THE UNIVERSITY OF MINNESOTA

GRADUATE SCHOOL

Report

of

Committee on Thesis

The undersigned, acting as a Committee of the Graduate School, have read the accompanying thesis submitted by Halbert Louis Dunn for the degree of Master of Arts. They approve it as a thesis meeting the requirements of the Graduate School of the University of Minnesota, and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Arts.

Richard E. Scammon
Chairman

C. T. Rasmussen

Henry W. Woltman (Signed by R. E. Scammon in his absence but with his concurrence)

May 25 19~~18~~ 20

THE UNIVERSITY OF MINNESOTA

GRADUATE SCHOOL

Report

of

Committee on Examination

This is to certify that we the undersigned, as a committee of the Graduate School, have given Halbert Louis Dunn final oral examination for the degree of Master of Arts . We recommend that the degree of Master of Arts be conferred upon the candidate.

Minneapolis, Minnesota

May 25 1920

Richard E. Scammon
Chairman

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F. H. Scott

The Growth of the Brain and Spinal Cord in the Human Fetus.

A thesis submitted to the
Faculty of the Graduate School of the
University of Minnesota

by
Halbert L. Dunn

In partial fulfillment of the requirements
For the degree of
Master of Arts.

1920

The Growth of the Brain and the Spinal Cord in the Human Fetus.

Halbert L. Dunn.

Institute of Anatomy, University of Minnesota.

Table of Contents.

The Growth of the Brain and the Spinal Cord in the Human Fetus.

The purpose of this study was two fold; first, to obtain accurate data (in the form of linear measurements, weight and volume determinations, and pictures and figures of gross structures) of the brain as a whole, its component parts, and the spinal cord during fetal life; second, to secure, by means of the graphic method of treatment, a correct conception of the time and rate of growth of the various parts of the nervous system of man in the prenatal period. This work was undertaken under the guidance of Dr. Richard E. Scammon, Professor at the University of Minnesota. Its fulfillment is due in a large measure to his kindness and advice. Thanks are due to Professor L. W. Jones of the School of Chemistry, University of Minnesota, for suggesting the type of volumetric apparatus which was used.

(b) Literature

The literature on this subject is scanty and touches the field only at minor points.

Miller ('13) published an article, "Prenatal Growth of the Human Spinal Cord". He sectioned five spinal cords and determined the proportion of grey and white matter present. He did not indicate rate of growth.

Dockeray ('15) obtained "Volumetric Determinations of the Parts of the Brain in a Human Fetus 156 (Crown Rump)" by sectioning the brain and reconstructing by the wax-plate method.

Retzius ('96) has presented an excellent series of photographs of fetal brains in his "Zur Entwicklungsgeschichte des Menschlichen Gehirns". However, he did not include tables showing size and detailed data.

Jackson ('09) determined the percentage volume of the brain and cord upon forty-three fetuses. From his tables the absolute volumes have been tabulated and recorded on tables XVI and XXV and graphs XI and XVIII. He showed that the maximum relative size of the brain to the body volume was not reached until the second fetal month.

No more material is available upon volume, but much scattered data upon weight has been compiled from every possible source. Five hundred and eight fetal brain weights have been gathered from the following authors: Arnovljevic ('84), Brandt ('86), E. Bischoff ('63), T.L.W.Bischoff ('80), Danielbekoff ('85), Faucon ('97), Handmann ('06), Rüdinger ('77), Schäffer ('92), Valtorta ('09), Welcher ('03). Table XXXVI is a summary of this material and graphs XIX and XXII, which are based upon it, illustrate the percentage increment in weight in fetal life. The number of cases serves as a check upon the one hundred and fifteen brain weights in the present series.

(c) Material

The material, on which the measurements were made, came from the collection of the department of Anatomy of the University of Minnesota. One hundred and fifteen fetuses were measured; forty-one were males, twenty-eight females, and in forty-six the sex was not known. These specimens range in crown heel length from 31 mm. to 536 mm. and were quite evenly distributed. In the entire range there was at least one case for every centimeter of total body length and in many of the centimeter intervals under 300 mm. crown heel length, there were from three to five cases. All specimens were chosen with the view of securing well fixed brains; many soft brains were used, however, for all measurements possible. The material had been fixed in ten per cent formalin, with the exception of five or six cases which had been preserved in alcohol; all had been in the preservative for six months or more.

(d) Methods

Five methods of approach were used in an attempt to gain all angles from which the problem of growth of the brain and spinal cord could be considered.

The first was lineal measurement. All measurements were taken with the vernier caliper and represent the shortest distance between two fixed points.

The second was that of midsagittal tracings. These were made with the brain in situ by placing a thin piece of ground glass upon the medial surface of the brain and outlining the principle features. These outlines were then transferred to tracing paper and filed with the records of the same specimen.

The third method was by photographing under water. For this method the best average brain in each five centimeter interval was selected and the photograph taken from a lateral view. The brain was photographed with a standard measurement so that the entire series is upon a like scale.

The fourth method was weighing. For this a scale was used which weighed accurately to a hundredth of a gram. In every instance before weighing, the brain or cord was stripped of meninges and placed in a piece of dry gauze for half a minute in order to absorb approximately the same amount of surplus fluid.

The fifth method was that of volumetric determination. These measurements were taken by a special apparatus pictured in figure 39. This apparatus was constructed on a plan suggested by

Professor L. W. Jones of the School of Chemistry, University of Minnesota. (A) represents a common iron standard with the clamp (B) attached. The clamp holds a stopper (C) through which a wire (D) passes and by which it is held. Upon this wire is a scratch at the arrow indication. (E) is a piece of isinglass about a centimeter square and pierced by a hole so that it slides easily upon the wire. The wire is placed in an open top bottle (F) which has a spigot at the base and which is partly filled with water. In using the apparatus, the water is drawn off until the isinglass disc, which floats on the surface, touches the scratch on the wire. The brain part, whose volume is desired, is then placed in the water. This raises the surface of the water in the bottle (F). The water is then drawn off into a beaker of known weight until the isinglass again reaches the scratch on the wire. Both the beaker and the water which it contains are weighed. The weight of the beaker alone is subtracted from the weight of the beaker and water in it; this gives the weight of the water displaced by the brain part, viz. its volume. With practice small volumes can be determined accurately with this apparatus. For small volumes it is best to use a 30 or 40 cc. bottle. The difference of one drop of water (approximately one-tenth gram weight which is determined by the area of outlet at the spigot) can be detected if the bottle is small; the difference of two or three drops, if the bottle is large.

The series of measurements taken fall into three groups: linear, volumetric and weight.

The linear measurements are as follows:

(a) Body linear measurements.

1. C.H.-crown-heel length, or total body length; from the

vertex to the tip of the heel.

2. C.R.-crown-rump length, or the sitting height; from the vertex to the tip of the coccyx. (Taken as a check on the crown-heel.)

(b) Brain, linear measurements.

3. F.O.-frontal-occipital length; from the frontal pole to the occipital pole of the cerebral hemispheres. The frontal pole is that point where the anterior, lateral, and inferior surfaces of the frontal lobe meet. In the large brains in situ this point is adjacent to the crista galli. The occipital pole is that point where the posterior, lateral, and inferior surfaces of the occipital lobes meet.

4. T.T.-temporal-temporal diameter; from the temporal pole to the temporal pole of the cerebral hemispheres. The temporal pole is that point most laterally placed upon the temporal lobe. This point becomes less definite in the larger fetuses but can still be approximated with some accuracy.

5. F.S.-frontal-spinal length; from the frontal pole of the cerebral hemispheres to the point of origin of the first cervical nerve. Usually this measurement was taken to the middle of the body of the first cervical vertebra as it was sometimes difficult to identify the first cervical nerve because of the inaccurate midsagittal splitting of the brain.

6. Sp.C.-spinal cord length; spinal cord length taken from the point of origin of the first cervical nerve to the tip of the conus medullaris; the cord is left in situ and a string measurement was taken in order to get the absolute length of the cord.

7. B.C.-brain cord length; the sum of Sp.C. (6), and F.S.(5).

8. P.-pons length; the greatest inferior length of the pons.

9. C.-colliculi length; from the most anterior point of the superior colliculus to the most posterior point of the inferior colliculus.

10. V.L.-vermis cerebellum length; the greatest length of the vermis cerebellum parallel with the axis of the pons and medulla.

11. V.H.-vermis cerebellum height; the greatest height of the vermis cerebellum perpendicular to the axis of the pons and medulla.

12. C.C.L.-corpus callosum length; the greatest length of the corpus callosum measured in a straight line.

13. C.C.H.-corpus callosum height; the greatest height of the corpus callosum at the apex of its curvature.

14. C.M.-corpus mamillare length; measurement of the length of the mamillare protuberance from the brain stem. (Not obtained in many cases.)

15. H.L.-hypophysis length; the greatest length of the hypophysis parallel to the F.O. measurement. (Not obtained in many cases.)

