PRENATAL GROWTH OF THE HUMAN SPINAL CORD

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Introduction.

In human embryology the changes in form and the histological differentiation in the cellular elements of the spinal cord have been studied very carefully. But as yet little has been done on the absolute and relative prenatal growth of the cord as a whole and of its various regions and parts. To throw light upon this matter the present study was undertaken. Measurements were made of the spinal cords of human embryos which show the absolute and relative growth of the spinal cord as a whole and of its various parts. The data here presented include:- First, the absolute and relative growth of the spinal cord in its entirety; second, the absolute and relative amounts and the rate of growth of the different regions of the cord; and third, the absolute and relative amounts and the rate of growth of the gray matter, the white matter and the ependyma with the canal. This investigation was carried on in the Anatomical Laboratory of the University of Missouri, under the direction of Prof. C. M. Jackson, to whom I am also indebted for the use of his collection of human embryos.

Review of Literature.

Altho the following articles discuss some of the same points presented in this paper there is to be found in the literature only very scant references concerning the prenatal growth of the human spinal cord.

Stilling (9) in 1859 completed a very exhaustive study of the areas in cross-section for the gray matter (including the anterior and posterior horns), the various columns of white matter, the ependyma, and the central canal in the various regions of the cord in both child and adult. He presents data on the spinal cords of several adults and three children. These data are used thruout this paper for comparison of the prenatal cord with that of postnatal life.

His(5), in 1886 describes the partial closure of the central canal in the human embryo about the end of the 2nd month (24mm). He noted that the anterior horns are at first larger than the posterior; forming 2/3 of the total gray matter in cross-sectional area at 6 or 7 weeks. At three months, practically all the various parts of the cord are distinguishable; but the white substance is relatively small in amount, and the anlages of the gray horns are very broad and thick.

Minot (8) in his Textbook of Human Embryology in 1892 states that the central canal of the human embryo remains stationary in absolute size but becomes relatively smaller between the 3rd and 5th months. He finds the anterior and posterior horns not clearly separated at five months. The cervical and lumbar enlargements are indicated at two months, and are well developed at three months.

In 1903, Donaldson and Davis (4) published some very instructive curves, illustrating the areas in cross-section of the spinal cord of the child and of the adult at the level of each pair of spinal nerves. These curves, for the most part, were plotted from Stilling's data. They used the data given by Stilling (9) for four adult cords in plotting the curves for a composite adult. For the curve of the child they used the areas given by Stilling for a two year old child and the length of the segments of a 3 1/2 year old child taken from Lüderitz's observations. These curves are reproduced (with variations as explained later) in this paper for comparison with the curves for the prenatal cord.

Bryce (3) states that the rudiments of the ventral (or anterior) horn of gray matter in the 5th week of prenatal life are sharply marked off from the rest of the gray matter by the character of their rounded and less-staining nuclei. He also states that the cervical and lumbar enlargement are only manifest at the end of the 3rd month.

Jackson (7), in 1909, gives a curve illustrating the rela - tive prenatal growth of the various organs and parts of the human embryo, including the spinal cord, as compared with the whole body.

In 1911, Streeter (10) makes a statement that the central canal is relatively large in the 2nd month of prenatal life (15mm embryo) and later decreases (up to 80mm) both in absolute and in relative size. He also says that in the 15mm embryo the ventral or anterior horn of gray matter, which forms somewhat earlier than the posterior horn , is present. He finds indications of both horns in the 15mm embryo, altho their shape or form is not characteristic till later. Furthermore, he finds indications of the cervical and lumbar enlargements at the end of the first month of prenatal life.

Materials and Methods.

The material used consisted of the following embryos:- 11mm (No. 60, 5th week), 17mm.(No.58, 6th week), 31mm. (No.57, 8th week), 65mm. (No.55, 12th week), and 150mm. (No.54, 5 months). The lengths are all crown-rump measurements. The ages are only approximate and all conclusions referring to them are therefore subject to more or less uncertainty.

The embryos had been prepared by the following methods:- No. 60 (♀?) was fixed and hardened in alcohol, stained in bulk in alum-cochineal, embedded in paraffin, and cut into transverse serial sections, 20µ thick. No.58 (♀) was fixed in formalin, hardened in alcohol, decalcified in acid-alcohol, stained in bulk in alum-cochineal, embedded in paraffin, and cut into transverse serial sections, 20µ thick. No.57 (♀) was fixed in formalin, hardened in alcohol, decalcified in acid-alcohol, stained in bulk in alum-cochineal, embedded in paraffin, and cut into transverse serial sections, 20µ thick. No.55 (♂) was fixed in formalin, hardened in alcohol, decalcified in 1% HCl in 70% alcohol, stained in bulk in alum-cochineal, embedded in paraffin, and cut into transverse serial sections,50µ thick. No.54 (♀) was fixed in formalin, decalcified in 2% nitric acid in 70% alcohol, embedded in celloidon, cut into transverse serial sections, 100µ thick, and stained with alum- haemotoxylin. This material is all in good condition, especially the younger embryos.

Sections of these embryos were magnified by means of an Edinger projection apparatus (E. Leitz-Wetzlar) and outline drawings made of cross-sections of the spinal cords. In the case of the 11mm., 17mm., 31mm., and 65mm. embryos every fourth section was drawn while in the embryo of 150mm. only every tenth section was used. In exceptional cases where the section to be drawn was torn or distorted, the adjacent section was drawn instead. The magnification used was 50 diameters, which corresponds to a magnification of 2500 times in cross-sectional area.

The areas of these drawings were measured with a planimeter (Coradi). This instrument on being tested showed an error of less than 0.25% which was chiefly due to the technique with which it was operated. Two entirely independent readings were made in each case and average used in order to minimize the error. The percentages of the gray matter (anterior and posterior horns), of the white matter (anterior, lateral, and posterior columns), and of the ependyma with the canal were first calculated from the original readings. The original readings were then reduced to their actual size from which again the percentages of the various parts were calculated. This gave a check on the accuracy of the calculation. Since the thickness of the sections was known it was easy to calculate the total volumes of the cords and their various parts.

The first section which showed filaments of the first pair of spinal nerves was taken as the upper level of the spinal cord. This, however, was not always the exact upper level, on account of the obliquity of the section caused by the normal curvature of the younger embryos. This error is in most cases not large enough to interfere seriously with the general results, but should be borne in mind.

The length of a segment was determined by taking all sections between the uppermost point of attachment of a nerve to the cord and the corresponding point of the next pair of nerves caudal to the first. Since the thickness of the sections was known, the lengths and volumes of the various segments were readily calculated. Owing to the curvature of the younger embryos it was impossible in these to obtain the exact length of the upper and the lower segments. This, however, did not interfere with obtaining accurately the total volume of the cord. In the 65mm. and 150mm. embryos the uppermost segments were missing. These were estimated by calculation from the other segments of the same cords assuming that the same relative increase takes place in these segments as in the other segments of the same cord when compared with the 31mm. cord. While the obliquity of some of the sections interfered in some respects, these exceptions are carefully noted so that they have not resulted in any great error in the accuracy of the work. The curvature and corresponding obliquity of cross-sections can be determined approximately by the graphic reconstructions in lateral view of the four younger embryos in the paper by Jackson (6).

