Early Human Development, 1977, 1/2, 145—149

Head circumference as an index of brain weight in the fetus and newborn

R.W.I. COOKE[1], A. LUCAS[1], P.L.N. YUDKIN[2] and J. PRYSE-DAVIES[3]

University Departments of [1] Paediatrics, and [2] Obstetrics and Gynaecology, John Radcliffe Hospital, Headington, Oxford, and [3] Queen Charlotte's Maternity Hospital, London, United Kingdom

Received 14 December 1976 Accepted 17 May 1977

SUMMARY

Postmortem brain weight and head circumference were measured in 485 fetuses and newborn infants. A cubic relationship was demonstrated between these two variables in normal infants. Statistically, a significantly larger brain weight for a given head circumference was found in small-for-gestational-age infants.

head circumference; brain weight; newborn

INTRODUCTION

Measurements of head circumference, usually the occipito-frontal circumference (OFC), have been used for many years as an index of brain size, although little direct or quantitative correlation of these two variables is available. Serial measurements of OFC are also often used to follow brain growth after the neonatal period. It is essential to be able to estimate brain size in live newborns when studies of brain metabolism or cerebral blood flow are carried out. Estimates based on body weight are likely to be inaccurate, owing to the wide natural variance of the ratio of brain weight to body weight [1], and so a correlation between brain weight and OFC was sought.

MATERIALS AND METHODS

The postmortem examination reports for all stillborn infants and infants dying in the first week of life at Queen Charlotte.s Hospital, London, between 1965 and 1975 inclusive were reviewed. Infants identified as suffering from hydrocephalus, anencephaly, neural tube defects, any recognizable chromosomal disorder, or macerated stillbirths were excluded. 485 infants (264 male, 221 female) remained. The gestational age according to last menstrual period, the birthweight, sex, head circumference measured at postmortem examination and brain weight were abstracted. Gestational age ranged from 18 to 43 wk, all but 9 infants being between 22 and 42 wk gestation with a mean gestation of 31.3 wk. 63 of these 485 infants had a birthweight below the 10th percentile for their gestational age [2] and were termed 'small-for-gestational-age' (SGA). Their gestational ages ranged from 24 to 42 wk, with a mean gestation of 32.9 wk. The remaining 422 infants were termed 'appropriate-for-gestational-age' (AGA).

RESULTS

There was a linear relationship between $\log_{10}$ brain weight and $\log_{10}$ OFC (Fig. 1). The relationship between brain weight and OFC could thus be described as:

$$\log_{10} BW = b. \log_{10} C + K \quad (1)$$

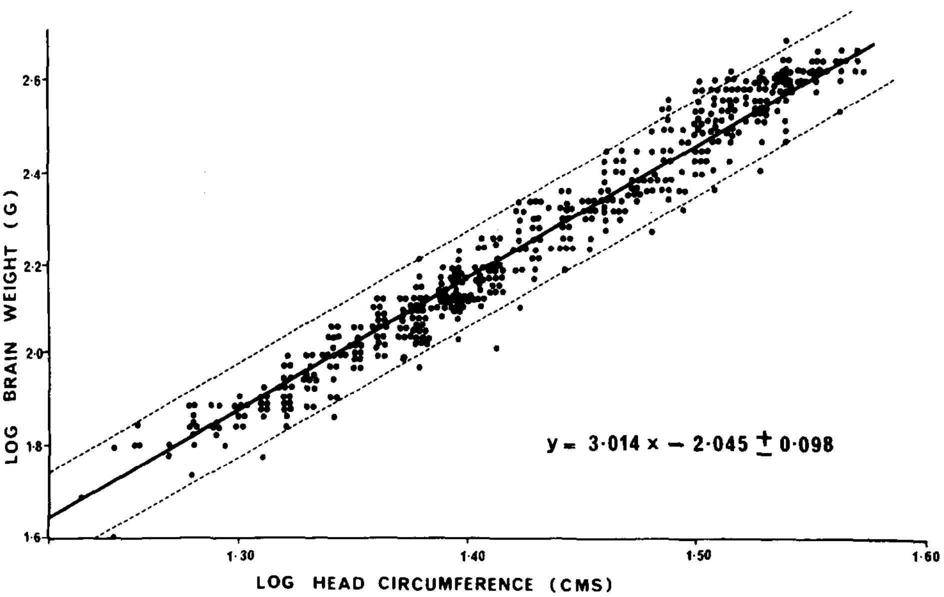

Fig. 1. Data for all infants (N = 485). Regression of $\log_{10}$ brain weight (G) with $\log_{10}$ OFC (cm), with 95% confidence limits for an individual prediction of brain weight from OFC.

where BW = brain weight; C = OFC; b = regression coefficient; K = constant let K = log k; by taking anti-logs of eq. (1), eq. (2) is derived

$$BW = C^b \times k \qquad (2)$$

The values for regression coefficient (b) and for a constant (K) in eq. (1), and correlation coefficients (r) were derived for all infants, for appropriate and small for gestational age, male and female subgroups.