16. H.H.-hypophysis height; the greatest diameter of the hypophysis perpendicular to the F.O. measurement. (Not obtained in many cases but included for reference.)

The volumetric determinations are as follows:

17. V.S.C.-volume of the spinal cord; cord taken from the first cervical nerve to the tip of the conus medullaris and freed from meninges and nerve roots.

18. V.P.M.-volume of the pons and the medulla; pons and medulla cut posteriorly at the first cervical nerve and anteriorly just in front of the pons. Meninges were removed.

19. V.M.B.-volume of the midbrain; midbrain cut just in front of the pons posteriorly and just in front of the superior colliculus and through the pedunculi cerebri behind the mamillare bodies anteriorly. Meninges were removed.

20. V.C.-volume of the cerebellum; severed velum medullaris anterior and posterior to free the cerebellum from the pons and medulla. Meninges were removed.

21. V.R.H.-volume of the right hemisphere; meninges were removed.

22. V.L.H.-volume of the left hemisphere; meninges were removed.

23. V.B.H.-volume of both hemispheres; computed by adding 21 and 22.

24. V.E.B.-volume of the entire brain; computed by the addition of 18, 19, 20, 21, and 22. This method was found to be more accurate in the soft brains than actually taking the volume of all the parts together because of loss of brain tissue in handling.

The weight determinations were taken with meninges removed and with brain parts cut as they were for volumetric determinations. They are as follows:

25. W.S.C.-weight of the spinal cord.

26. W.P.M.-weight of the pons and medulla.

27. W.M.B.-weight of the midbrain.

28. W.C.-weight of the cerebellum.

29. W.R.H.-weight of the right hemisphere.

30. W.L.H.-weight of the left hemisphere.

31. W.B.H.-weight of both hemispheres.

32. W.E.B.-weight of the entire brain.

Treatment of data.

All measurements were completed before any graphic treatment of the data was attempted. In this way the personal equation was eliminated in the accumulation of data. A temporary table was compiled giving all measurements for each fetus. From these records, tables were drawn up giving the average of any measurement for each five centimeter interval.

The graphic treatment consists essentially of three methods. First, the preparation of a series of graphs based upon absolute measurements; second, the construction of a series of graphs showing percentage increments (rate of growth); and third, the preparation of a series of graphs showing the percentage of the measurement to a larger unit.

The first series includes graphs in which the linear, volumetric, or weight determinations for each specimen were plotted against the crown heel length. These are field graphs and represent absolute measurements. In each five centimeter interval of the field graph, two mean points were indicated, the arithmetic average and the median. In each five centimeter interval the position of the mean points were weighted according to the average crown-heel length. Both the arithmetic and the median average are valuable. If the cases are evenly scattered the weighted numerical average is the safer; if they are well clustered with the exception of one or two which are widely divergent, the weighted median is the better. On each graph a smooth curve is drawn. Obviously, if there were a great many cases for each interval the numerical average would become a smooth curve. A smooth curve of this kind is essential in order to translate the absolute graph into terms of percentage increment. However, the material was not sufficient of itself to obtain such a result; consequently, a smooth curve was drawn by <u>inspection</u>. If the average points were too widely divergent to inspect a curve with accuracy, the averages were connected by straight lines.

The second series of graphs consists of a series of percentage increment curves showing rate of growth for every five centimeters of fetal length. Percentage increment is obtained from smooth curves by subtracting the absolute measurement (A) at the beginning of a five centimeter interval from the absolute measurement (B) at the close of the same interval and dividing the result by the former (A).

Example: Let A equal 2 grs. at 25 cm. C.H.

Let B equal 10 grs. at 30 cm. C.H.

Percentage increment

The third series of graphs were field graphs each point of which represent a given measurement (lineal, volumetric, or weight) in percents of some larger unit. This larger unit for the linear measurement was the crown-heel length; for volume, the entire brain volume; and for weight, the entire brain weight. After these points were plotted individually against crown-heel lengths, the weighted numberical and weighted median averages were obtained and then a curve drawn by inspection as previously described.

Observation and Discussion.

The observations and discussion which follow are based upon the data recorded in the tables, graphs, and figures forming a part of this paper. This requires constant reference to these materials. A short index to facilitate this process will be found at the close of this discussion.

Discussion will be limited to the consideration of the absolute growth, the relative growth, and the rate of growth of the brain and its constituent parts, and of the spinal cord. The age estimates which are included in the discussion are based upon the application of Mall's and Hasse's rules to determinations of the crown-heel and the crown-rump length of the specimens studied. Mall's rule was used from the second fetal month to the fifth fetal month and Hasse's from the fifth month to birth. For convenience in reference the relations between the crown-heel and the crown-rump length and age, as determined by these formulae, are tabulated below:

Crown heel length (mm.)	Crown rump length (mm.)	Estimated age (days)	Estimated age (months)
50	38	62	2.
100	72	85	2.8
150	105	105	3.5
200	138	138	4.33
250	172	158	5.25
300	205	187	6.25
350	238	197	6.6
400	272	221	7.33
450	305	265	8.8
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Consideration of the growth of the central nervous system will be taken up in three parts: (a) the growth of the brain as a whole, (b) the growth of the parts of the brain, and (c) the growth of the spinal cord.

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(a) The growth of the brain as a whole.

The growth of the brain as a whole represents a summation of its various parts. In the young fetus, the pons and medulla and the midbrain represent a relatively large part of the brain tissues; in the larger fetuses the hemispheres make up the great bulk.

The absolute curve of the entire brain volume (graph 18), when based on crown heel or total body length, is a concave curve like all curves of volumes or weights of organs of the body. By the third fetal month the volume of the total brain is 1.3 cc. This increases steadily to 102 cc. at the end of the sixth fetal month. The curve of absolute volume then bends sharply upward to reach 360 cc. at birth.

The rate of growth or percentage increment in brain volume (graph 22) is approximately 450 per cent per month by the middle of the third fetal month. It is easy to err in estimating percentage increment of such magnitude in early fetal life for the width of a pencil line, in the smoothed curve from which the increment is taken, might cause a variance of 25 per cent.[1] The percentage increment descends rapidly from 450 per cent until by the middle of the sixth month it is about 53 per cent, but during the last of the sixth and the first of the seventh months it again rises to about 70 per cent. A corresponding increase is observed in the rate of growth at a similar time (it may be slightly sooner or later) in every volume of the brain and all parts of the brain. In all probability, therefore, the rise in the percentage increment curve of the entire brain volume is a reflected rise of its component parts. From the middle of the seventh fetal month up to

Footnote

(1)The percentage increment of the entire brain volume (table XXIV) is given for the first and second fetal months as 300 per cent and for the succeeding month as 390 per cent. Undoubtedly these rates of growth are too low. Only four fetuses were available under the age of two prenatal months and these were very nearly two months old. From the second to the middle of the third months eleven fetuses were available. In only two of these, however, were the brains well fixed. The rate of brain growth in the first three months should approximate somewhat the body growth of that period. Relative to the volume of body growth during this time Jackson states (Am. Journal An.,Vol. 9, p. 22), "Thus we obtain for the relative monthly growth of the first month, 9999; for the second month, 74; for the third month, 11." At the present time in view of more recent data on early body growth it is generally conceded that the body growth during this time is even higher than Jackson's figure. In all probability the percentage increment of the entire brain volume is far above 500 per cent prior to the middle of the third month of intra-uterine life.

(2)The increment curve as pictured in all the graphs stop at 500 mm. crown heel length. This point is considered as representing birth for an increment curve because it has been obtained in each case from the measurement at 550 mm. crown heel length.

birth, the rate of growth gradually falls from 70 per cent to 33 per cent.(2)

(b) The growth of the parts of the brain.

The growth of the brain parts in the fetus represents a field of study practically untouched, and there exists no data in the literature against which the present results may be checked. The growth of the hemispheres, the cerebellum, the midbrain, and the pons and medulla will be considered separately.

The growth of the cerebral hemispheres is portrayed by graphs based on volumetric and linear measurements and by figures.

The absolute volume of the right and left hemispheres (graphs 15 and 16) show no marked difference. The minor distinctions probably fall within the margin of error. The absolute volume curve of the hemispheres shows the same concave form as that of the entire brain volume, although between 25 and 35 crown heel body length it is not as deep. By the last of the second fetal month the hemispheres are about 1 cc. in volume. From that time on a steady growth proceeds until, by the first of the sixth month, they reach the volume of 27 cc. After this time the volume curve increases more rapidly, attaining the average of about 170 cc. by birth.

The percentage increment of the hemispheres (graph 22) approximates that of the entire brain. As was shown in the case of the total brain, the calculated percentage increment prior to the middle of the third month of fetal life is undoubtedly too low. From the third month a rapid drop in the rate of growth is registered until it reaches the level of 65 per cent by the first of the sixth fetal month. During the last of the sixth month a slight rise in the rate of growth is indicated in both hemispheres and this is followed by a gradual decline of the increment curve until it reaches the level of about 34 per cent at birth.

