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.

RICHARD E. SCAMMON AND MEREDITH B. HESDORFFER.

From the Graduate Faculty and the Institute of Child Welfare, University of Minnesota.

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-

[1] Hesdorffer, M. B., and Scammon, R. E., PROC. SOC. EXP. BIOL. AND MED., 1935, **33**, 415.

[2] Hesdorffer, M. B., and Scammon, R. E., *Anat. Rec.*, 1936, **64**, in press.

TABLE I.
Cerebral Indices in Prenatal and Postnatal Life.

Order by Cerebral Volume	Arithmetic		Geometric		"Free" to Spherical "Total" Surface		Age	
	$\frac{S}{V}$	$\frac{FS}{V}$	$\frac{S}{V^{2/3}}$	$\frac{FS}{V^{2/3}}$	$\frac{S}{S'}$	$\frac{FS}{S} \times 100$		
(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	
1	3.80	2.96	6.57	5.12	1.36	77.9	3.7 lunar	months
2	2.70	2.26	6.61	5.53	1.37	83.7	4.6 "	"
3	2.63	2.31	6.97	6.11	1.44	87.7	4.7 "	"
4	2.27	1.90	6.35	5.31	1.31	83.6	4.8 "	"
5	2.62	2.10	7.38	5.90	1.53	80.0	4.5 "	"
6	1.97	1.67	5.59	4.74	1.16	84.8	4.8 "	"
7	1.85	1.36	7.09	5.22	1.47	73.6	5.9 "	"
8	1.47	1.07	6.53	4.74	1.35	72.6	7.4 "	"
9	1.66	1.00	7.85	4.72	1.62	60.2	8.1 "	"
10	1.62	1.11	7.78	5.34	1.62	68.7	7.2 "	"
11	2.12	0.69	14.51	4.70	3.00	32.4	Newborn	
12	2.11	0.71	14.70	4.95	3.04	33.7	"	
13	1.93	0.66	13.92	4.80	2.88	34.5	0.17 years	
14	2.08	0.72	16.49	5.76	3.34	34.9	0.32 "	
15	2.17	0.68	15.95	4.98	3.38	31.2	0.44 "	
16	1.81	0.62	16.74	5.75	3.46	34.4	Adult (age unknown)	
17	1.64	0.58	15.14	5.39	3.13	35.6	49 years	
18	1.57	0.43	17.01	4.66	3.52	27.4	2 "	
19	1.54	0.52	16.35	5.53	3.38	33.8	26 "	
20	1.72	0.61	15.80	5.58	3.27	35.3	44 "	

Explanatory note: Ages of fetuses calculated from body length by the Scammon-Calkins ('29) empirical formula. S = observed "total" cerebral surface; V = observed cerebral volume; FS = observed "free" cerebral surface; S′ = calculated surface of a sphere equal in volume to observed volume of corresponding cerebrum. Broken line in (E) indicates mean value of observed indices. Dotted line in (E) indicates calculated value of ratio of surfaces and volumes of spheres equivalent to observed volumes of cerebri.

brum has a volume of nearly 100 cc. (in the eighth lunar month), and shows practically no regular trend of change thereafter.

A better index is the "total" surface of the cerebrum divided by the two-thirds power of the cerebral volume, for this measure considers the factor of dimensionality. The index thus determined [Table I, column (d), Fig. 1, panel (B)] shows no prominent change until the cerebrum attains a volume of nearly 100 cc. (in the eighth fetal or lunar month) and rises abruptly to a new plateau at a period (just before birth) when there is relatively little increase in volume, and thereafter shows little significant change. There could hardly be a better demonstration of the great relative increase in cerebral surface area by fissuration in later fetal life.