The exact line of demarcation of gray from white matter was sometimes difficult to determine, due to their intermingling, In the younger embryos in which only the anlages of the anterior and posterior horns are present, a horizontal line was drawn from the small recess in the boundary zone of the gray matter, which was very thin, to the nearest point of the central canal. This line arbritarily separated the anterior from the posterior horns. The lateral horn was not present in the younger embryos. In the older stages the lateral horn was included with the anterior, thus dividing the gray matter into a posterior and antero-lateral horn. (See Plate I).

The white matter was separated into the anterior, posterior, and lateral columns. The lateral border of the anterior column is the line of emergence of the outermost fascicles of the nerve roots. This separates the anterior and lateral columns. The dorso-lateral sulcus at the attachment of the posterior nerve roots separated the posterior and lateral columns. In the 11mm. specimen the lateral columns showed such an irregularity that they were measured with the anterior columns. For exact lines of demarcation see Plate I.

Observations and Discussion.

Cord as a Whole.

1. General Form of the Prenatal Spinal Cord. (Tables II to VI inclusive.)

The spinal cord in human embryos shows various points of resemblance in form to the cord in the adult, as shown in Plate II. Passing caudad from the brain there are indications, however, that the spinal cord diminishes gradually in its diameters to about the region of the 3rd cervical segment. This resembles the cord of the child but not of the adult. From here there is in all the embryos a slight but constant increase which reaches its maximum in the region of the 4th or 5th cervical segment. This enlargement in the cervical region corresponds to the cervical enlargement or intumescentia cervicalis. This is followed by a more gradual or steady decrease in area of cross-section which extends to about the 3rd thoracic segment. The diameters of the thoracic segments, from the 3rd to the 8th, have practically the same area of cross-section in each of the embryos examined. This is also true in the child and to a less extent in the adult. Near the lower end of the thoracic region, in the vicinity of the 9th or 10th segment, there are indications of the lumbar enlargement or intumescentia lumbalis. The cord increases in area of cross-section from the lower thoracic segments to the 5th lumbar segment or thereabout, whence there is a gradual tapering of the cord as it decreases in cross-sectional area to its end in the filum terminale. The lower ends of the cords are somewhat conical in shape.

In general shape the prenatal cord in cross-section is at first oval, being compressed in its transverse diameter. (See Plate I.) Later, however, it becomes compressed in the dorso-ventral diameter and expanded laterally. In the thoracic region, the spinal cord more nearly retains a cylindrical form. In these respects the fetal cord approaches the postnatal condition. If we compare the increase in cross-sectional area at successive stages with the increase in volume of the spinal cord, we find in general that the volume increases the more rapidly. That is, the cord becomes relatively longer and slenderer during the prenatal life, and this tendency continues in the child to the adult.

2. Special Features in the Various Embryos. (Plate I and Tables II to VI, inclusive.)

In the 11mm. embryo (No. 60) only the cervical and thoracic segments were measured separately. By referring to Table II and Plate II, Fig. I, one can readily see that this embryo differs somewhat from the preceding general description. Owing to the obliquity of the section in the cervical and lower thoracic region, (due to the normal curvature of the spinal cord in embryos of this length) not much stress can be laid on the apparent increase in area of cross-section in these regions as shown in the curve. However, from measurements of the transverse diameters of these sections, which show an increase in the cervical region, the indications are that there is a slight increase in cross-sectional area in the region of the cervical emlargement. There is, however, no evident lumbar enlargement. The apparent increase shown in the curve in the lower thoracic region is due entirely to the obliquity of the sections. The cord seems to taper from the cephalic end to its caudal extremity. The lower end of the cord is so curved that the segments could not be separated. The shape of the cord (Plate I, Figs. 1 and 2) is in general like that of a rectangle with the corners rounded. The outline is not smooth, due probably to the fact that the columns of white matter are as yet not formed.

The spinal cord of the 17mm. embryo (No.58) presents(as shown in Table III, Plate I, and Fig. II, Plate II) some of the same features as the cord of the 11mm. specimen. From the increase in areas of cross-section and in the lateral diameters of the sections, it is evident that there is in this cord a noticeable increase in the region of the cervical enlargement, and a very slight increase in the lower thoracic and upper lumbar segments which is possibly due in part to the beginning of the lumbar enlargement. The increases both in the cervical and thoraco-lumbar regions are less than apparently shown on the curve, due to the curvature of the cord and the corresponding obliquity of the sections.

In the 31mm. embryo (No. 57; Table IV, Plate I, and Fig.III, Plate II) the upper three segments are so cut as to contain both medulla and spinal cord. The outline of the cord could be made out separately, however, and only the cord was measured. The cervical enlargement is recognizable also in this cord. This is the youngest embryo in which there is a well-marked lumbar enlargement, which is followed by a decrease in the sacral region. The preceeding does not agree with Bryce (3) who states that the cervical and lumbar enlargements are only manifest at the end of the 3rd month. However, Streeter (10) finds indications of the enlargements at the end of the first month while Minot (8) states that they occur at 2 months (well developed at 3 months). The cord of the 31mm. embryo is but slightly larger in area of cross-section (and even smaller in places) than of the 17mm. specimen. The difference may be due in part to individual variation and in part to the growth being chiefly along the longitudinal axis about this period, as will be shown later.

The upper two cervical segments in the 65mm. embryo (No. 55; Table V and Fig. IV, Plate II) are lacking. They were estimated to complete the data. This was done by assuming that these segments would show the same relative increase, as other segments of the same cord, when compared with corresponding segments of the cord in the 31mm. specimen. They are enclosed in parentheses in the tables. A very marked variation occurs in this cord. The cervical enlargement appears relatively small. The lumbar enlargement shows a greater area of cross-section than the cervical enlargement. As this relation is not found in any other cord examined, it is probably due either to more rapid relative growth of the lower portion of the cord at this period or to an individual variation. The tapering of the lower extremity of the cord is definitely shown here since all the lower segments were measured separately in this specimen.

In the cord at the middle of the prenatal period (150mm. embryo No.54) (Table VI and Fig. V, Plate II) the upper three cervical segments are missing. These were estimated as above. This cord agrees well with the general description previously given.

3. Growth of the Cord as a Whole.

The total volumes of the spinal cord measured are shown in Table I. From these data and volumes of the entire body (which were known) the percentages that the cords bear to the entire body were calculated. They are as follows:-

C.R. Length of Embryo.	Body Volume.	Volume of Spinal Cord.	% Total Body Volume.
	cc.	cc.	
11mm.	.0976	.004024	4.13 (4.85)
17"	.3788	.01194	3.15 (3.43)
31"	1.693	.02115	1.25 (1.53)
65"	(20.00) *	.1505	.755
150"	(200.00) *	.3969	.198

* Estimated.

The difference in the percentages obtained by Bonnot and Seevers (1) for the 11mm.,and Jackson (7) for the 17mm. and 31mm. specimens, and those by myself is quite marked. Their results are given in parentheses, and are larger in every case. This difference is due chiefly to a difference in technique. In measuring the area of the various sections they took the border on the outer edge of the meninges immediately surrounding the cord, and passed directly over the anterior fissure and posterior sulcus, while I in all cases measured on the surface of the spinal cord proper, leaving out the meninges and following the various breaks in the continuity of the outline. The small difference would be expected, due to this difference in technique.

