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Growth of Human Nervous System. I. Growth of Cerebral Surface.

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The interest in the extent and variability of the cortex of the human brain has led to a number of estimates of the surface area of the cerebrum (generally in the adult) by a variety of ingenious methods.[1-7] We have attempted to extend these studies by an experimental investigation of this area through a portion of the developmental period (from the fourth fetal or lunar month of prenatal life to 2 postnatal years) and in maturity. Our technique is described in detail in a forthcoming paper.[8] Briefly stated, the method consists of sectioning formalin fixed brains enclosed in a matrix with a mechanical device into slices 2 to 3.5 mm. in thickness. The area is then determined by measuring the outline of each section with a chartometer and multiplying the reading by the thickness of the section. The surface of the cerebrum is approximated by the sum of the values so obtained. Attempts to improve this technique by computing the sections as segments of cones and taking the means of their anterior and posterior outlines did not increase the accuracy of our determinations. Twenty cerebri were so studied. Figure 1 shows 10 of these drawn to scale (left lateral views) to illustrate the changes in size and form and in the configuration of the sulci in the series.

In measuring these structures figures were obtained for both "total" and "free" surface. "Total" surface indicates the entire cerebral surface including that portion buried in all of the cerebral fissures regardless of their depth. "Free" surface is a term used for the visible or external surface of the cerebrum only. In determining this value the chartometer was passed around the periphery of each

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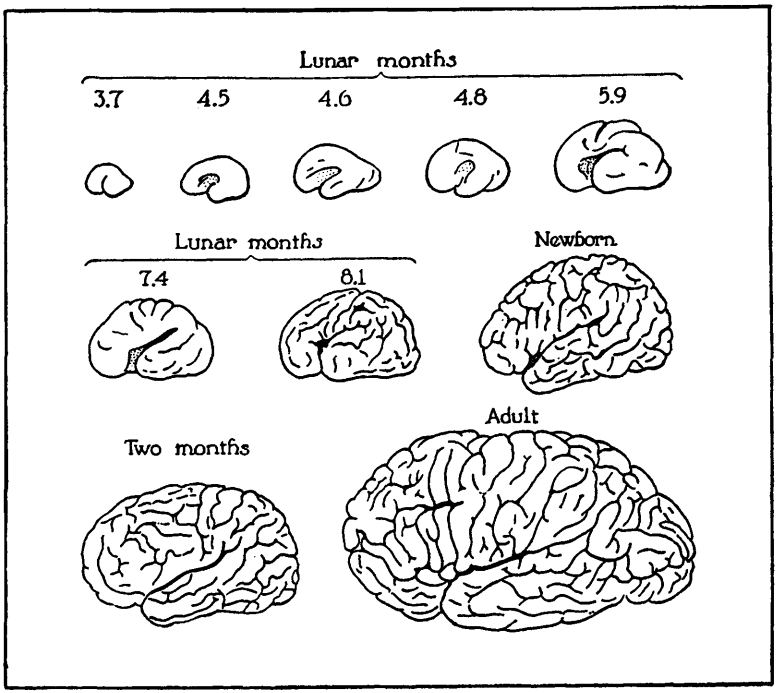

FIG. 1.
Ten outline drawings of the left lateral surfaces of human cerebri used in this study. All drawings made to absolute scale.

section but only dipped into the lips of the sulci to the shallow point where their sides meet. The medial surfaces of the cerebri were included in both types of measurement, but with the exclusion in both instances of the connecting masses of tissue such as the corpus callosum, the basal nuclei, the surface of the third ventricle, and the like. The results of these measurements are shown in Table I and Fig. 2.

There seem to be 3 stages in the growth with respect to time of "total" cerebral surface. Apparently there is a very rapid increase in the fourth lunar month, although we think our material is too limited to indicate any great or even regular increase in the fifth or sixth month. In the seventh and eighth lunar months, however, there is evidently a very vigorous increase in total surface of the cerebrum and there is obviously an even greater growth between 8 lunar months and birth.

In postnatal life there seems to be a marked absolute, although not relative, increase in infancy and very early childhood, but there is comparatively little, if any, increase after the latter period. The

TABLE I.
Observations of Human Cerebral Surface.

