Newborn Brain:Body Weight Ratios

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ABSTRACT Newborn brain:body weight ratios are generally considered to be constant in man. In autopsy studies many factors influence the measured weight of the brain, and therefore the conclusions based on such observations, including the gestational age of the material, the presence or absence of intrauterine growth retardation, and the cause of death. In this study these influences have been eliminated by careful selection of normally grown fullterm newborns not subject to the factors influencing brain weight. Using double logarithmic plots, brain size in fullterm newborns is found to be related to the 0.64 power of birth weight. There is a negative correlation between relative brain size and increasing fullterm birth size in man.

The concept of cephalisation put forward by Jerison ('55) has been widely used in inter-specific comparisons. The index, however, has not been applied when comparing population groups within a species. Nor is there a comparable index providing a basis for such analysis. While brain size varies widely, the ratio of brain to body weight in adults varies within narrow limits. The same is said to be true of the fullterm fetus or neonate.

The ratio of brain to body weight is constantly changing during fetal growth. It is high in the early fetal period and falls progressively to term, when it reaches a value of approximately 9–10%. Certain observations are to be noted when comparing autopsy data from different sources. Calculations made on the findings of Potter and Yerushalmy ('61) and those of Nikhailets (quoted by Young, '71), e.g., show the following.

1. The brain to body ratio has a fairly wide range in full-term fetuses. In the Potter-Yerushalmy series it varies from 13.04 to 8.55%.

2. Concordance is lacking when comparing the ratio in comparable weight categories drawn from the two series.

Numerous factors are responsible for the variations in this ratio in cross-sectional material of this type. They have an important bearing on the selection of cases in studies to determine the ratio in normally grown newborn.

1. Autopsy material, unless carefully selected, is liable to contain a number of fetuses and newborn with inappropriate growth. Growth retardation may affect the brain and general body mass to different degrees. When the condition is due to placental vascular insufficiency bodily growth is retarded but brain growth is unaffected, so that brain size is normal for gestational age but relatively large for the size of the fetus. In contrast to this type of growth retardation, maternal protein restriction produces symmetrical retardation and the brain is not spared (Osofsky and Schaefer, '73).

2. A neonate of 3000 gm born at the 37th week of gestation would have attained a weight of approximately 3600 gm at term. It may, in the absence of precise information on the menstrual history and other data, be classified as a fullterm infant at autopsy. Yet the brain-to-body ratio in a fetus of 37 weeks gestational age differs significantly from that of an equal sized fetus born at fullterm.

3. Much of the additional weight in the very large full-term newborn is due to the deposition of fat and glycogen and, in the case of infants of diabetic and pre-diabetic mothers, retention of water in the subcutaneous tissues. The additional weight in these instances has nothing to do with

growth in the usually understood meaning of the term. It may produce a deviation of the brain to body ratio. It is also known (Jordaan, '73) that in a rectangular diagram the plot for the very large (over 4000 gm) infants consistently falls below the regression line of brain on body weight. (The over 4000 gm group has in fact been excluded from the data used to determine the relation between brain and birthweight in the full-term fetus in this study).

What then is the quantitative relationship between brain and body weight in full-term fetuses of different weight? Of several theoretical possibilities two are mentioned here. The ratio of the brain weights of two fetuses may have the same relationship as that of their respective body weights, i.e., the brain is a fixed percentage of the body weight; or the brain weight with greater full-term size may be proportional to a certain power of the increased weight, that is, there is an allometric relation between brain and body weight.

MATERIAL

Newborns satisfying the following criteria were selected for inclusion in the study group.

1. *Maturity*

Only infants with these criteria for maturity were included in the normal group.

(a) A gestational age of 39 to 41 weeks provided the antenatal record showed the fundal height to correspond with the calculated gestational age (based on the menstrual history in those with regular cycles). The date fetal movements were first felt and the time the fetal heart was first audible were of value in some instances.

(b) A minimal fetal length of 48.5 cm (or 19 inches).

(c) A paediatric gestational score corresponding to at least 39 weeks according to the score sheets used in the Groote Schuur Hospital Pediatric Units. A copy of the score sheet is reproduced here (fig. 1).

(d) Additional data, sometimes available, were of help in establishing the age of the fetus: (i) radiological evidence, (ii) information on the amniotic creatinine value (Pitkin and Zwirek, '68), (iii) the amniotic sphingomyelin/lecithin ratio (Gluck et al., '71) and (iv) amniotic cytology (Brosens and Gordon, '68).

2. *Intra-uterine growth retardation*

Only cases with no growth retardation were selected. The diagnosis of this condition was suspected on the basis of the following.

(a) Failure of the mother to gain weight in a satisfactory manner in the course of antenatal supervision. The weight gain standards applied in this series are those suggested by Eastman and Jackson ('68).

(b) Failure of the fundus uteri to rise in the expected manner during the period of antenatal care.

(c) Cases in which maternal urinary estriol assay revealed either initial low 24 hour values or a failure to rise on repeated assays.

