calculate the effect of one independently of the other. To assess the effect that the two independent variables exert separately, one must go on to calculate multiple regression.

Calculation of the multiple regression equation enables the two regression coefficients to be evaluated comparatively, and $\hat{Y}$ to be calculated on the basis of each of the two independent variables. Such double calculation of $\hat{Y}$ is particularly valuable when, as a result of abnormal conditions – even when these are linked with individual variability – the estimate of $\hat{Y}$ as a function of X and Z, respectively, yields appreciably different values.

Lastly, the evaluation of the coefficient of partial regression allows the standardized coefficients of partial regression to be calculated. Once standardized, such coefficients are adjusted for their variability and may be compared. It thus becomes possible to discover which of the two independent variables the dependent variable is more closely correlated with.

Results

The results are shown in Tables 1–4 and Figs. 1–7.

Table 2 shows the mean weight of the organs examined, as a function of the subject's age, which has been divided into classes corresponding to the first twelve months of life. For ease of consultation the first month has been subdivided into the first and the other three weeks. The variability of the sample is expressed by the standard deviation, s. The Table also gives the number of different observations, n, contributing to the calculation of each mean.

For each organ (Figs. 1–7) two graphs have been drawn. These show the relationship between the weight of the organ, Y, and body weight, X, in one case, and the subject's age, Z, in the other. The straight line given by calculating linear regression has been drawn on each of the Cartesian planes. This line

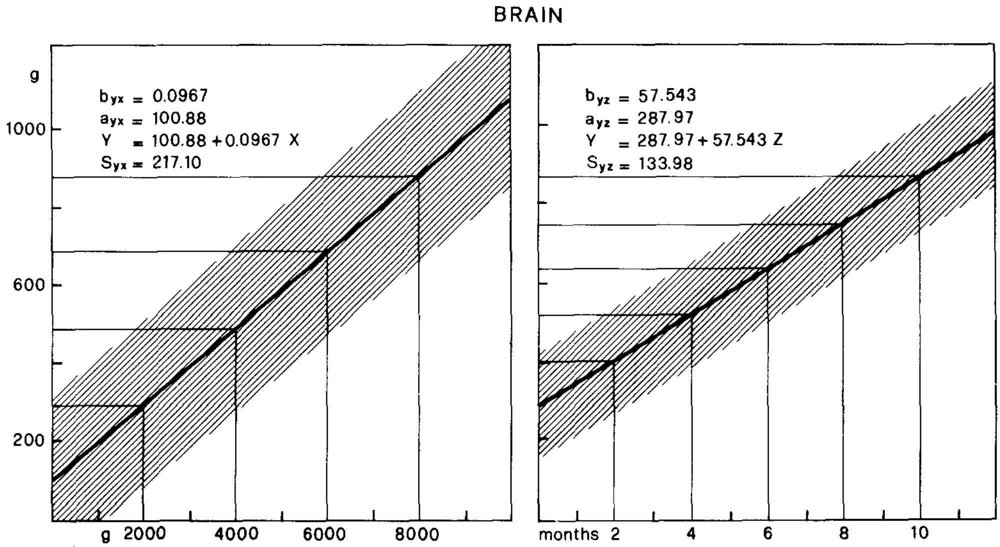

Fig. 1. Regression lines for the prediction of the weight of brain (Y) from body weight (X) or age of subject (Z)