The three linear measurements taken, also offer information upon the growth of the cerebral hemispheres. The frontal-occipital pole length represents the anterio-posterior axis of cerebral growth, the temporal to temporal pole diameter gives an index of lateral cerebral growth, and the corpus callosum length portrays to some extent the interassociation between the cerebral hemispheres.

The frontal-occipital pole length is the most exact measurement of the brain. This value, even the individual cases, varies but slightly from the averaged line based upon the entire group. The constancy of the frontal-occipital length is due probably to its close conformance to the skull and to the fact that it is not affected greatly by the tortion of the brain parts or general brain axis in growth. Its constancy has justified its use as a basic measurement.

The absolute length of the frontal to the occipital pole (graph 1) starts at 12 mm. at the second fetal month and increases at a constant absolute rate to 95 mm. at birth.

The percentage increment of the frontal occipital length gradually declines from 90 per cent at the third fetal month to 10.4 per cent at birth. It shows no increase during the sixth or seventh fetal months as do the percentage increments of brain volume. This measurement indicates a steady, absolute cerebral growth in the anterio-posterior axis accompanied by a constant diminution of the rate of growth.

The curve of absolute temporal to temporal diameter (graph 2) is also a straight line. Starting at 10 mm. in the second fetal month it increases steadily to 76 mm. at birth.

The rate of growth of the temporal to temporal diameter decreases fairly steadily from 70 per cent at the last of the second fetal month to 9.5 per cent at birth. The transverse axis of the cerebral hemispheres therefore shows a constant diminution in the rate of growth, month by month, during fetal life.

The corpus callosum length (graph 10) shows a tremendous absolute growth from the third to the fifth fetal month. In this period the absolute corpus callosum length increases from 8.5 mm. in the middle of the third fetal month to 28 mm. by the sixth fetal month. After the sixth month the growth is not so rapid. It reaches 41 mm. by birth.

The rate of growth of the corpus callosum length as shown by the percentage increment (graph 20) starts at 100 per cent at the first of the fourth fetal month and drops to 22 per cent by the sixth. Undoubtedly this rapidity of growth at a comparatively late period has some significance. It may be due to an increase of commissural fibers at this period of fetal development, or possibly to an increase of interstitial tissue.

The growth of the cerebellum is portrayed by graphs based upon volumetric and linear measurements and by figures. The absolute volume of the cerebellum (graph 14) presents a concave volume curve. The cerebellum is not grossly visible before the second fetal month. By the middle of the third month its volume is .15 cc. and this increases slowly to 2. cc. by the middle of the sixth fetal month (320 C.H.). The absolute volume curve turns sharply upward at this point and from the middle of the sixth fetal month until birth--a period of only four months--the cerebellum increases in volume from 2 cc. to about 23 cc. This tremendous growth in volume--1150 per cent in the last four fetal months--, coming late in intra-uterine life when all other brain parts are growing far less rapidly, is characteristic only of the growth of the cerebellum.

The percentage increment of the cerebellum (graph 21) reflects the increase in the absolute volume curve. Dropping from 125 per cent at the fourth fetal month, it is 90 per cent in the first of the fifth fetal month. It then increases to 127 per cent during the first of the sixth month and finally falls to 55 per cent at birth.

The evidence concerning the relative growth of the cerebellum is seen illustrated by the per cent which it forms of the entire brain volume (graph 35). This curve starts at 2.6 per cent in the middle of the third fetal month and, with slight variations, forms only 2.8 per cent of the brain volume in the middle of the sixth month. At this time the tremendous growth of the cerebellum becomes a predominating factor. By the first of the seventh month it becomes 3.5 per cent of the entire brain volume, and by the middle of the ninth up to birth it is 6 per cent of the entire brain volume.

The absolute length of the vermis cerebellum (graph 8) also brings out the great growth of the cerebellum in the last four fetal months. At the end of the second month the vermis cerebellum length is only 5.5 mm., by the first of the fifth it is 10 mm. After this time it acquires a more rapid rate of absolute growth rising to 19.5 mm. by the first of the seventh month and 27.5 mm. at birth.

The rate of growth of the vermis cerebellum length (graph 20) shows a gradual decrease from 39 per cent in the first of the fourth fetal month to 15 per cent at birth. A small drop observed in the fifth month in the x increment rate is probably not significant. The entire percentage increment curve is higher by 8 per cent than any other percentage increment based on a straight line measurement, with the exception of the vermis cerebellum height.

The absolute height of the vermis cerebellum (graph 9) varies even more from a straight line than does the vermis cerebellum length. Indeed it looks like a shallow absolute volume curve. It is 3 mm. by the last of the second fetal month; 5.5 mm. by the first of the fourth; 9.5 mm. by the first of the sixth; and from that time on it ascends rapidly to attain 22 mm. at birth.

The percentage increment of the vermis cerebellum height (graph 20) shows a gradual decrease from 47 per cent at the middle of the third fetal month to 17 per cent at birth. This decrease forms a smooth increment curve but during the last four months of intra-uterine life it is 8 per cent higher than all other straight line increments with the exception of that of the vermis cerebellum length.

The great growth of the cerebellum during the last part of fetal life is also easily recognized in the midsagittal drawings (figures 3,4,5,6,7,8,9). In the third fetal month (fig. 3) the cerebellum grows posteriorly and parallel to the pons and medulla; by the middle of the sixth fetal month (fig. 4,5,6) it assumes its characteristic shape and its characteristic position in relation to the cerebral hemispheres. From the middle of the sixth fetal month to birth (figures 7,8,9,10) each succeeding tracing indicates a greater relative size.

The growth of the pons and medulla (graph 12) present a typical volume curve. By the last of the second fetal month they are .35 cc. in volume; by the last of the fifth, .8 cc; by the middle of the sixth, 1.7 cc.; by birth, 5.2 cc.

The percentage increment of this volume curve (graph 21) starts at 75 per cent in the middle of the third month; falls to 46 per cent at the beginning of the sixth fetal month;makes a rise at the beginning of the sixth month to 50 per cent; and then falls gradually to 33 per cent at birth. The curve falls to a low point in the beginning of the fourth month but this probably has no significance. The increased rate of growth at the middle of the sixth fetal month is reflected in each volumetric curve, however, and is doubtless a constant factor.

The most interesting fact concerning the pons and medulla is the per cent it forms of the entire brain volume during fetal life (graph 33). At the last of the second fetal month the pons and medulla form 9.1 per cent of the entire brain volume; by the first of the fourth month they form only 2.5 per cent; from that time they gradually decrease until at birth they represent only 1.4 per cent of the entire brain volume. This decrease is due in all probability to the great increase in the absolute growth of the cerebral hemispheres and of the cerebellum during the last half of fetal life.

The pons length offers little assistance in obtaining a conception of the growth of the pons and medulla. The absolute graph on pons length (graph 6) is practically a straight line. It increases relatively rapidly from 3 mm. at the last of the second fetal month, to 5.7 mm. by the middle of the third month. From that time a steady increase in length proceeds until a length of 15 mm. is recorded at birth.

The percentage increment of the pons length (graph 20) starts at 90 per cent in the middle of the third fetal month and falls to 13 per cent by the sicth month. It decreases gradually to 8.4 per cent at birth.

There is no doubt that the pons and medulla form a large per cent of the brain in early fetal life. Figs. 12,13,14,15,16, substantiate graph 33 to show that the per cent which the pons and medulla forms of the entire brain. By the second fetal month (fig. 12) fully 10 per cent of the brain, as it appears midsagittally, is formed by the pons and medulla. In the second month to the fifth month (figs. 13,14,15,16) the pons and medulla become relatively smaller.

A consideration of the colliculi or the midbrain does not lead to quite such clean cut results. The mid brain, as it was prepared for volume and weight determinations, includes not only the colliculi above the iter but also a portion of the brain stem below the iter. Growth of the entire midbrain is probably shown best by the volume curves since the colliculi length measurement depends upon the colliculi alone.

The absolute volume of the midbrain (graph 13) represents a shallow but typical volume curve. By the middle of the third month the absolute midbrain volume is .25 cc., and it steadily rises to .9 cc. in the middle of the sixth month. From this time the absolute volume increases at a faster pace reaching 2.6 cc. by birth.

The percentage increment of the midbrain volume (graph 21) starts at 46 per cent in the first part of the fourth fetal month; and falls to 36 per cent in the last of the sixth month; it then shows a slight increase to 40 per cent in the first of the seventh month, and decreases from that time to 34 per cent at birth.

This slow growth of the midbrain is reflected in the per cent which the midbrain forms of the entire brain volume (graph 24). Beginning at 3.2 per cent in the first of the third fetal month, the curve steadily declines until it forms but .72 per cent of the entire brain volume at birth.

The colliculi measurement is not a true check on the midbrain growth; at least that portion below the iter.