The absolute growth of the prenatal cord is very marked in the younger embryos as shown by the total volumes of the cords in Table I. This is what is expected since the neural tube or anlage of the spinal cord forms very early in the embryo. The growth of the spinal cord during the 2nd month of prenatal life seems to be in the length of the cord more than in the cross-sectional area as will be shown later. The rate of growth seems, in general, to decrease with the age of the embryo. During the 2nd and 3rd months (11mm. to 65mm.), the cord has increased 36 times, or 3600%. In the 4th and 5th months (65mm. to 150mm.) together the increase is only approximately 160%.

The relative growth-rate decreases with age as is also shown by the decline in percentages which the spinal cord forms of the entire body. This agrees with the rate of absolute growth in that as the age increases the rates of growth become relatively slower. Vierordt (11) gives .18% of the total body weight for the spinal cord in the newborn and .06% in the adult. These figures added to my results show that the decrease in growth-rate continues thru prenatal into postnatal life. This agrees with the conclusion reached by Jackson (7).

4. Growth of the Various Regions.

a. Cervical Region.

The different regions of the spinal cord show in their rates of growth some slight differences when compared with the rate of growth of the entire cord. The cervical region exhibits a slower rate of growth than the whole cord up to the 31mm. embryo while from here to the end of the first half of prenatal life (150mm. embryo) it slightly exceeds the growth rate of the whole cord. The cervical region increases approximately 175% while the entire cord during the same period increases less than 166%.

In area of cross-section, using the 5th cervical segment for comparing the growth of the cervical region, it is observed

(Tables III to VI, inc., also Plates I and II.) that the area increases as growth in volume proceeds. However, a comparison of the 17mm. and 31mm. embryos show that the cross-sectional area increases only about 60% while the volume in the same period increases over 100%. This indicates that during this period the growth along the longitudinal axis is greater than in the transverse diameters. The 65mm. embryo in cross-sectional area shows a small absolute decrease over the 31mm. embryo in the cervical region. This decrease is evidently due to individual variation. During the latter part of the first half of prenatal life the relative growth in area of cross-section is relatively less than the growth in volume, as compared with the younger stages. By using the areas of cross-section of the 5th cervical segment as given by Donaldson and Davis (4) (taken from Stilling) for a child of two years and a composite adult, an increase of 600% occurs in the child as compared with the 150mm. embryo and and of only 100% between the child and the adult. This indicates that in the cervical region the growth in area of cross-section decreases relatively (compared with volume) with age up to maturity, as previously mentioned for the entire cord.

The relative amounts by volume which the different regions form of the entire cord as given in Table I. The cervical region in the 11mm. embryo constitutes 37% of the entire cord. This is probably somewhat too large owing to the obliquity of the cord in this region. However, it is readily seen that there is a slight decrease to about 28% in the mid-fetal cord (150mm.) In the 2 year old child it is relatively larger, forming 36% of the entire cord. There is a decrease to 31% between this and the adult stage which seems to correspond to the increase in the thoracic region.

b. Thoracic Region.

The thoracic region, in volume, shows an increase of slightly less than 400% between the 11mm. embryo and the 65mm. specimen. This is more than the increase in the cervical region during the same time which is less than 300%. From the 65mm. embryo to the midfetal period (150mm.), the thoracic continues to increase slightly more rapidly than the cervical region. This is also true, for the thoracic region, when compared with the cord as a whole, as shown in Table I.

In cross-sectional area the thoracic segments from the 3rd to the 8th are practically constant. The increase in area of cross-section is more marked between the 11mm. and 17mm. specimens, being 250%, than between any other two embryos of adjacent periods. (Plate I. In the thoracic region the relative decrease in cross-sectional area (with a relative increase in volume) from the 17mm. to the 31mm. specimens (Tables III and IV) is in agreement with the previous statement that during this period the growth is greatest along the longitudinal axis. This continues thru the prenatal period and continues into postnatal life. The 65mm. embryo is slightly smaller in cross-sectional area than the 31mm. embryo in the thoracic region. This absolute decrease is probably due to individual variation. By using data for the child and adult taken from Donaldson and Davis (4) and Stilling (9) it is shown that in the time which elapses between the midfetal period and the 2nd year of postnatal life the cross-sectional area of the thoracic region increases approximately 1000%, while from here to the adult there is only an increase of about 100%. This shows that the cervical and thoracic regions have nearly the same growth-rate in area of cross-section from the child to the adult stage.

The thoracic region is relatively smaller than the cervical region in the 11mm. embryo. However, it shows a much more rapid rate of growth and in the 17mm. embryo is larger both relatively and absolutely than the cervical region. This growth continues thruout prenatal life and continues into the postnatal period until in the adult the thoracic region is nearly twice as large as the cervical region, as shown in Table I.

c. Lumbo-sacral Region.

The lumbo-sacral region of the spinal cord shows (Table I) approximately the same rate of growth, in volume , as the thoracic region and a faster one than the cervical region up to the 17mm. embryo. After they can be differentiated (31mm.) the lumbar region grows relatively faster in absolute size than the sacral region. In the 31mm. embryo the lumbar region is 1 6/10 times, while in 150mm. embryo it is 3 3/4 times as large as the sacral region.

The 4th lumbar segment is used to compare the areas of cross-section in the lumbar region (Plate I). In the younger embryos (11mm. and 17mm.) this segment could not be measured owing to the curvature of the cord. In the 65mm. embryo the cross-sectional area of the lumbar region is much larger, relatively and absolutely, than the cervical region, as previously stated. The rates of growth of the lumbar region in area of cross-section is slower than that for the cervical or thoracic regions in the 65mm. and 150mm. embryos. This same relative decrease continues in this region in the child and adult.

The lower region of the cord, including both the lumbar and sacral forms 31% of the entire cord in the 11mm. embryo. It increases relatively until in the 31mm. specimen when it comprises 38% of the whole, the lumbar division forming 8/13 of this lower region. The lower region decreases in relative size in later prenatal life and in the child until in the adult it forms only 18% of the entire cord. The sacral region decreases relatively more than the lumbar as previously noted.

This relative decrease in the lumbar and sacral regions was unexpected, for it seems that since the corresponding parts of the body, (the pelvis ~~and lower~~ and lower extremity) increase in relative size during this period, we should expect a relative increase in this region of the cord. This decrease is evidently associated with the shortening of the spinal cord within the vertebral canal, which begins about the 3rd month and results in the well known retraction of the lower end of the cord.

In comparing the rates of growth in volume and in average cross-sectional area of the spinal cord, let it be assumed that the volume and the cross-sectional area in the 11mm. embryo each equals to 1. Then it is noted that in the 17mm. specimen the volume has increased relatively twice as much as the area of cross-section. In the 31mm. embryo the increase in length is to the increase in area as 3 is to 2. This relatively greater increase in volume, over the cross-sectional area, is also found in the 65mm. and 150mm. embryos tho not so marked in these. This indicates that the growth in length is relatively greater than in area of cross-section as previously stated.

Gray Matter.