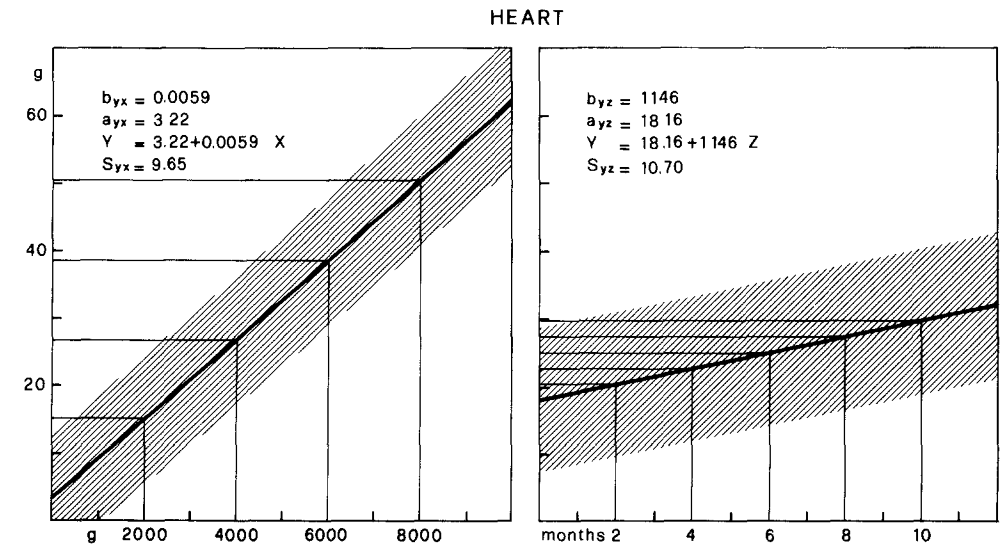

Fig. 2. Regression lines for the prediction of the weight of heart (Y) from body weight (X) or age of subject (Z)

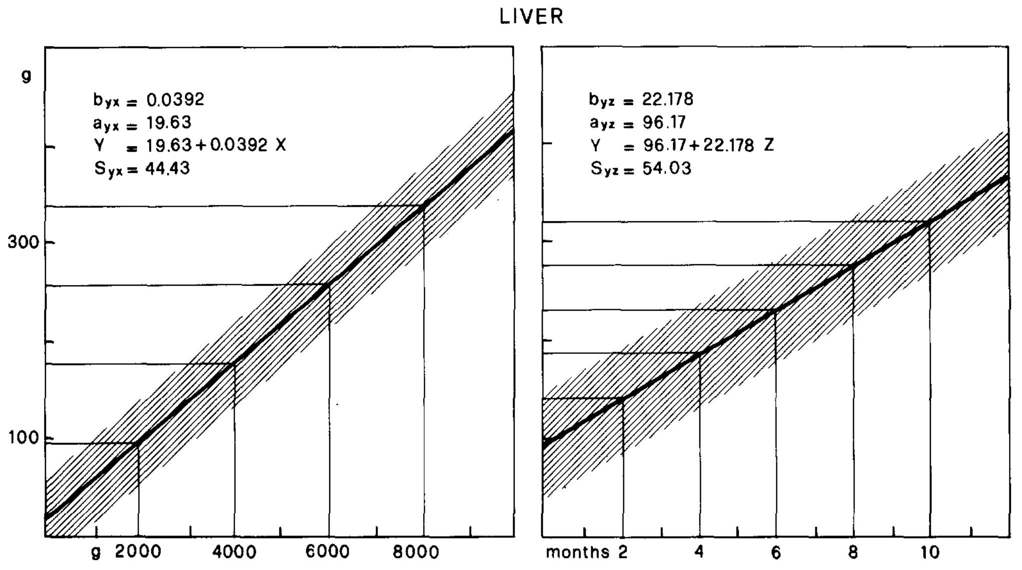

Fig. 3. Regression lines for the prediction of the weight of liver (Y) from body weight (X) or age of subject (Z)