The curve of the absolute length of the colliculi (graph 7) is a straight line. It starts at 7 mm. in length in the middle of the third fetal month and is 12.3 mm. in length at birth. In a three and one-half month fetus no line of demarcation exists between the superior colliculus and the thalmencephalon--in another of the same age a sharp line separates the colliculi and the thalmencephalon. The colliculi, therefore, represent a division of the brain stem by a line of demarcation.

This conclusion is supported by ocular evidence in figures 12,13 and 14. Figures 12 and 13 prior to the third fetal month show no colliculi; figure 14 shows colliculi well marked off and relatively longer than in a newborn specimen.

The midbrain volume represents a true growth of a brain part, while the colliculi merely a demarcation of a part of the brain stem.

(c) The growth of the spinal cord.

The growth of the spinal cord resembles that of the brain growth and particularly that of the pons and medulla. The absolute volume of the spinal cord (graph 11) is a very shallow but typical volume curve. The absolute volume at the end of the second fetal month is approximately 0.1 cc. The curve increases steadily until it reaches 1.0 cc. in the last of the sixth month. From this time it proceeds upwards at a sharper pitch reaching the volume of 2.7 cc. at birth. The data of Jackson ('09) (table XVI) shows a uniformly higher average for the absolute spinal cord volumes. His small fetuses (obtained by sectioning) have an absolute volume of .034cc. at approximately the close of the first fetal month. His two largest fetuses at the natal period have a cord volume of about 3 cc.

The percentage increment of the spinal cord volume (graph 21) is 83.3 per cent at the middle of the third fetal month. It rapidly falls to 29.3 per cent in the last of the sixth month. It then shows a distinct increase in the rate of growth reaching the height of 45.3 per cent in the last of the eighth month. From that time the rate drops off to 38.7 per cent at birth.

The relation of the spinal cord volume to the volume of the entire brain is shown in graph 32. At the middle of the second month the cord volume is equal to 4.4 per cent of the total brain volume; it then drops as is shown by a regular concave curve to

0.7 per cent of the total brain volume at birth.

The absolute length of the spinal cord (graph 4) ascends rather sharply from the 23 mm. length at the second fetal month to 9.5 mm. at the first of the fifth month. From that time the ascent is more gradual ending at about 14.5 mm. at birth.

The percentage increment of the cord length (graph 21) decreases rapidly from 74 per cent in the last of the second fetal month to 11.6 per cent in the first of the sixth month; from the middle of the sixth month it falls to about 5 per cent at birth.

There is undoubtedly a very rapid growth of the cord up to the fifth fetal month as is indicated by both the volume and the length curves. A secondary increase appears in the volume increment curve in the eighth and ninth months.

The subject of growth in the brain parts and the spinal cord have been considered without mentioning weight measurements. At all times volumes have been used to read growth. Weight determinations could have been used, however, with practically identical results. Each individual weight dot has been placed on the field graph for volume (graphs 11,12,13,14,15,16,and 17) together with the corresponding volume dot. By a careful consideration of the points on these graphs the accuracy of the volume cases and the weight cases seem to be about equal. On the whole, the volume cases run a little lower than the weight. The curve for average weight and volume were superimposed for the graph of both cerebral hemispheres (graph 17). This demonstrates how closely the weight and the volume absolute curves accord in this particular instance. The data was treated from the volumes in this thesis because it is the most acceptable form to many researchers.

III. Summary.

(a) The growth of the brain as a whole.

1. The curve of the absolute volume of the entire brain shows a relatively slow but steady increase during the first six fetal months and a more rapid growth from that time until birth.

2. The rate of growth of the entire brain, as shown by the percentage increment curve based upon volume, is extremely rapid during the first three months of fetal life; it shows a secondary slight increase about the seventh month.

(b) The growth of the parts of the brain.

3. The differences between the right and left cerebral hemispheres in fetal life fall within the ~~margin~~ limits of error.

4. The curve of the absolute volume of the cerebral hemispheres increases more rapidly in the last four fetal months of fetal life than it does in the first five months.

5. The rate of growth of the cerebral hemispheres, as shown by the percentage increment curve based upon volume, shows a high percentage in the first three months of fetal life and a slight secondary increase during the last of the sixth.

6. A steady, absolute growth of the cerebral hemispheres in the anterio-posterior axis is accompanied by a constant diminution in the rate of growth in this axis.

7. The constancy of the frontal occipital pole length justifies its use as a basic measurement.

8. A constant, absolute growth of the cerebral hemispheres in the transverse axis is accompanied by a steady decrease in the rate of growth.

9. A tremendous absolute growth in the corpus callosum length from the third to the fifth fetal month, accompanied by a high rate of growth, indicates either a great increase in commissural nerve fibers or an unusual growth in the interstitial tissue at this time.

10. The curve of the absolute volume of the cerebellum shows a slow, constant growth during the first five fetal months and a remarkable increase during the last four fetal months.

11. The rate of growth of the cerebellum, as taken from the curve of the volume of the cerebellum, falls from a high percentage early in fetal life to 90 per cent about the sixth month, and then increases in rate a second time during the last four fetal months.

12. The cerebellum is less than two or three per cent of the entire brain volume until the middle of the sixth fetal month; it then increases from 3 per cent to 6 per cent in the last four months.

13. The absolute length of the vermis cerebellum is a gradual increase during early fetal life and it increases more rapidly from the sixth month until birth.

14. The rate of growth of the vermis cerebellum length, as shown by the percentage increment curve, is probably high in early intra-uterine life and is 8 per cent greater than any other straight line measurement, with the exception of that based upon the vermis cerebellum height, during the last four months.

15. The absolute height of the vermis cerebellum increases rapidly during early fetal life and more rapidly during the last four months.

16. The rate of growth of the vermis cerebellum height is probably high in early fetal life, and is greater than any other percentage increment curve based upon a straight line measurement in the last four months.

17. The curve of the absolute volume of the pons and medulla shows a steady increase; while the rate of growth, otherwise a smooth increment curve, portrays a slight rise at the beginning of the sixth fetal month.

18. The volume of the pons and medulla decreases from 9 per cent of the entire brain volume in the second fetal month to 2.5 per cent at birth.

19. The curve of the absolute length of the pons increases steadily, while the rate of growth decreases constantly, from early fetal life until birth.

20. The curve of the absolute midbrain volume shows a gradual increase during prenatal life; while the rate of growth based upon the midbrain absolute volume portrays a steady decrease except for a slight rise in the first of the seventh month.

21. The entire midbrain exhibits the growth of a true brain part.

22. The colliculi represent merely a demarcation of the brain stem.

(c) The growth of the spinal cord.

23. The curve of the absolute volume of the spinal cord increases steadily from the second to the sixth fetal month and more rapidly from that time until birth.

24. The rate of growth of the spinal cord volume is relatively high in the third and fourth months of fetal life; it shows an extremely high secondary increase (8 per cent) during the last of the eighth month.

25. The curve of the absolute length of the spinal cord shows a rapid increase prior to the fifth fetal month after which time it is more gradual.

26. The rate of growth based upon the absolute length of the spinal cord is relatively high in the second and third fetal months; after this time it is low and regular.

(d) Value of weight and volume determinations.

27. The volume and weight determinations are equally accurate in showing the absolute growth and the rate of growth of a brain part.

28. The absolute volume of individual cases are uniformly at a slightly lower level than the corresponding absolute weight of these cases.

IV. Conclusion.

From a survey of ~~the scope of~~ this work, certain general conclusions may be attained.

1. Any curve based upon absolute volume in the central nervous system, when it is plotted against crown heel length, is a concave curve ascending more rapidly in the last half of fetal life than it does prior to that time.

2. Any curve based upon absolute linear measurements in the central nervous system, when plotted against crown heel length, approximates a straight line with slight irregular variations.

3. A curve showing rate of growth is useful only when based upon an absolute curve which has been smoothed in some manner.

4. All curves showing rate of growth show a tremendous decline in their rate during the first three fetal months.

5. All the curves of percentage increment based upon volume or weight determinations show a slight increase in their rate about the seventh fetal month; while all of the curves of percentage increment based upon linear measurements show no increase at this time.

6. All curves based upon per cents which the linear, volume, or weight measurements of a brain part, form of larger units(crown heel, the entire brain volume, or the entire brain weight respectively) show the relative rate of growth between the various parts of the central nervous system.

7. No essential difference appears between volume and weight determinations respective to their value of showing growth and rates of growth.

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VI. Index of tables, graphs, and figures.

(c) Of per cents of a brain part to a larger unit.

XXVI. Per cent of F.O.(3), T.T.(4), F.S.(5), Sp.C.(6), P.(8), C.(9), V.L.(10), V.H.(11), and C.C.L.(12), to the larger length unit of crown heel.

XXVII. Per cent of V.S.C.(17), V.P.M.(18), V.M.B.(19), V.C.(20), V.R.H.(21), V.L.H.(22), and V.B.H.(23) to the total brain volume; and the per cent of the W.B.H.(31) to the total brain weight.