1. General Form. (Tables II to VI, inc., Plate I and Plate II.)

The gray matter , which constitutes the cellular part of the spinal cord, in the older embryos studied shows an increase in cross-sectional area in the regions of the enlargements as compared with that found in the thoracic region. In the youngest embryo (11mm.) the gray matter was of about the same area in all segments. The anterior (or ventral) Horns form more than one half of the gray matter in all specimens studied. In the youngest embryo the anterior horn anlage is approximately three times as large as the posterior (or dorsal) horn, which agrees approximately with the statement of His (5). Later, however, the posterior approach the ventral (or anterior) in size. The lateral horn is not well marked except in the older embryos. (See Plate I.) In all cases when present it is included with the anterior horn. The gray matter shows much variation in shape in different segments. This seems to agree with Bruce (2), who states that the gray matter has a different shape in the various adult segments.

2. Special Features in the Various Regions.

In the 11mm. embryo (Table II and Fig.I, Plate II) there seems to be more gray matter (in cross-sectional area) in the cervical than in the thoracic region but this is at least in part due to the obliquity of the section. In the 17mm. embryo (TableIII) there is a slight increase in the area of cross-section in the cervical region (as compared with the thoracic) which probally corresponds to the cervical enlargement. The small increase shown by the data in the lower thoracic and upper lumbar segments is due for the most part to the curvature of the cord. The 31mm., 65mm., and 150mm. embryos all seem to correspond closely to the general description (Tables IV, V, and VI, and Plate II).

The 65mm. embryo shows a relatively larger area of cross-section in the lumbar region than in the cervical region. In the others the cervical region is the largest. This is true for the cross-sectional area of the whole cord as well as for the gray matter.

3. Growth as a Whole.

The total volumes of gray matter, both absolute and relative, are given in Table I. The gray matter comprises about 38% of the entire cord in the 11mm. embryo. In the 17mm. embryo it has increased in absolute volume approximately 300% and now comprises about 50% of the entire cord. The increase in absolute volume continues, but relatively slower, to the 65mm. embryo where it forms 58% of the total cord. In the 150mm. embryo (at the midfetal period) the relative volume shows a slight decrease (to 53%) while the absolute volume continues to increase. This continues into postnatal life, until of the cord of the child it forms only 27% of the whole and in the adult only 20%.

As previously stated the anterior horns are relatively much larger in the earlier stages. Plate I. The anterior horns can be distinguished from the posterior horns in the 11mm. embryo altho they are far from the characteristic shape assumed later. His (5) recognized the anlages of the posterior and anterior horns early in the 2nd month, but states that they do not assume their definite form until later, being very broad at 3 months. Minot (8) found them fused at about 5 months. Streeter (10) and Bryce (3), however, state that in the 15mm. embryo (5th week) the rudiments of the anterior horns can be seen.

4. Growth of Various Regions. (Plate II, Tables I and IX to XII inc.)

The cervical region of the cord contains relatively more gray matter by volume than the cord as a whole. In the 31mm.

embryo the gray matter is 57% of the cervical region while it is slightly less in the entire cord (55%). This hold true in all the embryos studied and is seen, by the data on the child and adult to continue into postnatal life. The differences are probably relatively less in the 11mm. and 17mm. embryos than in the older specimens altho they seem to be more as shown by the curve. This is due to the curvature of the embryo. The gray matter of the cervical region reaches the maximum relatin size in the 31mm. embryo while in the entire cord the maximum of gray matter is in the 65mm. specimen. The gray matter in the thoracic region has practically the same rate of growth as the gray matter in the cord as a whole up thru the stages examined. The gray matter in the lower regions grows faster than the gray matter in the entire cord up to the 17mm. embryo when it grows relatively slower during the rest of the first half of prenatal life.

By comparing the areas of gray matter as given in Tables II to VI inc., it is shown that, in general, the rate of increase in all regions is relatively the same as found for the entire cross-sectional area in the various regions. The gray matter of the lumbar region tends to show a relatively more rapid growth than either the cervical or thoracic regions during the period from the third month (65mm.) to the end of the first half of the prenatal period (150mm.). This is what we might expect since it is just preceeding this time that the lumbar enlargement makes its appearance.

White Matter.

1. Form.

In any given segment the white matter shows in general the same increase in cross-sectional area as the the increase in the entire cross-sectional area of the corresponding segment. (Plates I and II.) The various columns are indefinitely formed in the 11mm. embryo and later gradually assume their typical shape and relation to the gray matter.

2. Growth as a Whole. (Table I.)

The white matter shows a steady increase in the total amount both absolutely and relatively from the youngest embryo (11mm.) examined to the adult, as shown in Table I. In the 11mm. specimen, the white matter forms 13% of the entire cord while in the 150mm. embryo (midfetal period) it constitutes 46% of the whole cord. In the child of two years it forms 73% and in the adult 80%. This is considerably different from the gray matter, which increases relatively up to the 65mm. embryo and thereafter decreases relatively into postnatal life. The data for the different columns indicate that the rate of growth for the various columns is irregular. In some stages one pair of columns is relatively the largest and in the following stage another pair is the largest. This may be due to the formation of the different nerve tracts at different periods.

3. Growth in Different Regions. (Tables I and IX - XV inc.)

The white matter in the cervical region of the 11mm. and 17mm. embryos, is seen to be relatively larger than in the cord as a whole. In the 31mm. embryo it is about equal and in the 65mm. and 150mm. specimens it is less. Over 50% of the total white matter of the 11mm. embryo is in the cervical region. In the older embryos the greatest amount of white matter is found in the thoracic region. The length of the thoracic region accounts for the larger volume since the area of cross-section in this region is smaller than in either the cervical or lumbar region. In each of the various regions there is a relative increase of white matter present from the youngest embryo to the adult, the same as in the entire cord.

Ependyma With the Central Canal.

1. Form.

The ependyma and central canal are measured together in this study. They undergo some very marked changes during prenatal life. Only the volume and area in cross-section are considered here. They are uniform in area of cross-section thruout the thoracic region of the cord in any given cord. At the cephalic end where it is continuous with the 4th ventricle the canal is slightly enlarged. A corresponding enlargement, tho more marked is found at the caudal end in the conus medularis where it forms the sinus rhomboidalis (which is so well marked in birds). After the 17mm. stage the canal is always decidedly narrower in the thoracic region. (Plates I and II)

2. Growth.

The areas of the ependyma and canal are shown in Plates I and II and in Tables II to VI inclusive, while the volumes are given in Table I. The ependyma with the canal in the 11mm. embryo forms 49% of the entire cord. In the 17mm. embryo they have decreased in relative size to 24% but show an absolute increase. From this stage they both show a decrease in relative and in actual size until in the midfetal period (150mm. embryo) they form only .59% of the whole cord. This decrease corresponds to the closure of the dorsal part of the central canal described by His (5). The ependyma and canal are too small to be shown in the curves after the 65mm. embryo. It is readily seen that the ependyma and canal reach a maximum size during the second month. This agrees with Streeter (10) who finds it relatively large in the 15 mm. embryo. This, however, does not quite agree with Minot (8) who says the canal remains stationary from the 3rd to 5th months of prenatal life.