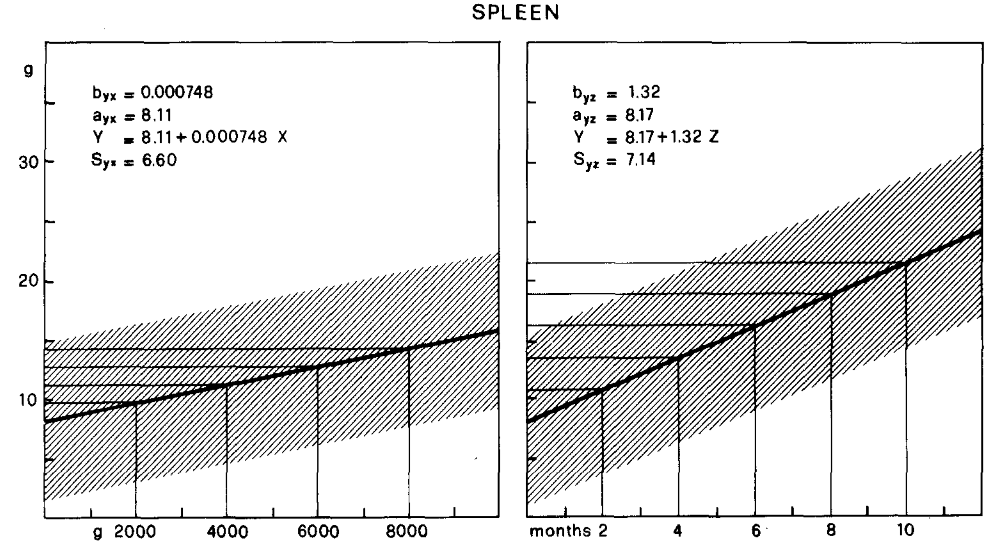

Fig. 4. Regression lines for the prediction of the weight of spleen (Y) from body weight (X) or age of subject (Z)

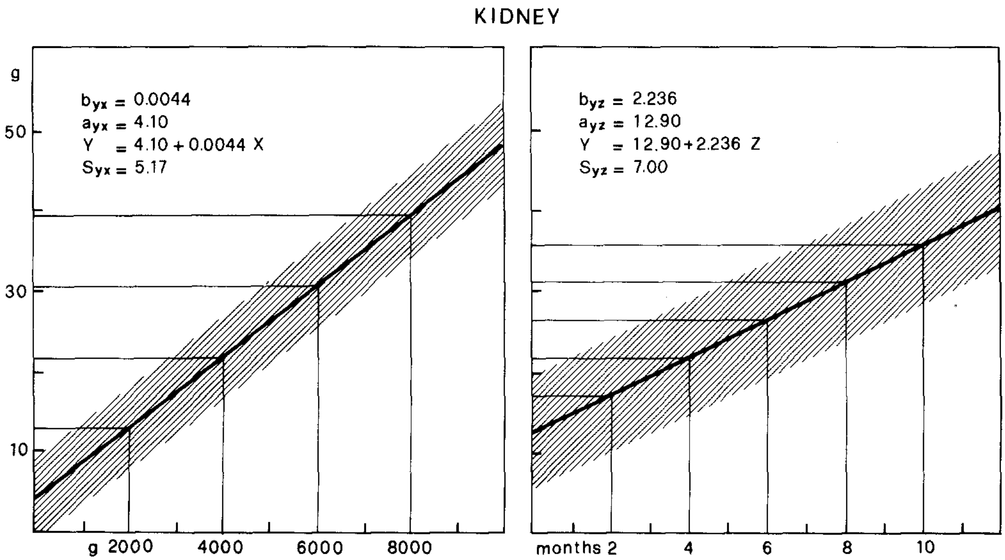

Fig. 5. Regression lines for the prediction of the weight of kidney (Y) from body weight (X) or age of subject (Z)