Column (f) and panel (C) show indices of the "total" surface area divided by a value called S′, which is the geometrically calculated surface of spheres of volumes equal to those of the corresponding observed cerebri. Obviously the picture is much the same as

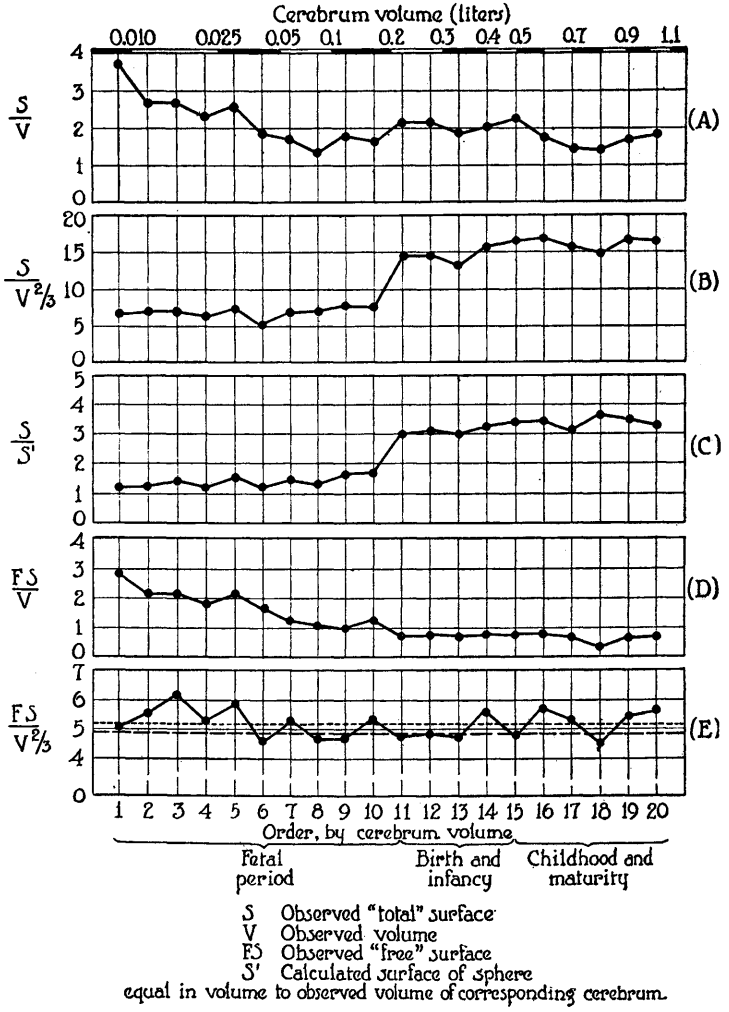

FIG. 1.
Indices of the growth of cerebral surface and volume in man.

in (B), although the numbers and irregularities in the values shown on the graph are smoothed by use of the fractional exponent in the denominator.

Column (c) and panel (D) in Fig. 1 show the relation of the "free" surface of the cerebrum to cerebral volume. Here, as in (A), we see a gradual decline in the index until the cerebrum attains a volume of somewhat over 300 cc. (at birth) and little change thereafter.

Column (e) and the lowest panel (E) in Fig. 1 show the index of the "free" surface of the cerebrum to the two-thirds power of its

volume, again a ratio which is theoretically correct dimensionally. The index so calculated shows no significant change in the series of observations (from a cerebrum having a volume of 5.2 cc. to one with a volume of over 1600 cc.). The values fluctuate, probably with the intrinsic variability of the material and technical inaccuracies of determining cerebral surface and volume. The upper, broken line on this panel of the graph is the mean for the entire number of observed indices in this series (5.2); the lower line is the ratio (R) of the surface of a sphere to the two-thirds power of its volume. This is,

$$R = \frac{4\pi r^2}{(4/3\,\pi r^3)^{2/3}} = 3^{2/3} \cdot (4\pi)^{1/3} = 4.84$$

The closeness of these calculated and observed ratios seems to us very striking and hardly to be accounted for by chance.

Finally, the relation between the "free" and the "total" cerebral surface was determined in the form of a ratio by dividing the former by the latter. The figures thus obtained are shown in Table I, column (g). In general "free" surface is equal to between four-fifths and two-thirds of the "total" surface until the cerebrum attains a volume of the order of 100 cc. (in the eighth fetal month). The ratio then drops rapidly as fissuration takes place until birth, and in postnatal life the "free" surface is approximately one-third of the "total" surface, regardless of the cerebral size.