The ependyma with the central canal show a relatively slower rate of growth than the gray matter up to the 17mm. embryo when they reach the maximum absolute size. The gray matter, until it reaches its maximum relative size in the 65mm. embryo grows relatively faster than the white matter. It seems as tho from the 17mm. to the 65mm. specimen the gray and white matter both grow chiefly at the expense of the canal and ependyma and thereafter the white matter continues to increase while the gray matter decreases in relative volume.

Summary.

Some of the more important observations and conclusions may be summarized as follows:-

1. In the 11mm. embryo,(Fig. I, Plate II) indications of the cervical enlargement first appear. In the 31mm. embryo, (Fig. III, Plate II) the lumbar enlargement is first definitely shown tho it may also be present at 17mm. (Fig.II, Plate II). The 11mm. cord, in general, tapers from the cervical end to the caudal extremity. In the 65mm. and 150mm. embryo the cervical and lumbar enlargements appear very prominent.

2. The percentage which the spinal cord forms of the entire body declines rapidly during the 2nd and 3rd months of prenatal life and later more slowly as shown by Jackson (7). The actual rate of absolute growth of the cord is much more rapid during the early prenatal months than during the later periods of life.

3. The various regions of the cord form different percentages of the whole cord at different ages. The cervical region forms approximately 37% of the whole cord in the 11mm. specimen and decreases to 28% in the midfetal stage (150mm.). In the child and adult it forms 36% and 31% of the whole, respectively. In the thoracic region there is a gradual increase from 32% in the 11mm. embryo to 41% in the (150mm.) midfetal stage; to 45% in the child and 50% in the adult. The lumbo-sacral region of the cord increases relatively from 31% in the 11mm. embryo to a maximum of 38% at 31mm. This is followed by a gradual decrease to 31% in the midfetal stage and 18% in both the child and adult. The decrease in relative size which occurs from the 2nd month of

prenatal life and extends into the postnatal period, is associated with the shortening of the cord in the vertebral canal. It is very remarkable when compared with the relative increase at the same time in the corresponding portions of the body (pelvis and lower extremity). This decrease is most marked in the sacral region of the cord. The thoracic region appears to grow at the expense of the cervical region up to about the 2nd month of prenatal life, and thereafter at the expense of the lumbo-sacral region, continuing up to the adult cord.

4. The gray matter constitutes about 38% of the whole in the 11mm. embryo increasing relatively to about 58% in the 65mm. specimen. Thereafter it decreases until in the child it forms 27% and in the adult less than 20% of the whole cord. The relative amount of gray matter in the cervical region from the earliest stages, and in the lumbo-sacral region from the 31mm. stage, is slightly greater than in the thoracic region. The ventral horn is about three times as large as the dorsal horn in the youngest embryo (11mm.). This difference in size becomes less in the later stages so that the ventral horn is later only about 50% greater than the dorsal horn, which is the ratio in the adult cord.

5. The white matter has a rate of growth different from that of the gray matter. It increases steadily from 13% in the 11mm. stage to 46% of the whole cord in the mid-fetal period (150mm. embryo). In the child it forms 73% and in the adult 80%, showing that the steady increase is continuous into postnatal life. In the white matter as also in the gray matter the relative increase in the different regions is about the same as the increase

in the cord as a whole. The different columns of white matter present many irregularities in growth which may be due to the successive formation of various tracts at different ages.

6. The ependyma with the canal show some very interesting growth relations. In the 11mm. embryo they form nearly 50% of the entire cord. This is followed by a gradual, rapid, relative decrease until by middle of the fetal period (150mm.) they form only .59% of the whole. This marked relative decrease is accompanied by a decrease in the absolute size from the 17mm. stage onward. With the exception of a slight dilation at the extremities, the canal is practically uniform in caliber in the 11 and 17mm. stages, but from the 31mm. stage is more constricted in the thoracic than in the other regions. The white and gray matter both grow at the expense of the ependyma and canal until about the 3rd month when the gray matter begins to decrease in relative amount while the white matter continue to increase.

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Table I.

Showing Total Volumes of Spinal Cords of Various Ages; the Absolute and Relative Amounts of Gray Matter, White Matter, of Ependyma with the Canal, and the Different Regions of the Cord.

Embryo No.	60	58	57	55	54	Child. (Stilling)	Adult.
Length in mm.	11	17	31	65	150	--	--
Age in Days (Estimated)	33	41	56	81	140	2-3.5 yrs.	-
Total Volume of Cord (cu.cm)	.00402	.01194	.02115	.1505	.3969	7424.2	27327.5
Vol. of Gray Matter	.00152	.00594	.01161	.0870	.2115	1980.9	5353.1
Vol. of White Matter	.00053	.00308	.00686	.0603	.1831	5443.3	21974.4
Vol. of Ependyma & Canal	.00197	.00292	.00268	.0032	.0023	- -	- -
% Gray Matter	37.93	49.76	54.90	57.82	53.29	26.68	19.58
% White Matter	13.18	25.79	32.43	40.03	46.12	73.32	80.42
% Ependyma and Canal	48.89	24.45	12.67	2.15	.59	- -	- -
Vol. of Cervical Region	.00148	.00376	.00573	.0419	.1098	2697.2	8556.8
Vol. of Thoracic Region	.00129	.00410	.00739	.0589	.1640	3359.0	13662.3
Vol. of Lumbar Region	.00125 (Lumbar and Sacral)	.00408 (Lumbar and Sacral)	.00510	.0315	.0771	914.5	4012.0
Vol. of Sacral Region			.00293	.0182	.0460	453.5	1096.4
% Cerv. Region	36.75	31.52	27.09	27.82	27.66	36.33	31.33
% Thor. Region	32.19	34.32	34.94	39.12	41.32	45.34	50.00
% Lumb. Region	31.06 (Lumb. and Sacr.)	34.16 (Lumb. and Sacr.)	24.11	20.93	19.43	12.32	14.68
% Sacr. Region			13.86	12.13	11.59	6.01	3.99

Table II.

Areas of Cross-Sections of the Spinal Cord in an 11 mm, Human Embryo. Showing the Absolute and Relative Amounts of Gray Matter, White Matter, and Ependyma with Canal.

Segment.		Area of Cross-Section.	Area of Gray Matter.	Area of White Matter.	Area of Ependyma & Canal.	% of Gray Matter.	% of White Matter.	% of Ependyma & Canal.
		sq. mm.	sq. mm.	sq. mm.	sq. mm.			
Cerv.	I.	.600	.244	.120	.236	40.67	20.00	39.33
"	II.	.560	.232	.112	.216	41.43	20.00	38.57
"	III.	.540	.224	.112	.204	41.48	20.74	37.78
"	IV.	.528	.220	.108	.200	41.67	20.45	37.88
"	V.	.544	.204	.104	.236	37.50	19.12	43.38
"	VI.	.532	.208	.084	.240	39.10	15.79	45.11
"	VII.	.508	.224	.072	.212	44.10	14.17	41.73
"	VIII.	.464	.168	.068	.228	36.21	14.65	49.14
Thor.	I.	.436	.160	.064	.212	36.70	14.68	48.62
"	II.	.416	.148	.060	.208	35.58	14.42	50.00
"	III.	.392	.136	.056	.200	34.69	14.29	51.02
"	IV.	.384	.148	.044	.192	38.54	11.46	50.00
"	V.	.364	.144	.040	.180	39.56	10.99	49.45
"	VI.	.380	.132	.056	.192	34.73	14.74	50.53
"	VII.	.384	.148	.052	.184	38.54	13.54	47.92
"	VIII.	.376	.144	.044	.188	38.30	11.70	50.00
"	IX	.372	.136	.052	.184	36.56	13.98	49.46
"	X.	.344	.136	.040	.168	39.53	11.63	48.84
"	XI.	.364	.132	.044	.188	36.26	12.09	51.65
"	XII.	.396	.144	.044	.208	36.36	11.11	52.53

Table III.