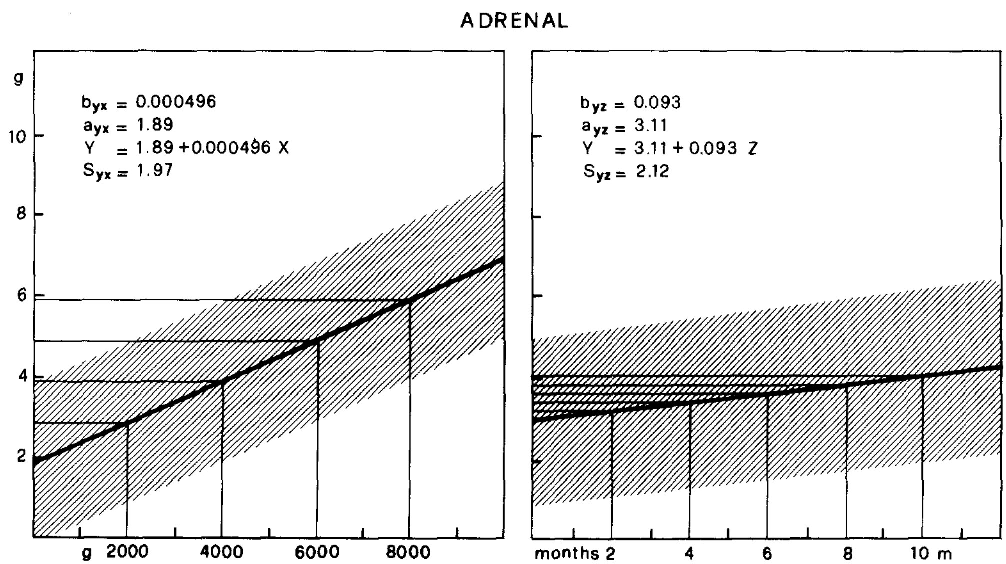

Fig. 6. Regression lines for the prediction of the weight of adrenal (Y) from body weight (X) or age of subject (Z)

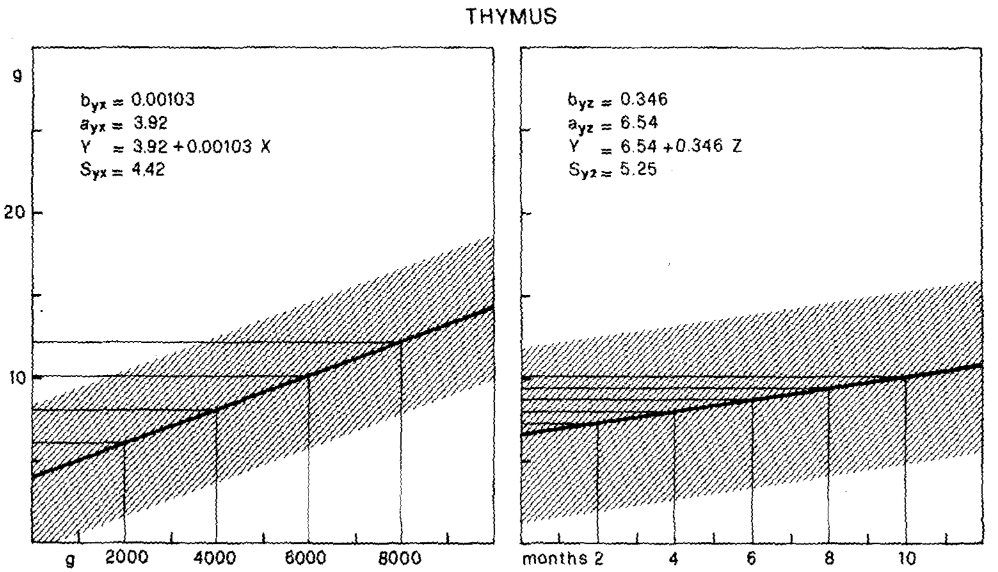

Fig. 7. Regression lines for the prediction of the weight of thymus (Y) from body weight (X) or age of subject (Z)

Table 3. Multiple regression equations for the prediction of the weight of an organ (Y) from body weight (X) and age of subject (Z)

Organ	Multiple regression equations
Brain	$\hat{Y}=156.08+0.0615\,X\ +29.732\,Z$
Heart	$\hat{Y}=\ 3.89+0.00546\,X+\ 0.374\,Z$
Liver	$\hat{Y}=\ 38.13+0.0261\,X\ +12.964\,Z$
Spleen	$\hat{Y}=\ 6.59+0.000556\,X+\ 1.201\,Z$
Kidney	$\hat{Y}=\ 5.16+0.00351\,X+\ 1.008\,Z$
Adrenal	$\hat{Y}=\ 1.73+0.000615\,X-\ 0.121\,Z$
Thymus	$\hat{Y}=\ 3.75+0.00116\,X\ -\ 0.138\,Z$

Y and X are expressed in grams, Z in months

is accompanied by two ideal straight lines running parallel to it; their known term differs from that of the regression line by $\pm 1\ S_{yx}$. The shaded area enclosed by these two lines includes two-thirds of all the observations made. When the weight of an organ, Y, falls outside the fiducial limit demarcated by the interval spanning $\pm 2\ S_{yx}$ which centers on the expected value of Y, $\hat{Y}$, as calculated from the regression equation for X or Z, it must, from a statistical viewpoint, be considered significantly different ($P<0.05$) from the sample population, and thus pathological.