	Age	Cerebral Volume (cc.)	Cerebral Surface* "Total" (sq. cm.)	Cerebral Surface* "Free" (sq. cm.)	Cerebral Length (cm.)
(1)	3.7 lunar months†	5.2	19.7	15.4	2.5
(2)	4.5 " "	22.5	58.9	47.1	4.8
(3)	4.6 " "	14.7	39.7	33.2	3.8
(4)	4.7 " "	18.7	49.2	43.2	4.5
(5)	4.8 " "	22.8	45.0	38.2	4.5
(6)	4.8 " "	22.0	49.8	41.7	4.1
(7)	5.9 " "	57.0	105.2	77.6	6.5
(8)	7.2 " "	114	184.2	126.6	7.2
(9)	7.4 " "	87.0	128.2	93.1	7.0
(10)	8.1 " "	106	176.0	105.8	8.0
(11)	Newborn	320	679.3	219.9	11.0
(12)	"	340	716.2	241.2	10.2
(13)	0.17 yr.	375	724.1	249.9	11.0
(14)	0.32 "	455	954.1	333.2	13.3
(15)	0.44 "	440	944.1	294.8	11.8
(16)	2 "	970	1666.4	457.3	15.6
(17)	26 "	1000	1635.3	552.9	17.2
(18)	44 "	1025	1610.1	568.7	17.2
(19)	49 "	955	1468.7	523.1	16.5
(20)	Adult (age unknown)	795	1437.2	494.0	17.0

*Cerebral surface calculated to 2 decimals and thrown to one.
†Ages of fetuses calculated from body length by the Scammon-Calkins ('29) empirical formula.

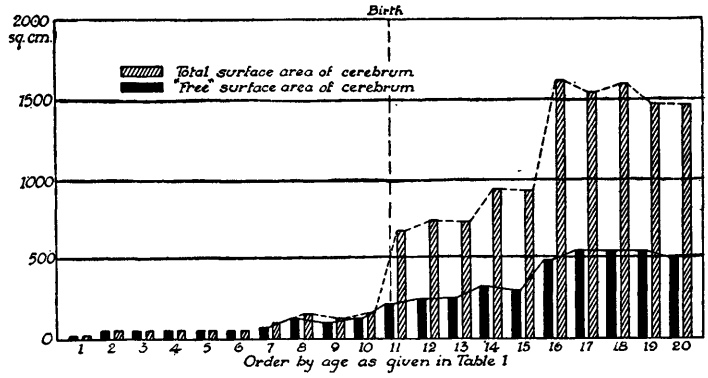

FIG. 2.

A bar diagram illustrating the growth of the "total" and "free" surface of the cerebrum. The shaded bars represent "total" cerebral surfaces and the black bars the concomitant "free" cerebral surfaces. The bars are arranged in order of age, but no attempt has been made to space them with respect to time.

"total" surfaces of the cerebrum more than double in postnatal life, but our limited set of observations (assuming that case No. 16 is normal, as all objective evidence indicates) is a process confined to early postnatal life.

The "free" cerebral surface follows much the same course as "total" surface until about 8 lunar months, but the increase between

this time and two years, while striking, is much less rapid. As in the case of "total" surface, the relative increase is small.

We may, then, regard the interval from about 6 lunar months to some time in the second postnatal year as the period of rapid absolute increase in cerebral surface, with a peak of the most noticeable growth in "total" surface area in the last trimeter of fetal life. These observations seem to be in accord with earlier purely morphologic observations on the time and extent of formation of the cerebral sulci in man. Our figures indicate some decrease in cerebral surface after the third decade, but again we do not think the series sufficiently large to warrant this assumption.

The relationships of cerebral volume and length to cerebral surface, which seem to us the more interesting, will be considered in following papers.

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Growth of Human Nervous System. II. Indices of Relation of Cerebral Volume to Surface in Developmental Period.

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The estimation of the area of the human cerebrum has become a matter of considerable interest since the mass of the cerebral cortex is closely related to the surface area of the brain.

This subject has been investigated by a quantitative study of 20 brains ranging in age from the fourth (lunar) month of prenatal life to the close of the fifth decade and in volume from about 5 cc. to over 1000 cc. The method of measuring surface area is described in other papers[1, 2] and the volume was determined by the displacement method. Various indices of the relation of cerebral volume to surface are shown in Table I and in Fig. 1. In both the table and the figure the observations are arranged in order of cerebral volume.

Column (b) of the table and panel (A) of Fig. 1 show the index of "total" surface area divided by cerebral volume (surface in sq. cm., volume in cc.). The index drops slowly at first, until the cere-

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