Areas of Cross-Sections of the Spinal Cord in a 17 mm, Human Embryo. Showing the Absolute and Relative Amounts of Gray Matter, White Matter, and Ependyma with Canal.

Segment.	Area of Cross-Section.	Area of Gray Matter.	Area of White Matter.	Area of Ependyma & Canal.	% of Gray Matter.	% of White Matter.	% of Ependyma & Canal.
	sq, mm.	sq. mm.	sq. mm.	sq. mm.			
Cerv. I.	1.300	.644	.376	.280	49.54	28.92	21.54
" II.	1.188	.596	.356	.236	50.17	29.97	19.86
" III.	1.152	.576	.348	.228	50.00	30.21	19.79
" IV.	1.180	.576	.372	.232	48.81	31.53	19.66
" V.	1.264	.652	.372	.240	51.58	29.43	18.99
" VI.	1.256	.636	.376	.244	50.64	29.93	19.43
" VII	1.232	.636	.340	.256	51.62	27.60	20.78
" VIII	1.128	.560	.340	.228	49.64	30.14	20.22
Thor. I.	1.036	.524	.280	.232	50.58	27.03	22.39
" II.	.932	.444	.272	.216	47.64	29.18	23.18
" III.	.924	.448	.256	.220	48.49	27.70	23.81
" IV.	.880	.424	.248	.208	48.18	28.18	23.64
" V.	.920	.464	.240	.216	50.44	26.08	23.48
" VI.	.932	.484	.244	.204	51.93	26.18	21.89
" VII.	.908	.460	.232	.216	50.66	25.55	23.79
" VIII.	.900	.444	.232	.224	49.33	25.78	24.89
" IX.	.916	.456	.232	.228	49.78	25.33	24.89
" X.	.896	.428	.232	.236	47.77	25.89	26.34
" XI.	.872	.420	.220	.232	48.16	25.23	26.61
" XII.	.956	.448	.248	.260	46.86	25.94	27.20
Lumb. I.	1.044	.492	.268	.284	47.13	25.67	27.20
" II.	1.076	.516	.276	.284	47.96	25.65	26.39
" III.	1.128	.540	.292	.296	47.87	25.89	26.24

Table IV.

Areas of Cross-Sections of the Spinal Cord in a 31 mm, Human Embryo. Showing the Absolute and Relative Amounts of Gray Matter, White Matter, and of Ependyma with Canal.

Segment.	Area of Cross-Section.	Area of Gray Matter.	Area of White Matter.	Area of Ependyma & Canal.	% of Gray Matter.	% of White Matter.	% of Ependyma & Canal.
	sq, mm.	sq. mm.	sq. mm.	sq. mm.			
Cerv. I.	2.166	1.175	.701	.290	54.25	32.36	13.39
" II.	2.142	1.182	.688	.272	55.18	32.12	12.70
" III	2.080	1.160	.670	.250	55.77	32.21	12.02
" IV.	2.112	1.204	.672	.236	57.01	31.82	11.17
" V.	1.984	1.120	.668	.196	56.45	33.67	9.88
" VI.	1.780	.992	.596	.192	55.73	33.38	10.89
" VII	1.496	.808	.532	.156	54.01	35.56	10.43
" VIII	1.268	.652	.488	.128	51.42	38.49	10.09
Thor. I,	1.100	.564	.424	.112	51.27	38.55	10.18
" II.	.904	.460	.352	.092	54.88	38.94	10.18
" III.	.852	.416	.348	.088	48.83	40.84	10.33
" IV.	.816	.400	.328	.088	49.02	40.20	10.78
" V.	.764	.384	.296	.084	50.26	38.74	11.00
" VI.	.812	.404	.320	.088	49.75	39.41	10.84
" VII.	.808	.400	.324	.084	49.50	40.10	10.40
" VIII	.848	.436	.308	.104	51.42	36.32	12.26
" IX.	.860	.436	.312	.112	50.70	36.28	13.02
" X.	.944	.492	.320	.132	52.12	33.90	13.98
" XI.	.992	.536	.332	.124	54.03	33.47	12.50
" XII.	1.216	.708	.368	.140	58.22	30.26	11.52
Lumb. I.	1.248	.672	.412	.164	53.85	33.01	13.14
" II.	1.428	.768	.432	.228	53.84	33.02	13.14
" III	1.488	.832	.436	.220	53.78	30.25	15.97
" I IV.	1.540	.848	.476	.216	55.91	29.30	14.79
" V.	1.528	.832	.460	.236	55.45	30.11	15.44
Sacr. I.	1.392	.764	.408	.220	54.89	29.31	15.80
" II.	1.372	.748	.400	.224	54.52	29.15	16.33

Table V.

Areas of Cross-Sections of the Spinal Cord in a 65 mm, Human Embryo. Showing Absolute and Relative Amounts of Gray Matter, White Matter, and Ependyma with Canal.

Segment.		Area of Cross-Section.	Area of Gray Matter.	Area of White Matter.	Area of Ependyma & Canal.	% of Gray Matter.	% of White Matter.	% of Ependyma & Canal.
		sq. mm.	sq. mm.	sq. mm.	sq. mm.			
Cerv.	I.	(1.936)	(1.016)	(.880)	(.040)	(52.48)	(45.45)	(2.07)
"	II.	(1.832)	(1.000)	(.796)	(.036)	(54.59)	(43.45)	(1.96)
"	III	1.772	.976	.764	.032	55.08	43.12	1.80
"	IV.	1.808	.992	.784	.032	54.87	43.36	1.77
"	V.	1.896	1.028	.832	.036	54.22	43.88	1.90
"	VI.	1.756	1.008	.716	.032	57.40	40.78	1.82
"	VII	1.592	.904	.664	.024	56.78	41.71	1.51
"	VIII	1.376	.756	.592	.028	54.94	43.02	2.04
Thor.	I.	1.120	.612	.484	.024	54.64	43.21	2.15
"	II.	1.020	.588	.408	.024	55.65	40.00	2.35
"	III	1.044	.604	.420	.020	57.85	40.23	1.92
"	IV.	.960	.556	.384	.020	57.92	40.00	2.08
"	V.	.988	.548	.420	.020	55.46	42.51	2.03
"	VI.	.980	.564	.392	.024	57.55	40.00	2.45
"	VII	1.040	.576	.440	.024	55.38	42.31	2.31
"	VIII	1.024	.572	.424	.028	55.86	41.41	2.73
"	IX.	1.096	.612	.456	.028	55.84	41.61	2.55
"	X.	1.208	.680	.500	.028	56.29	41.39	2.32
"	XI.	1.244	.724	.492	.028	58.20	39.55	2.25
"	XII	1.508	.860	.616	.032	57.03	40.85	2.12
Lumb.	I.	1.820	1.036	.748	.036	56.92	41.10	1.98
"	II.	2.184	1.224	.912	.048	56.04	41.76	2.20
"	III	2.416	1.404	.972	.040	58.11	40.23	1.66
"	IV.	2.560	1.516	1.000	.044	59.22	39.06	1.72
"	V.	2.412	1.448	.920	.044	60.03	38.14	1.83
Sacr.	II.	2.344	1.420	.872	.052	60.58	37.20	2.22
"	II.	1.828	1.120	.660	.048	61.27	36.10	2.63
"	III	1.416	.892	.492	.032	62.99	34.75	2.26
"	IV.	1.032	.616	.384	.032	59.69	37.21	3.10
"	V.	.560	.288	.252	.020	51.43	45.00	3.57
Coccygeal		.360	.216	.124	.020	60.00	34.45	5.55
Conus Med.		.244	.100	.132	.012	40.98	54.10	4.92
Fil. Term.		.168	.016	.128	.024	9.52	76.19	14.29

Table VI.