(d) Of weight measurements.

XXVIII. Weight of the spinal cord.

XXIX. Weight of the pons and medulla.

XXX. Weight of the mid brain.

XXXI. Weight of the cerebellum.

XXXII. Weight of the right hemisphere.

XXXIII. Weight of the left hemisphere.

XXXIV. Weight of both hemispheres.

XXXV. Weight of the entire brain.

XXXVI. Weight of the entire brain compiled from literature.

Graphs.

(a) Of absolute measurements against crown heel.

(a') Linear measurements.

1. Frontal occipital length.
2. Temporal to temporal diameter.
3. Frontal spinal length.
4. Spinal cord length.
5. Brain cord length.
6. Pons length.
7. Colliculi length.

8. Vermis cerebellum length.

9. Vermis cerebellum height.

10. Corpus callosum length.

(b') Volumetric and weight measurements.

11. Spinal cord volume. (Includes data of C.M. Jackson.) (Weight plotted.)

12. Volume of the pons and medulla. (Weight plotted.)

13. Volume of the mid brain. (Weight plotted.)

14. Volume of the cerebellum. (Weight plotted.)

15. Volume of the right hemisphere. (Weight plotted also.)

16. Volume of the left hemisphere. (Weight plotted.)

17. Volume and weight of both hemispheres.

18. Volume of the entire brain. (Includes data of C.M. Jackson.) (Weight plotted.)

19. Weight of the entire brain from the literature.

(b) Of percentage increment taken from the smoothed curves on the field graphs.

20. All straight line measurements(from graphs 2,3,4, 5,6,7,8,9,10).

21. Volume measurements (from graphs 11,12,13, and 14).

22. Volume measurements (from graphs 15,16,17,18 and 19).

(c) Of per cents of a brain part to a larger unit.

(a') Linear per cents to crown heel length.

23. Per cent of frontal occipital length to crown heel.

24. Per cent of the temporal to temporal length to the drown heel.

25. Per cent of the frontal spinal length to the crown heel.

26. Per cent of the spinal cord length to the crown heel.

27. Per cent of the pons length to the crown heel.

28. Per cent of the colliculi to the crown heel.

29. Per cent of the vermis cerebellum length to the crown heel.

30. Per cent of the vermis cerebellum height to the crown heel.

31. Per cent of the corpus callosum length to the crown heel.

(b') Volumetric per cents to the entire brain volume.

32. Per cent of spinal cord volume to the entire brain volume.

33. Per cent of the pons and medulla volume to the entire brain volume.

34. Per cent of the mid brain volume to the entire brain volume.

35. Per cent of the cerebellum volume to the entire brain volume.

36. Per cent of the right hemisphere volume to the entire brain volume.

37. Per cent of the left hemisphere volume to the entire brain volume.

38. Per cent of both hemispheres volume to the entire brain volume.

(c') Weight per cent to the entire brain weight.

39. Per cent of both hemispheres weight to the entire brain weight.

Figures.

(a) Midsagittal sections of the brain at actual size.

1. Midsagittal sections of a 40 mm. fetus.
2. Midsagittal sections of an averaged 50-100 mm. fetus.
3. Midsagittal sections of an averaged 100-150 mm. fetus.
4. Midsagittal sections of an averaged 150-200 mm. fetus.
5. Midsagittal sections of an averaged 200-250 mm. fetus.
6. Midsagittal sections of an averaged 250-300 mm. fetus.
7. Midsagittal sections of an averaged 300-350 mm. fetus./
8. Midsagittal sections of an averaged 350-400 mm. fetus.
9. Midsagittal sections of an averaged 400-450 mm. fetus.
10. Midsagittal sections of an averaged 450-500 mm. fetus.
11. Midsagittal sections of an averaged 500-550 mm. fetus.

(b) Midsagittal sections of the series just preceding which have been raised to a scale in which their frontal occipital length equals the frontal occipital length of the newborn (550 mm.) fetus.

12. Midsagittal figure of a 40 mm. fetus to a scale of 10.7.

13. Midsagittal figure of an averaged 50-100 mm. fetus raised to the scale of 5.7.

14. Midsagittal figure of an averaged 100-150 mm. fetus raised to the scale of 4.05.

15. Midsagittal figure of an averaged 150-200 mm. fetus raised to the scale of 3.11.

16. Midsagittal figure of an averaged 200-250 mm. fetus raised to the scale of 2.1.

17. Midsagittal figure of an averaged 250-300 mm. fetus raised to the scale of 1.8.

18. Midsagittal figure of an averaged 300-350 mm. fetus raised to the scale of 1.6.

19. Midsagittal figure of an averaged 350-400 mm. fetus raised to the scale of 1.4.

20. Midsagittal figure of an averaged 400-450 mm. fetus raised to the scale of 1.2.

21. Midsagittal figure of an averaged 450-500 mm. fetus raised to the scale of 1.07.

22. The hemisphere outlines of the preceding group of figures raised to scale superimposed upon each other with the frontal and occipital poles fixed points.

(b) Photographs showing the lateral view of the best brain in a five centimeter length.

23. Photograph of the lateral surface of the brain of a 40 mm. fetus.

24. Photograph of the lateral surface of the brain of a 54 mm. fetus.

Table I.

Crown Rump Length (mm.)

Range of C.H. Length (mm.)	Average of C.H.Length	Average	Maximum	Minimum	No of cases	Ratio of Newborn (%.)
0-50	39	33	41	27	4	9.3
50-100	72	57	69	41	12	16.0
100-150	122	85	102	65	15	23.9
150-200	168	113	129	97	13	31.7
200-250	225	154	167	132	12	43.2
250-300	271	177	190	150	14	49.7
300-350	324	214	237	190	12	60.1
350-400	370	248	270	220	9	69.7
400-450	428	290	300	265	6	81.5
450-500	483	326	337	310	7	91.5
500-550	522	356	384	332	8	

Table II.

Frontal Occipital Pole Length (mm.)

Range of C.H. Length (mm.)	Average of C.H. Length	Average	Maximum	Minimum	Percentage increment (%)	No. of cases	Ratio of Newborn (%)	Percent of C.H. Length (%)
0-50	40	8.6	11	7	—	3	9.3	21.9
50-100	71	5.9	20	12	90.4	10	17.3	19.7
100-150	122	22	27	14.5	47.5	15	23.9	18.2
150-200	166	32	39	23	32.2	13	34.8	19.1
200-250	225	44	49	37	21.2	12	47.8	19.6
250-300	270	51	65	44	18.4	16	55.4	19.1
300-350	324	58	65	51	15.2	12	63.1	17.8
350-400	370	68	77	63	13.2	9	73.9	18.3
400-450	428	78	83	76	11.6	6	84.8	18.7
450-500	483	86	93	75	10.4	7	93.5	17.7
500-550	522	92	100	80	—	8	—	17.7

Table III.

Temporal Temporal Pole Diameter (mm.)

Range of C.H. Length (mm.)	Average of C.H. Length	Average	Maximum	Minimum	Percentage increment (%.)	No. of cases	Ratio of Newborn (%.)	Percent of C.H. Length (%.)
0-50	39	8.5	10.0	7.0	—	4	10.8	21.7
50-100	81	14.5	20.0	12.0	70.	7	18.5	16.9
100-150	122	21.	35.0	15.0	32.1	12	26.7	16.1
150-200	166	26.	34.0	18.0	28.8	13	33.1	15.5
200-250	225	31.7	39.0	26.0	23.3	12	40.3	14.1
250-300	270	40.7	46.0	32.0	18.9	15	51.8	15.0
300-350	322	44.2	48.0	38.0	15.9	10	56.2	13.7
350-400	371	55.6	68.0	51.0	14.1	8	70.8	15.0
400-450	428	64.	67.0	58.0	12.0	6	81.4	14.6
450-500	483	68.	72.0	66.0	10.7	7	86.5	14.3
500-550	522	78.6	104.0	69.0	—	7	—	15.0

Table IV.

Frontal Spinal Length (mm.)

Range of C.H. Length (mm.)	Average of C.H. Length	Average	Maximum	Minimum	Percentage increment (%)	No of cases	Ratio of Newborn (%)	Percent of C.H. Length (%)
0-50	40	8.6	10.	7.		3	12.7	22.7
50-100	68	14.	17.	10.5	74.3	9	20.6	18.5
100-150	124	22.	28.	19.	42.1	13	32.4	17.3
150-200	167	29.5	35.	26.	28.8	12	43.4	17.6
200-250	225	39.3	45.	32.	21.5	11	57.8	17.5
250-300	270	41.	46.	34.	14.7	15	60.3	15.2
300-350	325	48.2	53.	43.	11.3	10	70.8	14.8
350-400	370	56.	65.	51.	9.6	9	82.4	15.1
400-450	428	61.	68.	57.	7.9	6	89.7	14.4
450-500	483	63.	69.	59.	7.3	7	92.7	13.1
500-550	522	68.	73.	63.		8		13.