(d) Failure of the fetal biparietal diameter to follow the trajectory shown in figure 2 in those cases in which ultrasonography was used to determine the pattern of intra-uterine growth.

(e) Multiparous gravid subjects in their sixth and subsequent pregnancies were excluded from the series. Their exclusion is based on the observation that in this population (Jordaan, '73) birth weight rises significantly ($r = 0.78$) with birth order up to the 5th pregnancy and thereafter falls.

Other criteria

Infants who at postmortem examination had any abnormality, such as intracranial haemorrhage or disease of an inflammatory nature were excluded from the study, as were those with genetic and congenital anomalies. The list includes Trisomy 21 (Down's syndrome), microcephaly, Patau's syndrome, Cri du chat (elimination of the short arm of the 5th chromosome), and hydrocephaly.

Only infants who were stillborn (i.e., fresh stillbirths) and neonates dying within the first 24 hours were selected.

The cause of death affects the weight of the brain in post mortem observations in adults, higher mean values being encountered in those who die from hanging, barbiturate poisoning, and shock, whereas lower values are found where death follows brain disease, general pathology, head trauma, protracted haemorrhage, carcinoma, and arteriosclerosis. The relationship between the mean brain weight and the cause of death is discussed by Tobias ('70). Those cases where the numerous factors known to af-

SOMERSET HOSPITAL

GESTATIONAL SCORE SHEETS

SCORE	GESTATIONAL AGE (WEEKS)	SCORE	GESTATIONAL AGE (WEEKS)	SCORE	GESTATIONAL AGE (WEEKS)
5	28.1	15	35.9	25	40.3
6	29.0	16	36.5	26	40.6
7	29.9	17	37.1	27	40.8
8	30.8	18	37.6	28	41.0
9	31.6	19	38.1	29	41.1
10	32.4	20	38.5	30	41.2
11	33.2	21	39.0	31	41.3
12	33.9	22	39.4	32	41.4
13	34.6	23	39.7	33	41.4
14	35.3	24	40.0	34	41.4

NAME : ....

OEDEMA	0 - 2
SKIN TEXTURE	0 - 4
SKIN COLOUR	0 - 3
SKIN OPACITY	0 - 4
LANUGO	0 - 4
PLANTAR CREASES	0 - 4
NIPPLE FORMATION	0 - 3
BREAST SIZE	0 - 3
EAR FORM	0 - 3
EAR FIRMNESS	0 - 3
GENITALIA	0 - 2
SCORE	
POSTURE	0 - 4

Figure 1

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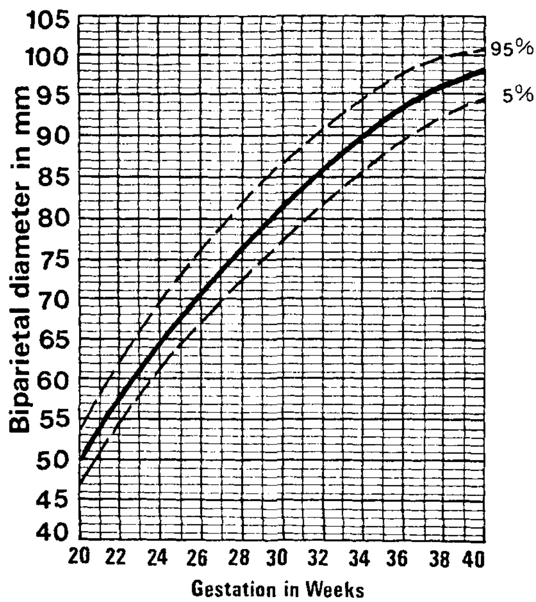
FETAL BIPARIETAL DIAMETER GRAPH



Mean and 95% and 5% tolerance limits. (Campbell 1971)

Figure 2

fect the measured brain weight were present, were excluded from the series: neonates dying in the first 24 hours from septicaemia, pneumonia, gastro-enteritis, and intracranial haemorrhage. Fresh stillbirths due to intra-uterine pneumonia and intracranial haemorrhage were also rejected.

The postmortem interval

Only those cases in which the autopsy was performed within 24 hours of death and the cadaver had been refrigerated until the time of the autopsy, were included in the series.

Of 576 autopsies in the series, 393 were rejected as unsuitable for the type of information required, leaving 183 cases in the study group.

METHOD

1. The weights of the infants were tabled using a class interval of 400 gm. The mean birth weight and the mean brain weight for each category were recorded as well as the logarithm (to base 10) of each value (tables 1, 2).