Areas of Cross-Sections of the Spinal Cord in a 150 mm, Human Embryo. Showing Absolute and Relative Amounts of Gray Matter, White Matter, and Ependyma with Canal.

Segment.	Area of Cross-Section.	Area of Gray Matter.	Area of White Matter.	Area of Ependyma & Canal.	% of Gray Matter.	% of White Matter.	% of Ependyma & Canal.
	sq. mm.	sq. mm.	sq. mm.	sq. mm.			
Cerv. I.	(7.728)	(4.452)	(3.220)	(.056)	(57.61)	(41.67)	(.72)
" II.	(7.460)	(4.160)	(3.248)	(.052)	(55.82)	(43.54)	(.64)
" III	(7.360)	(4.032)	(3.280)	(.048)	(54.78)	(44.57)	(.65)
" IV.	7.388	4.040	3.304	.044	54.68	44.72	.60
" V.	7.560	4.280	3.232	.048	56.61	42.75	.64
" VI.	7.748	4.476	3.224	.048	57.77	41.61	.62
" VII	7.164	4.036	3.080	.048	56.34	42.99	.67
" VIII	5.256	2.676	2.540	.040	50.91	48.33	.76
Thor. I.	3.640	1.816	1.800	.024	49.89	49.45	.66
" II.	2.812	1.496	1.296	.020	53.20	46.09	.71
" III	2.412	1.256	1.140	.016	52.07	47.26	.67
" IV.	2.524	1.308	1.204	.012	51.82	47.70	.48
" V.	2.404	1.236	1.156	.012	51.41	48.09	.50
" VI.	2.500	1.260	1.228	.012	50.40	49.12	.48
" VII	2.464	1.252	1.196	.016	50.81	48.51	.65
" VIII	2.420	1.216	1.188	.016	50.25	49.09	.66
" IX.	2.652	1.384	1.252	.016	52.19	47.21	.60
" X.	2.832	1.464	1.352	.016	51.69	47.74	.57
" XI.	3.132	1.632	1.480	.020	52.11	47.25	.64
" XII	3.636	1.812	1.804	.020	49.84	49.62	.54
Lumb. I.	4.228	2.264	1.944	.020	53.55	45.98	.47
" II.	5.268	3.028	2.220	.020	57.48	42.14	.38
" III	5.796	3.328	2.444	.024	57.42	42.17	.41
" IV.	6.140	3.584	2.536	.020	58.37	41.30	.33
" V.	6.080	3.620	2.440	.020	59.54	40.13	.33
Sacr. I.	5.792	3.396	2.372	.024	58.63	40.95	.42
" II.	4.948	2.644	2.284	.020	53.44	46.16	.40
" III	4.204	2.272	1.916	.016	54.04	45.58	.38
" IV.	3.540	2.040	1.480	.020	57.63	41.81	.56
" V.	3.104	1.772	1.304	.028	57.09	42.01	.90
Coccygeal	2.296	1.220	1.048	.028	53.14	45.64	1.22
Conus Med.	1.644	.884	.732	.028	53.77	44.53	1.70
Fil. Term.	.424	.032	.280	.112	7.55	66.04	26.41

Table VII.

Showing the Average Cross-Sectional Area of Gray Matter in the Various Regions and the Relative Amounts of the Anterior and Posterior Horns.

Region.	Embryo.	11mm.	17mm.	31mm.	65mm.	150mm.	Child.	Adult. (Stilling)
Cerv. V, VI, VII, & VIII.	(sq.mm.) Area of Gray Matter.	.201	.621	.893	.924	3.867	15.91	17.89
	% Ant. Horn.	74.63	69.40	58.45	62.45	54.69	- -	58.80
	% Post. Horn.	25.37	30.60	41.55	37.55	45.31	- -	41.20
Thor. Region.	(sq.mm.) Area of Gray Matter.	.142	.454	.460	.625	1.382	6.45	5.36
	% Ant. Horn.	79.58	72.03	58.69	64.48	53.62	- -	49.16
	% Post. Horn.	20.42	27.97	41.31	35.52	46.38	- -	50.84
Lumbar Region.	(sq.mm.) Area of Gray Matter.	- -	.515	.790	1.326	3.165	14.55	14.41
	% Ant. Horn.	- -	73.59	56.58	57.16	55.04	- -	52.80
	% Post. Horn.	- -	26.41	43.42	42.84	44.96	- -	47.20

Table VIII.

Showing the Average Cross-Sectional Area of White Matter in the Various Regions and the Relative Amounts of the Anterior, Lateral, and Posterior Columns.

Region.	Embryo.	11mm.	17mm.	31mm.	65mm.	150mm.	Child.	Adult. (Stilling)
Cerv. V, VI, VII, & VIII,	(sq.mm) Area of White Matter.	.082	.357	.571	.701	3.019	42.24	37.64
	% Post. Column.	36.59	20.45	35.20	28.10	25.55	- -	33.00
	% Lat. Column.	63.41	59.38	51.14	48.08	41.75	- -	36.40
	% Ant. Column.		20.17	13.66	23.82	32.70	- -	30.60
Thor. Region.	(sq.mm) Area of White Matter.	.050	.245	.336	.453	1.387	23.47	24.22
	% Post. Column.	38.00	20.41	35.71	26.27	32.30	- -	27.60
	% Lat. Column.	62.00	60.00	51.49	46.14	45.93	- -	54.05
	% Ant. Column.		19.59	12.80	27.59	21.77	- -	18.35
Lumbar Region.	(sq.mm) Area of White Matter.	- -	.279	.444	.910	2.321	21.88	20.80
	% Post. Column.	- -	20.43	26.80	31.65	34.38	- -	30.20
	% Lat. Column.	- -	56.99	53.40	47.47	40.84	- -	39.80
	% Ant. Column.	- -	22.58	19.80	20.88	24.78	- -	31.00

Table IX & X.

Absolute and Relative Volumes of White Matter, Gray Matter, and Ependyma with the Canal in Various Regions of the Cord in the 11 and 17mm. Embryo.