Table V.

Spinal Cord Length (mm.)

Range of C.H. Length (mm.)	Average of C.H. Length	Average	Maximum	Minimum	Percentage increment (%)	No of cases	Ratio of Newborn (%)	Percent of C.H. Length (%)
0-50	39	19.2	25.	14.		4	13.2	46.
50-100	77	30.	40.	23.	74.0	9	20.7	38.5
100-150	123	46.	53.	40.	57.5	14	31.7	37.3
150-200	168	70.	97.	53.	28.6	12	48.3	39.9
200-250	228	90.	105.	70.	17.3	11	62.	39.6
250-300	269	97.5	107.	85.	11.6	14	67.2	36.5
300-350	324	109.	133.	90.	9.6	11	75.2	33.6
350-400	371	133.	165.	115.	7.7	8	91.8	36.
400-450	428	135.	170.	110.	7.1	6	93.	31.7
450-500	483	137.	148.	130.	5.2	7	94.4	28.7
500-550	522	145.	158.	132.		8		27.8

Table VII.

Pons Length (mm.)

Range of C.H. Length (mm.)	Average of C.H. Length	Average	Maximum	Minimum	Percentage increment (%)	No. of cases	Ratio of Newborn (%)	Percent of C.H.Length (%)
0-50								
50-100	100	3.	3.	3.		1	20.2	
100-150	125	4.7	6.	4.	90.	11	31.5	3.8
150-200	167	6.4	8.	5.	28.1	11	43.	3.8
200-250	224	8.4	9.	7.	17.8	9	56.4	3.8
250-300	270	8.6	11.	6.	12.8	13	57.7	3.2
300-350	325	10.	12.	9.	12.4	9	67.1	3.2
350-400	371	12.5	15.	10.5	10.1	8	84.	3.3
400-450	428	12.5	14.	10.	10.	6	84.	2.9
450-500	483	13.7	16.	12.	8.4	7	92.	2.9
500-550	522	14.9	17.	13.		8		2.9

Table VIII.

Colliculi Length (mm.)

Range of C.H. Length (mm.)	Average of C.H. Length	Aver-age	Maxi-mum	Mini-mum	Percent-age in-crement (%)	No. of cases	Ratio of Newborn (%)	Percent of C.H. Length (%)
0-50								
50-100								
100-150	129	7.	9.	5.		7	58.3	5.4
150-200	171	7.	9.	5.	7.	12	58.3	4.3
200-250	224	8.1	10.	7.	9.1	10	67.5	3.6
250-300	269	9.	10.	7.	9.5	12	75.	3.2
300-350	325	10.	17.	8.	7.6	9	83.4	3.2
350-400	370	9.5	10.	9.	7.1	8	79.2	2.6
400-450	428	11.	12.	10.	6.6	6	91.6	2.6
450-500	483	12.3	14.	11.	7.1	7	102.5	2.5
500-550	522	12.	13.	11.		8		2.3

Table IX.

Vermis Cerebellum Length (mm.)

Range of C.H. Length (mm.)	Average of C.H. Length	Average	Maximum	Minimum	Percentage increment (%)	No. of cases	Ratio of Newborn (%)	Percent of C.H. Length (%)
0-50								
50-100	100	4.	4.	4.		1	14.6	
100-150	129	4.8	7.	3.	35.	10	17.6	3.8
150-200	172	6.	11.	4.	38.8	12	22.	3.5
200-250	224	9.2	12.	7.	33.3	9	33.7	4.1
250-300	270	11.5	18.	9.	35.6	14	42.1	4.3
300-350	325	14.	17.	11.	25.8	9	51.3	4.3
350-400	370	17.6	19.	16.	21.9	8	64.5	4.7
400-450	428	22.7	25.	20.	18.0	6	83.2	5.3
450-500	483	25.	25.	22.	14.8	7	91.6	5.3
500-550	522	27.3	28.	16.		8		5.2

Table X.

Vermis Cerebellum Height (mm.)

Range of C.H. Lenght (mm.)	Average of C.H. Lenght	Aver-age	Maxi-mum	Mini-mum	Percent-age in-crement (%)	No. of cases	Ratio of Newborn (%)	Percent of C.H. Lenght (%)
0-50								
50-100	100	3.	3.	3.		1	13.6	
100-150	129	4.1	6.	3.	46.6	8	18.6	3.3
150-200	172	4.5	7.	2.	36.4	12	20.4	2.8
200-250	224	7.5	9.	6.	28.3	9	34.1	3.4
250-300	270	8.5	10.	6.	27.2	14	38.6	3.2
300-350	325	10.6	14.	8.	25.5	9	48.2	3.3
350-400	370	16.	19.	11.	22.8	8	72.7	4.3
400-450	428	17.	20.	14.	20.5	6	77.3	4.
450-500	483	20.5	25.	16.	16.5	7	93.2	4.2
500-550	522	22.	28.	16.		8		4.2

Table XI.

Corpus Callosum Length (mm.)

Range of C.H. Length (mm.)	Average of C.H. Length	Average	Maximum	Minimum	Percentage increment (%)	No. of cases	Ratio of Newborn (%)	Percent of C.H. Length (%)
0-50								
50-100								
100-150	127	5.	5.	5.		1	11.9	3.9
150-200	176	12.	17.	8.	100.1	6	28.6	6.7
200-250	234	23.	26.	15.	40.8	5	54.8	10.
250-300	268	24.6	29.	21.	21.7	14	58.7	9.2
300-350	322	31.	42.	26.	14.7	7	73.8	9.6
350-400	373	35.5	40.	32.	9.8	6	84.5	9.7
400-450	422	36.	37.	35.	6.7	5	85.7	8.5
450-500	482	39.	45.	32.	5.5	6	93.	8.1
500-550	522	42.	46.	35.		6		8.09

Table XII.

Corpus Callosum Height (mm.)

Range of C.H. Length (mm.)	Average of C.H. Length	Average	Maximum	Minimum	No. of cases	Ratio of Newborn (%)
0-50						
50-100						
100-150	127	2.	2.	2.	1	52.6
150-200	175	2.1	3.	1.5	5	55.2
200-250	234	2.	2.5	1.	5	52.6
250-300	268	2.5	4.	1.5	14	65.8
300-350	322	2.5	3.	2.	6	65.8
350-400	370	3.6	4.	3.	5	94.7
400-450	434	3.3	4.	3.	3	86.8
450-500	483	3.	3.	3.	5	79.
500-550	522	3.8	5.	2.5	6	

Table XIII.

Corpus Mamillare Length (mm.)

Range of C.H. Length (mm.)	Average of C.H. Length	Average	Maximum	Minimum	No. of cases	Ratio of Newborn (%)
0-50						
50-100						
100-150						
150-200	158	1.	1.	1.	1	25.
200-250	228	1.75	2.	1.5	2	43.8
250-300	269	2.	2.6	1.5	4	50.
300-350	333	5.	8.	2.	2	125.
350-400	368	2.8	3.	2.	5	70.
400-450	430	2.9	4.	2.	3	72.5
450-500					0	
500-550	524	4.	5.	3.	5	

Table XIV.

Hypophysis Length (mm.)

Range of C.H. Length (mm.)	Average of C.H. Length	Average	Maximum	Minimum	No. of cases	Ratio of Newborn (%)
0-50						
50-100						
100-150	138	1.5	1.5	1.5	1	31.8
150-200	164	2.5	3.	2.	2	53.2
200-250	230	3.5	4.	3.	4	74.5
250-300	278	3.9	6.	2.5	6	83.
300-350	333	4.	4.	4.	3	85.
350-400	375	4.	4.	4.	2	85.
400-450	428	4.5	5.	4.	4	95.8
450-500	485	4.7	5.	4.	3	100.
500-550	517	4.7	5.	4.	3	

Table XV.

Hypophysis Height (mm.)

Range of C.H. Length (mm.)	Average of C.H. Length	Average	Maximum	Minimum	No. of cases	Ratio of Newborn (%)
0-50						
50-100						
100-150	138	1.5	1.5	1.5	1	34.9
150-200	164	1.	1.	1.	2	23.3
200-250	230	2.3	3.	2.	4	53.2
250-300	278	2.7	3.	2.	6	62.8
300-350	333	2.7	3.	2.	3	62.8
350-400	375	3.	3.	3.	2	69.8
400-450	428	3.7	4.	3.	4	86.
450-500	485	3.3	4.	3.	3	76.8
500-550	517	4.3	5.	4.	3	

Table XVI.

Spinal Cord Volume (cc.)

(Based on data of Jackson, '09.)