A close correlation between $\log_{10}$ brain weight and $\log_{10}$ OFC was found in each group ($r \geqslant 0.979$). The confidence limits on an individual prediction were such that a useful estimate of brain weight could be made from OFC. These values are summarized in Table I.

TABLE I

Summary of value for constants in eqs. (1) and (2), with correlation coefficients and confidence limits for an individual prediction of brain weight

Groups	N	r	b	K	95% confidence limits	k(anti-log K)
All infants	485	0.980	3.014	−2.0458	±0.098	0.0090
AGA (M and F)	422	0.981	3.001	−2.0306	±0.097	0.0093
SGA (M and F)	63	0.981	3.225	−2.3188	±0.096	0.0048
All male infants	264	0.979	3.078	−2.1367	±0.099	0.0073
All female infants	221	0.982	2.951	−1.9547	±0.096	0.0111

The calculated 95% confidence limits for a single prediction of brain weight from OFC varied very little with changing values of OFC. Their value for the mean OFC only in each group is given in Table I.

The regressions of $\log_{10}$ brain weight with $\log_{10}$ OFC for appropriate and small for gestational age, and for male and female groups were compared by means of analysis of covariance.

SGA infants had a statistically significantly higher brain weight for a given OFC than AGA infants ($P < 0.005$) (Table II). No difference in the relationship between $\log_{10}$ brain weight and $\log_{10}$ OFC in males and females was found.

TABLE II

Analysis of covariance table for AFG/SGA groups

Source	df	Total SSq	SSq due to regression	SSq about regression	df	MSq
Between groups	1	.0523				
Within groups	484	30.9494	29.7944	1.1550	483	.0024
Total	485	31.0016	29.7965	1.2051	484	
Difference for testing adjusted means				.0501	1	.0501

$F\ (1{,}483) = 20.960; P < .005$.

DISCUSSION

Measurement of OFC in the newborn is a widely used indicator of brain size, although until recently, few data directly relating the two were available. Winick and Rosso [3] showed a correlation between OFC and brain weight in a small group of infants dying in the first year of life. The relationship was described by a square law. Bray [4] measured intracranial volume (ICV) in live infants using multiaxial radiography, and showed a close correlation between ICV and OFC. Buda [5] using the same technique derived a regression equation relating OFC and ICV which was linear and contained a constant which depended on sex and age. He concluded that measurement of ICV by multiaxial radiography gave no better guide to brain size than OFC, provided that the infant's skull shape was normal. Since the relationship between the volume of an object and its circumference is not linear, this equation could only be used to derive values of ICV from OFC over short ranges defined by the constant used. It could not be used in small infants with OFC less than 32 cm.

Gruenwald [6], in extensive postmortem studies, showed a correlation between brain weight and gestation, and between OFC and gestation. He did not correlate these two variables directly as he felt that the effects of growth retardation prevented this being a useful method of assessing brain weight. He states that errors would arise from the fact that subdural and subarachnoid spaces of preterm infants are larger than in growth retarded infants. For the same OFC, a growth retarded infant would have a larger brain than a preterm infant. However, in the present study, we find a good correlation between OFC and brain weight in all groups of infants, although statistically significantly larger values for brain weight for a given OFC in small for gestational age infants.

The use of OFC as a means of deriving brain weight, suffers from the errors involved in measuring OFC. Subdural space variation, scalp oedema, scalp thickness and differing measurement techniques may all introduce error [6] . Head shape will alter the relationship between OFC and intracranial volume [5] . Where this has occurred due to biparietal flattening in premature infants, biaxial measurement of the skull and application of a correction factor may reduce error [7] . Of the infants examined, all had died too early to develop marked skull flattening.

Nevertheless, we conclude that OFC is a useful index of neonatal brain weight, and an actual value for brain weight may be obtained from OFC using the regression equation for the appropriate group. Small for gestational age infants statistically have a relatively larger brain weight for OFC.

REFERENCES

1 Dobbing, J. and Sands, J. (1973): Quantitative growth and development of human brain. Arch. Dis. Child., 48, 757—767.
2 Lubchenco, L.O., Hansman, C., Dressler, M. and Boyd, E. (1963): Intrauterine growth as estimated from liveborn birth weight data at 24 to 42 weeks gestation. Pediatrics, 32, 793—800.
3 Winick, M. and Rosso, P. (1969): Head circumference and cellular growth of the brain in normal and marasmic children. J. Pediatr., 74, 774—778.
4 Bray, P.F., Shields, W.D., Wolcott, G.J. and Madsen, J.A. (1969): Occipitofrontal head circumference, an accurate measure of intracranial volume. J. Pediatr., 75, 303—305.
5 Buda, B.F., Rabe, E.F. and Reed, J.C. (1975) : Skull volume in infants, methodology, normal values and application. Am. J. Dis. Child., 129, 1171—1176.
6 Gruenwald, P. (1969): In: Perinatal Problems, the Second Report of the 1958 British Perinatal Mortality Survey, pp. 141—169. Editors: N.R. Butler and E.D. Alberman. E. & S. Livingstone Ltd., London.
7 Baum, J.D. and Searle, D. (1971): Head shape and size of pre-term low birth weight infants. Dev. Med. Child Neurol., 13, 576—581.