Region.		11mm. Embryo. Volume. c.c.	% of Region.	% of Total.	17mm. Embryo. Volume. c.c.	% of Region.	% of Total.
Cerv.	White Matter.	.000269	18.18	50.69	.001094	29.07	35.54
	Gray Matter.	.000643	43.48	42.14	.001919	51.00	32.31
	Canal & Ependyma.	.000567	38.34	28.81	.000750	19.93	25.69
Thor.	White Matter.	.000166	12.82	31.38	.001073	26.20	34.86
	Gray Matter.	.000485	37.45	31.77	.002005	48.95	33.76
	Canal & Ependyma.	.000644	49.73	32.73	.001018	24.85	34.88
Lumb. & Sacr.	White Matter.	.000095	7.60	17.92	.000911	22.35	29.60
	Gray Matter.	.000398	31.84	26.09	.002015	49.42	33.93
	Canal & Ependyma.	.000757	60.56	38.46	.001151	28.23	39.43

Table XI & XII.

Absolute and Relative Volumes of White Matter, Gray Matter, and Ependyma with the Canal in Various Regions of the Cord in the 31 and 65mm. Embryo.

		31mm. Embryo.			65mm. Embryo.		
Region.		Volume. c.c.	% of Region.	% of Total.	Volume. c.c.	% of Region.	% of Total.
Cerv.	White Matter.	.00187	32.64	27.26	.01625	38.80	26.97
	Gray Matter.	.00326	56.89	28.08	.02480	59.22	28.49
	Canal & Ependyma.	.00060	10.47	22.39	.00083	1.98	25.70
Thor.	White Matter.	.00276	37.35	40.23	.02644	44.90	43.88
	Gray Matter	.00427	55.07	35.06	.03181	54.02	36.55
	Canal & Ependyma.	.00056	7.58	20.89	.00064	1.08	19.81
Lumbar.	White Matter.	.00157	30.78	22.89	.01182	37.52	19.61
	Gray Matter.	.00284	55.64	24.46	.01860	59.05	21.37
	Canal & Ependyma.	.00069	13.58	25.75	.00108	3.43	33.44
Sacr.	White Matter.	.00066	22.52	9.62	.00575	31.49	9.54
	Gray Matter.	.00144	49.15	12.40	.01183	64.79	13.59
	Canal & Ependyma.	.00083	28.33	30.97	.00068	3.72	21.05

Table XIII.

Absolute and Relative Volumes of White Matter, Gray Matter, and Ependyma with the Canal in Various Regions of the Cord in the 150 mm. Embryo.

Region.		Volume. c.c.	% of Region.	% of Total.
Cerv.	White Matter.	.04848	44.16	26.47
	Gray Matter.	.06059	55.19	28.65
	Canal & Ependyma.	.00071	.65	30.60
Thor.	White Matter.	.08087	49.31	44.16
	Gray Matter.	.08213	50.09	38.82
	Canal & Ependyma.	.00100	.60	43.10
Lumb.	White Matter.	.03336	43.25	18.22
	Gray Matter.	.04345	56.33	20.57
	Canal & Ependyma.	.00032	.42	13.80
Sacr.	White Matter.	.02043	44.41	11.15
	Gray Matter.	.02528	54.96	11.96
	Canal & Ependyma.	.00029	.63	12.50

Tables XIV & XV.

Absolute and Relative Volumes of White Matter and Gray Matter, in Various Regions of the Spinal Cord in a Child of 2 Years (Stilling) and in a Composite Adult (Donaldson and Davis).

		Child.		Adult.	
		% of Region.	% of Total.	% of Region.	% of Total.
Cerv.	White Matter.	75.60	37.46	80.35	31.27
	Gray Matter.	24.97	33.23	19.65	31.41
Thor.	White Matter.	78.26	48.29	85.58	53.20
	Gray Matter.	21.74	36.87	14.42	36.89
Lumb.	White Matter.	63.04	10.59	70.47	12.99
	Gray Matter.	36.94	17.06	29.53	22.14
Sacr.	White Matter.	43.90	3.66	53.28	2.54
	Gray Matter.	56.10	12.84	46.72	9.56

Tables and Plates.

Explanation of Plate I.

The following figures represent outline drawings of actual cross-sections of different regions of the various spinal cords studied.

Fig. 1a.	5th Cervical	Segment,	11mm.	embryo.
Fig. 1b.	5th Thoracic	"	"	"
Fig. 2a.	5th Cervical	"	17mm.	"
Fig. 2b.	5th Thoracic	"	"	"
Fig. 3a.	5th Cervical	"	31mm.	"
Fig. 3b.	5th Thoracic	"	"	"
Fig. 3c.	4th Lumbar	"	"	"
Fig. 4a.	5th Cervical	"	65mm.	"
Fig. 4b.	6th Thoracic	"	"	"
Fig. 4c.	4th Lumbar	"	"	"
Fig. 5a.	5th Cervical	"	150mm.	"
Fig. 5b.	6th Thoracic	"	"	"
Fig. 5c.	4th Lumbar	"	"	"

These sections are reproduced with a magnification of 15 diameters. Where the sections drawn did not show any nerve roots, the lines of separation for the various columns of white matter were approximated. The letters used in the figures represent the various parts as follows:-

C.- Central Canal.

E.- Ependyma.

P.- Posterior Horns of Gray Matter.

A.- Anterior " " " "
l.- Lateral Columns of White Matter.
p.- Posterior " " " "
a.- Anterior " " " "

Description of Plate II.

This plate represents by curves, the areas of the cross-sections of several human spinal cords, as well as the areas of gray and white matter (also the ependyma with the canal in the first three curves) as they appear in each segment. The base line (abscissa) in all the charts is the same. It is taken from Donaldson and Davis (4) and in Fig.VII represents just one third of the length of the spinal cord which it represents. It is divided into lengths proportional to those of the spinal cord segments of which it is composed. On the ordinates representing the cross-sectional areas the scale differs for each figure. In order from above downward the curves are as follows:-

Fig. I.- Embryo of 11mm.

Fig. II.- " " 17 "

Fig. III.- " " 31 "

Fig. IV.- " " 65 "

Fig. V.- " "150 "

Fig. VI.- Child, data for area from Stilling's observations on the cord of a two year old child.

Fig. VII.- Composite adult, data from Donaldson and Davis, which were calculated from the data of four adult cords given by Stilling.

The following points must be held in mind to avoid error in comparing the various curves:-

1. Curves of Figs. I and II are incomplete at the lower end.

2. Curves of Figs. III are estimated at the lower end (dotted lines); also upper ends of Figs. IV and V (as previously explained).

3. The increase at the upper end (all the cervical region) of Fig.I is mostly due to the obliquity of the sections correspond-

ing to the curvature of the spinal cord. This also applies to the lower ~~six~~ thoracic segments of Fig.I; to the lumbar ~~and sacral~~ segments of Fig. II; the upper four cervical, to some extent, in Fig.III and in Fig.IV, all the cervical segments are slightly enlarged altho not enough to require dotted lines.

4. The various segments of the cords are drawn with the same relative length as in the composite adult (Fig.VII), and not as actually present in the individual embryos. No serious error results from this, if it is remembered that the curves illustrate area of cross-section and not actual volume.

5. The ordinates are not drawn to scale so as to represent the same total volume in each cord. Hence corresponding areas in different cords can not be directly compared as to size. But different regions of the same cord can be directly compared (with the limitation given under 4); as a general form of the curves can be compared for the different cords.