Range of C.H. Length (mm.)	Average of C.H. Length	Average	Maximum	Minimum	No. of cases	Ratio of Newborn (%)
0-50	17.7	.02225	.03625	.01625	3	.7
50-100	77.	.115	.12	.11	3	3.7
100-150	123.	.1671	.2	.15	3	5.5
150-200	171.	.3447	.589	.1995	5	11.3
200-250	224.	.667	.859	.503	4	21.9
250-300	274.	.908	1.2	.72	5	29.8
300-350	327.	1.53	1.82	1.35	2	50.3
350-400	385	1.8	1.8	1.8	1	69.2
400-450	442	3.3	3.3	3.3	1	112.
450-500	459				2	
500-550	519	3.04	3.48	2.6	2	

Table XVII.

Spinal Cord Volume (cc.)

Range of C.H. Length (mm.)	Average of C.H. Length	Average	Maximum	Minimum	Percentage increment (%)	No. of cases	Ratio of Newborn (%)	Percent of E.B. Volume (%)
0-50								
50-100	72	.05	.05	.05		3	2.	4.4
100-150	125	.18	.3	.1	83.3	12	7.2	3.4
150-200	165	.26	.5	.1	68.2	12	10.4	2.6
200-250	227	.48	.7	.3	48.6	10	19.2	1.8
250-300	269	.65	1.1	.3	36.3	14	26.	1.6
300-350	322	.85	1.35	.5	29.3	11	34.	1.3
350-400	371	1.	1.3	.7	32.	8	40.	.8
400-450	422	1.54	1.8	1.2	45.3	5	61.6	.77
450-500	480	2.43	3.1	1.4	38.7	6	97.2	.77
500-550	522	2.5	3.8	1.8		8		.7

Table XVIII.

Pons and Medulla Volume (cc.)

Range of C.H. Length (mm.)	Average of C.H. Length	Average	Maximum	Minimum	Percentage increment (%)	No. of cases	Ratio of Newborn	Percent of E.B. Volume (%)
0-50								
50-100	100	.2	.2	.2		1	3.8	9.1
100-150	127	.3	.4	.2	75.	4	5.8	5.2
150-200	171	.4	.7	.15	48.6	12	7.7	3.3
200-250	223	.64	.95	.4	51.9	8	12.3	2.6
250-300	270	.92	1.4	.5	45.6	13	17.7	2.1
300-350	323	1.36	2.1	.9	50.4	10	26.1	2.
350-400	372	2.15	2.4	1.6	45.1	7	41.3	1.7
400-450	428	3.	3.	2.5	40.	6	57.7	1.5
450-500	480	4.29	5.47	3.7	32.7	6	82.5	1.4
500-550	522	5.2	6.3	4.5		8		1.4

Table XIX.

Mid Brain Volume (cc.)

Range of C.H. Length (mm.)	Average of C.H. Length	Average	Maximum	Minimum	Percentage increment (%)	No. of cases	Ratio of Newborn (%)	Percent of E.B. Volume (%)
0-50								
50-100								
100-150	127	.2	.3	.1		4	8.3	3.2
150-200	171	.3	.4	.2	45.8	12	12.5	2.4
200-250	223	.39	.5	.3	37.1	8	16.1	1.2
250-300	270	.62	.9	.4	37.5	13	25.8	1.3
300-350	323	.75	1.4	.4	36.3	10	31.2	1.2
350-400	372	1.1	1.4	.8	40.	7	45.8	.86
400-450	428	1.58	2.	1.3	38.1	6	65.8	.76
450-500	480	2.2	2.9	1.5	33.9	6	91.6	.73
500-550	522	2.4	3.	1.8		8		.72

Table XX.

Cerebellum Volume (cc.)

Range of C.H. Length (mm.)	Average of C.H. Length	Aver-age	Maxi-mum	Mini-mum	Percent-age in-crement (%)	No. of cases	Ratio of Newborn (%)	Percent of E.B. Volume (%)
0-50								
50-100	100					1		
100-150	127	.15	.2	.1		4	.7	2.6
150-200	171	.37	.7	.2	125.	12	1.7	2.9
200-250	224	.75	1.2	.5	90.	9	3.5	2.4
250-300	270	1.34	2.7	.9	127.	13	6.3	2.9
300-350	323	1.8	2.8	1.	109.	10	8.4	2.6
350-400	372	5.2	7.	3.4	94.	7	24.4	4.
400-450	428	8.8	11.54	5.7	96.	6	41.3	4.
450-500	480	18.94	22.	14.	54.5	6	89.	5.9
500-550	522	21.33	26.	18.		8		5.8

Table XXI.

Right Hemisphere Volume (cc.)

Range of C.H. Length (mm.)	Average of C.H. Length	Average	Maximum	Minimum	Percentage increment (%)	No. of cases	Ratio of Newborn (%)	Percent of E.B. Volume (%)
0-50								
50-100	100	1.2	1.2	1.2		1	.72	50.
100-150	123	2.4	3.3	1.6	200.	5	1.44	44.5
150-200	171	5.9	10.63	2.07	183.4	12	3.55	43.5
200-250	225	14.18	21.58	12.o2	94.2	10	8.5	46.6
250-300	271	21.81	32.71	12.36	66.	12	13.1	46.5
300-350	322	32.7	46.46	21.05	68.	10	19.7	47.1
350-400	372	61.3	73.	48.7	65.2	7	36.8	46.5
400-450	428	90.	128.6	67.17	52.4	6	54.4	47.3
450-500	480	145.9	191.5	111.	37.5	6	88.	46.2
500-550	522	166.	185.3	148.		8		45.4

Table XXII.

Left Hemisphere Volume (cc.)

Range of C.H. Length (mm.)	Average of C.H. Length	Average	Maximum	Minimum	Percentage increment (%)	No. of cases	Ratio of Newborn (%)	Percent of E.B. Volume (%)
0-50								
50-100	100	1.	1.	1.		1	.59	41.7
100-150	123	2.5	4.1	1.33	167.	5	1.5	44.4
150-200	171	5.95	10.5	2.34	137.5	12	3.5	45.1
200-250	222	15.5	17.	11.9	84.2	8	9.1	46.8
250-300	271	21.74	30.	13.	62.8	13	12.8	46.4
300-350	324	33.3	48.6	21.	72.	11	19.6	46.1
350-400	372	61.2	74.7	46.8	56.1	7	37.	46.3
400-450	428	94.2	110.7	67.	49.7	6	55.4	45.8
450-500	480	144.	188.9	108.7	26.6	6	84.7	45.2
500-550	522	170.	192.	142.		8		46.2

Table XXIII.

Both Hemispheres Volume (cc.)

Range of C.H. Length (cc.	Average of C.H. Length	Aver-age	Maxi-mum	Mini-mum	Percent-age in-crement (%)	No. of cases	Ratio of Newborn (%)	Percent of E.B. Volume (%)
0-50								
50-100	72	2.2	2.2	2.2		1	.65	91.6
100-150	123	4.5	7.4	3.2	350.	5	1.34	88.3
150-200	169	12.	20.5	4.8	144.5	12	3.6	88.9
200-250	223	28.2	46.2	24.5	77.2	8	8.4	94.1
250-300	271	46.6	62.5	25.4	48.7	12	13.9	92.7
300-350	322	67.1	95.1	56.5	62.1	11	20.1	93.4
350-400	372	115.5	143.4	95.5	56.4	7	34.5	92.9
400-450	428	180.5	239.3	134.2	46.9	5	54.	93.
450-500	480	268.7	380.4	219.7	41.7	7	80.4	92.1
500-550	522	334.4	377.3	302.		8		92.1

Table XXIV.

Entire Brain Volume (cc.)

Range of C.H. Length (mm.)	Average of C.H. Length	Aver-age	Maxi-mum	Mini-mum	Percentage Increment (%)	No. of cases	Ratio of Newborn (%)
0-50	39	.3	.7	.1	(300.)	4	.08
50-100	72	1.29	2.4	.65	(390.)	12	.35
100-150	123	5.	8.5	2.1	450.	14	1.36
150-200	169	12.2	22.5	3.	109.	14	3.3
200-250	223	30.8	49.5	17.4	69.6	10	8.4
250-300	271	46.9	65.4	24.7	53.8	12	12.8
300-350	322	68.1	101.8	45.8	52.6	11	18.5
350-400	372	131.8	153.3	102.2	70.6	7	36.
400-450	428	207.8	256.9	145.3	46.	6	56.7
450-500	480	318.1	412.5	243.2	32.3	6	86.6
500-550	522	367.5	414.3	332.3		8	

Table XXV.

Entire Brain Volume (cc.)

(Based on data of Jackson, '09.)

Range of C.H. Length (mm.)	Average of C.H. Length	Average	Maximum	Minimum	No. of cases	Ratio of Newborn (%)
0-50	18	.1768	.4	.025	3	.047
50-100	77	2.83	3.6	2.	3	.75
100-150	123	13.7	20.	10.	3	3.7
150-200	172	27.2	40.	18.	5	7.3
200-250	224	45.9	60.	30.6	4	12.3
250-300	274	85.4	129.	52.7	5	22.8
300-350	327	123.3	126.7	120.	2	32.9
350-400	385	140.	140	140.	1	37.4
400-450	442	321.3	321.3	321.3	1	85.8
450-500	459	322.6	358.	287.2	2	86.8
500-550	519	374.	385.	363.	2	

Table XXVI.