TABLE 1

Birth and brain weights

Birth weight (gm)		Brain weight (gm)	Brain: body
Class interval	Class mean	*Mean*	*Ratio (%)*
2400–2799 (n = 63)	2603.73	345.70	13.28
2800–3199 (n = 56)	3034.60	382.73	12.61
3200–3599 (n = 37)	3398.00	412.30	12.13
3600–3999 (n = 14)	3720.03	430.59	11.57
4000+ (n = 13)	4211.90	444.66	10.56

2. Using a double logarithmic plot, a rectangular diagram was constructed demonstrating the two properties, brain and body weight, on the X and Y axes respectively. Only the first four categories of body

TABLE 2

Log_{10} birth and brain weights

Logarithm (base 10)		
Birthweight	Brain weight	Frequency
(X)	(Y)	
3.4157	2.5387	63
3.4821	2.5829	56
3.5312	2.6152	37
3.5705	2.6341	14
3.6244	2.6482	13

TABLE 3

Comparison of observed and calculated brain weights

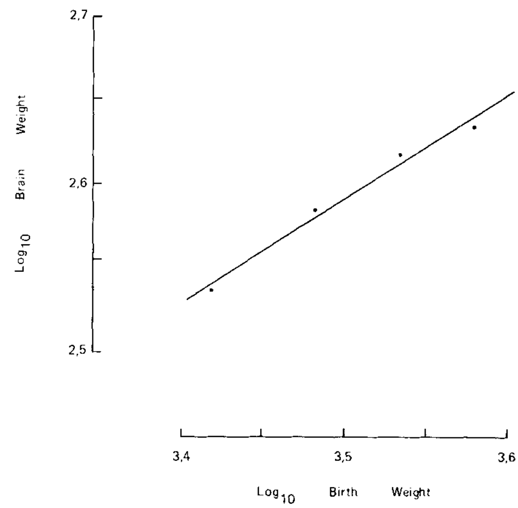
Birth weight	Observed brain weight	Calculated brain weight	Difference	Percentage error
(gm)	(gm)	(gm)	(gm)	
2603.73	354.7	346.99	+ 1.29	+0.37
3034.60	382.63	381.65	− 1.08	−0.28
3398.0	412.3	411.43	− 0.87	−0.21
3720.03	430.59	437.03	+ 6.44	+ 1.5

weight were used to determine the correlation between birth and brain weight, i.e., the highest birth weight category was excluded.

3. Inspection of the resultant plot showed the values to be closely scattered about a straight line. In order to eliminate subjectivity in defining the best straight line, a regression line using the method of least squares was plotted (fig. 3).

DOUBLE LOGARITHMIC PLOT OF

BRAIN WEIGHT AGAINST BIRTH WEIGHT



Brain weight = 2,21 (Birth weight)^{0,64}

Correlation coefficient : r = 0,9990

Regression line : y = 0,64x + 0,35

(y = $\log_{10}$ brain weight; x = $\log_{10}$ birth weight)

Figure 3

RESULTS

The following results were obtained.

(i) Brain weight in fullterm fetuses is proportional to the 0.64 power of the birth weight.

(ii) The correlation coefficient between brain and birth weight is r = 0.9990.

(iii) The regression line of brain on body is

$$y = 0.64 \times + 0.35$$

where y = $\log_{10}$ (brain weight); X = $\log_{10}$ (birth weight). These relations are defined in the double logarithmic plot (fig. 3).

When the exponential of fullterm birth weight, to which brain weight is related, is applied to the class mean birth weight to determine the related brain weights (table 3), the deviations between the observed and calculated values are negligible. This is to be expected as the determination of the exponential is based on this population of figures. Because of the rigid application of the criteria of normality in selecting material for this study, the constant of proportionality (0.64) provides a useful method of determining the relative brain weight in normal fullterm fetuses or newborns of different weight or size.

DISCUSSION

The size of a body is rather a vague concept however important it may be from the biologic point of view. If size is expressed in a single measurement there is a choice from a number of different total dimensions, such as length or volume or even the measurement of a single organ which bears a constant allometric relation to any total measurement. While volume is the most general measurement providing a standard of comparison of quantity, it is not regularly or easily obtained. Total body weight, however, provides a satisfactory standard of comparison of size. The weight of a body is equal to the product of its volume and specific gravity. Because the latter is constant for a species, the weight relation between two members of the same species is the same as that between their respective volumes. The relationship between brain and body weight in fullterm fetuses may, therefore, be expressed as brain weight is proportional to the 0.64 power of the total volume. This value is very close to the 0.66 or 2/3nd power of the volume, a well-known relation in geometry: in a series of homomorphic bodies the numerical values of the surface area are proportional to the 2/3nd power of the volumes. Brain weight in the fullterm fetus is, therefore, closely correlated with the total body surface area.

When brain weight is expressed as a percentage of total body weight the index ranges from 10.56 to 13.28% with a mean value of 12.67% (table 1). These figures appear to be high compared with, for example, those of Potter and Yerushalmy ('61) in which the range is from 8.55% in the highest (over 4500 gm) birth weight category to 13.28% in the lowest birth weight stratum. The apparent difference in the two ranges can be accounted for by the exclusion of the highest birth weight group in the present study. The mean value of 12.67% does not differ significantly from Young's ('71) figure of 12.81% calculated on Mühlman's autopsy data.

The exponential (0.64) of birth weight to which brain size is related in human newborn is almost identical to the value of 0.63 (Stephen, '72) expressing the size relationship between brain and body weight in inter-specific comparisons of related groups of different mammals.

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