Each graph is accompanied by the equation defining the regression line and by the standard error with respect to the values expected.

Table 3 shows the equations for multiple regression.

Lastly, Table 4 shows the standardized coefficients of partial regression, and compares them by subtracting the coefficient of partial regression for age, $b_{z'}$, from that for body weight, $b_{x'}$.

Table 4. Standardized b coefficients for each of the multiple regression equations, and the differences between the coefficients in each case

Organ	$b_{x'}$	$b_{z'}$	D	D_{mod}
Brain	+0.549	+0.429	+0.120	+0.120
Heart	+0.769	+0.151	+0.618	+0.618
Liver	+0.525	+0.402	+0.123	+0.123
Spleen	+0.257	+0.480	−0.223	−0.223
Kidney	+0.636	+0.289	+0.347	+0.347
Adrenal	+0.432	−0.143	+0.575	+0.289
Thymus	+0.391	−0.131	+0.522	+0.260

b' = standardized b coefficient
$D = b_{x'} - b_{z'}$
$D_{mod} = |b_{x'}| - |b_{z'}|$

Discussion

The results shown in the figures and tables are self-explanatory, so that discussion will be restricted to a few outstanding points.

First of all it may be noted that the biometric data previously reported in the literature consist basically of tables of unprocessed data, whereas statistical analysis of the present findings on weight by means of linear regression has made it possible to reconstruct continuous variations from discontinuous data. Thus an absolutely definite normal value for the weight of an organ, with its fiducial limits, has been found for each age group and each value of body weight during the first year of life.

Figures 1–7 satisfy two different aims. The first is that of offering a convenient way of identifying the "expected" value of the weight of a normal organ, for any value of body weight or age of subject, and also of using the standard error to assess the statistical probability that a given value is the result of a normal or pathological condition.

The second – predictive – aim is that of demonstrating that the normal weight of an organ during the first year of life is a linear function both of body weight and of the subject's age.

Even a rapid glance at the graphs, however, makes it clear that this relationship is not equally close for all the organs examined, and that the role played by the two independent variables (body weight and age) in determining the dependent variable differs from organ to organ. It is, in fact, apparent from the graphs that body weight has a predominant role in allowing the weight of organs such as the heart, adrenal and thymus to be predicted, whereas it is more important to know a subject's age than his, or her, body weight in predicting the weight of the spleen.

Similarly, Table 3 can be read in two different ways – descriptive and predictive. Descriptively, it allows the greatest precision in evaluating the expected weight of an organ when both body weight and the age of the subject are known. To do this, one need only replace the two unknowns by the corresponding values of X and Z (expressed in grams and months, recpectively) and calculate the algebraic sum.

Attention must also be drawn to the meaning of the minus sign before the coefficient of partial regression for Z in the equations for the adrenal and thymus. This indicates that the weight of these organs would fall with age, if it were not for the positive effect expressed by the relationship linking this weight with body weight.

As regards the comparison between the standardized coefficients of partial regression in Table 4, it may be noted that the difference between them, D, is always positive, except in the case of the spleen, which appears to be the only one of these organs for which age is the predominant independent variable in determining the weight of the organ. With all the others, it is body weight which has the main role in determining the weight of the organ, so that D is positive, most clearly so in the case of the heart, adrenal and thymus.

The high positive value of D in the case of the adrenal and thymus does not, however, imply that age has no influence on the weight of the organ, but that its influence is negative.

Thus, if one wishes to evaluate the difference between the intensities of these two coefficients independently of the type of effect – increase or decrease – produced, this must be done by comparing the moduli of the values obtained, that is, after eliminating their sign. When this parameter, D_{mod}, is used, the values of D for adrenal and thymus are appreciably lower, whereas that for the heart is unchanged. This shows that the influence of body weight is strongly predominant only in this case.

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