Percent of Brain Parts to the Entire Brain Volume (%)

Range of C.H. Length (mm.)	Percent S.C.V. to the E.B.V. (%)	Percent P.M.V. to the E.B.V. (%)	Percent M.B.V. to the E.B.V. (%)	Percent C.V. to the E.B.V. (%)	Percent R.H.V. to the E.B.V. (%)	Percent L.H.V. to the E.B.V. (%)	Percent B.H.V. to the E.B.V. (%)
0-50							
50-100	4.4	9.1			50.	41.7	91.7
100-150	3.4	5.2	3.2	2.6	44.5	44.4	88.3
150-200	2.6	3.3	2.4	2.9	43.5	45.1	88.9
200-250	1.8	2.	1.2	2.4	46.6	46.8	94.1
250-300	1.6	2.1	1.3	2.9	46.5	46.4	92.7
300-350	1.3	2.	1.2	2.6	47.1	46.1	93.4
350-400	.8	1.7	.86	4.	46.5	46.3	92.9
400-450	.8	1.5	.76	4.	47.3	45.8	93.
450-500	.77	1.4	.73	5.9	46.2	45.2	92.1
500-550	.7	1.4	.72	5.8	45.4	46.2	92.1

Table XXVII.

Percent of Linear Measurements to C.H.Length (%)

Range of C.H. Length (mm.)	F.O. (%)	F.S. (%)	T.T. (%)	S.C. (%)	P. (%)	C.C.L (%)	C.L. (%)	V.L. (%)	V.H. (%)
0-50	21.9	22.7	21.7	46.					
50-100	19.7	18.5	16.9	38.5					
100-150	18.2	17.3	16.1	37.3	3.8	3.9	5.4	3.8	3.3
150-200	19.1	17.6	15.5	39.9	3.8	6.7	4.3	3.5	2.8
200-250	19.6	17.5	14.1	39.6	3.8	10.	3.6	4.1	3.4
250-300	19.1	15.2	15.	36.5	3.2	9.2	3.2	4.3	3.2
300-350	17.8	14.8	13.7	33.6	3.2	9.6	3.2	4.3	3.3
350-400	18.3	15.1	15.	36.	3.3	9.7	2.6	4.7	4.3
400-450	18.7	14.4	14.6	31.7	2.9	8.5	2.6	5.3	4.
450-500	17.7	13.1	14.3	28.7	2.9	8.1	2.5	5.3	4.2
500-550	17.7	13.	15.	27.8	2.9	8.	2.3	5.2	4.2

Table XXVIII.

Spinal Cord Weight (grams.)

Range of C.H. Length (mm.)	Average of C.H. Length	Average	Maximum	Minimum	No. of cases	Ratio of Newborn (%)
0-50	30	.015	.02	.01	2	.52
50-100	77	.05	.09	.025	7	1.75
100-150	125	.14	.29	.06	12	4.9
150-200	165	.27	.5	.14	12	9.6
200-250	227	.51	.71	.37	10	17.9
250-300	269	.69	1.2	.26	14	24.2
300-350	322	.88	1.17	.58	11	30.9
350-400	371	1.1	1.52	.69	8	38.6
400-450	422	1.56	1.85	1.24	5	54.8
450-500	480	2.4	3.	1.5	6	84.2
500-550	522	2.85	4.52	1.94	8	

Table XXIX

Pons and Medulla Weight (grams.)

Range of C.H. Length (mm.)	Average of C.H. Length	Average	Maximum	Minimum	No. of cases	Ratio of Newborn (%)
0-50						
50-100	100	.16	.16	.16	1	2.9
100-150	127	.29	.42	.17	4	5.3
150-200	171	.44	.71	.2	12	8.1
200-250	223	.73	1.03	.55	8	13.5
250-300	270	.92	1.34	.6	14	17.
300-350	323	1.46	2.16	.98	10	27.
350-400	372	2.33	2.6	1.73	7	43.
400-450	428	3.13	3.26	2,8	6	57,8
450-500	480	4.4	5.09	3.9	6	81.2
500-550	525	5.42	6.46	4.53	8	

Table XXX.

Mid Brain Weight (grams.)

Range of C.H. Length (mm.)	Average of C.H. Length	Average	Maximum	Minimum	No. of cases	Ratio of Newborn (%)
0-50						
50-100						
100-150	127	.23	.34	.12	4	8.7
150-200	171	.32	.45	.2	12	12.1
200-250	223	.43	.5	.32	8	16.3
250-300	270	.64	.87	.45	14	24.2
300-350	323	.791	1.31	.43	10	30.
350-400	372	1.18	1.43	.88	7	44.7
400-450	428	1.6	1.96	1.33	6	60.6
450-500	480	2.36	3.13	1.54	6	89.4
500-550	522	2.64	3.28	1.84	8	

Table XXXI.

Cerebellum Weight (grams.)

Range of C.H. Length (mm.)	Average of C.H. Length	Average	Maximum	Minimum	No. of cases	Ratio of Newborn (%)
0-50						
50-100	100	.05	.05	.05	1	.23
100-150	127	.14	.22	.05	4	.64
150-200	171	.4	.76	.19	12	1.8
200-250	224	.86	1.31	.54	9	3.9
250-300	270	1.39	2.58	.8	14	6.4
300-350	323	1.93	2.62	1.07	10	8.8
350-400	372	5.41	7.13	3.5	7	24.7
400-450	428	9.07	11.81	5.91	6	41.4
450-500	480	18.87	22.38	14.34	6	86.2
500-550	522	21.9	25.84	18.41	8	

Table XXXIII.

Left Hemisphere Weight (grams.)

Range of C.H. Length (mm.)	Average of C.H. Length	Average	Maximum	Minimum	No. of cases	Ratio of Newborn (%)
0-50						
50-100	100	.92	.92	.92	1	.53
100-150	123	2.3	3.94	1.48	5	1.3
150-200	171	6.2	11.35	1.97	12	3.6
200-250	222	15.7	25.13	12.21	8	9.2
250-300	271	22.4	31.17	13.27	13	12.9
300-350	324	33.83	50.16	21.37	11	19.4
350-400	372	63.4	74.35	47.7	7	36.4
400-450	428	95.52	114.93	68.22	6	54.9
450-500	480	148.7	194.7	111.7	6	85.4
500-550	522	173.97	196.5	149.1	8	

Table XXXIV.

Both Hemispheres Weight (grams.)

Range of C.H. Length (mm.)	Average of C.H. Length	Average	Maximum	Minimum	Percentage increment (%)	No. of cases	Ratio of Newborn (%)	Percent of E.B. Weight (%)
0-50								
50-100	72	2.1	2.1	2.1		1	.6	89.5
100-150	123	4.6	7.2	3.	350.	5	1.3	88.9
150-200	169	12.3	22.5	3.9	144.5	12	3.5	88.7
200-250	223	29.7	47.3	24.6	77.2	8	8.5	92.9
250-300	271	47.6	63.9	26.	48.7	12	13.6	92.4
300-350	322	65.3	98.7	58.4	63.8	11	18.8	92.5
350-400	372	119.1	146.3	96.5	56.8	7	34.2	92.6
400-450	428	182.2	247.9	138.7	49.	5	52.3	92.9
450-500	480	273.7	395.7	228.2	40.5	7	77.8	91.5
500-550	522	348.2	386.9	312.1		8		90.9

Table XXXV.

Entire Brain Weight (grams.)

Range of C.H. Length (mm.)	Average of C.H. Length	Average	Maximum	Minimum	No. of cases	Ratio of Newborn (%)
0-50	39	.335	.72	.09	4	.09
50-100	72	1.35	2.38	.58	12	.36
100-150	123	4.9	8.4	2.1	14	1.3
150-200	169	19.9	24.15	3.44	14	5.2
200-250	223	32.4	50.9	18.27	10	8.5
250-300	271	48.45	67.	28.63	12	12.7
300-350	322	70.5	105.9	46.95	11	18.6
350-400	372	135.	156.7	103.5	7	35.6
400-450	428	212.5	266.	150.19	6	59.4
450-500	480	328.37	425.46	252.19	6	85.6
500-550	525	378.78	424.54	339.7	8	

Table XXXVI.

Entire Brain Weight (grams.)

(Based on the Literature.)

Range of C.H. Length (mm.)	Average	No.Of Cases	Percentage Increment (%)	Ratio of Newborn (%)
0-50				
50-100	2.13	3	255	.52
100-150	7.57	18	152.4	1.8
150-200	19.09	34	57.4	4.7
200-250	30.03	76	79.4	7.3
250-300	53.88	88	73.3	13.2
300-350	93.41	82	50.3	22.8
350-400	140.3	76	67.	34.2
400-450	234.	52	39.4	57.2
450-500	326.3	68	25.3	79.8
500-550	409.	54		
550-600	465.	2		