A DESCRIPTION OF CHARTS SHOWING THE AREAS OF THE CROSS SECTIONS OF THE HUMAN SPINAL CORD AT THE LEVEL OF EACH SPINAL NERVE.

By Henry H. Donaldson and David J. Davis.

(From the Neurological Laboratory of the University of Chicago.)

A. CURVES SHOWING THE AREA OF THE CROSS-SECTION OF EACH SEGMENT OF THE MATURE SPINAL CORD.

Introduction.

The data which are presented in this paper were gathered for the purpose of preparing a curve based on the human spinal cord, with which to compare the areas of white and gray substance found in the cross sections of the spinal cords of other mammals. Reference to the literature shows that with the exception of the curve presented by Krause and Aguerre (1), which was published while this study was in progress, the series of curves appearing in the text-books and used to show the areas of the gray and white substance at different levels of the cord, was first introduced by Woroschiloff (2), while that investigator was making a study of the conduction paths in the spinal cord of the rabbit. Woroschiloff's curves were based on measurements published by B. Stilling (3).

The fact that the records which Woroschiloff chose as the basis for his curves were from a child of five years, and therefore from a cord not completely developed, has been recently pointed out by several writers. That Woroschiloff should have used these particular records of Stilling, instead of taking the records for mature cords, published in the same volume, is explained by the fact that only in the case of the five-year old child are the areas for the separate funiculi given, and his interest was at that time directed to the funiculus lateralis. Since the white substance in the cord of the five-year old child is, *both absolutely and proportionately, less than* in the adult, the use of this series of curves to illustrate the gray and white substance in the mature spinal cord is necessarily misleading, yet these curves are at present employed in the text-books, without any accompanying statement to show that they are based on the measurements from an immature cord.

It is intended in this paper to present a chart which shall more accurately show the true relations between the gray and white matter as they appear in the adult, and thus shall replace the older charts now in use. In order to do this, not only should the measurements of the areas be those from the adult spinal cord, but there is another correction which applies to all the charts thus far published, including that of KRAUSE and AGUERRE (1), and which consists in representing the segments of the cord in their true lengths.

I. Representation of the Length of the Segments.

Heretofore, in these charts, the abscissa has always been divided into 31 *equal parts*—each part representing the length of a segment of the spinal cord. Manifestly this will give an incorrect form to the curve, because the segments of the cord are really of unequal length.

As any ordinate representing the area of a cross section applies strictly to the sum of half the distance from it to the ordinates next above and next below the point at which it is erected, it follows that by multiplying the areas represented by any ordinate by the length of the cord to which it applies, we get an approximation of the volume of the segment. It is evident, also, that the volume of a segment thus determined when the divisions of the abscissa are equal, would be different from that determined when the divisions of the abscissa represent the segments in their true length. To make a correct construction, it was therefore necessary to gather data on the lengths of the segments of the spinal cord. The measurements of these lengths recorded by STILLING (3, p. 619), are insufficient, having been made between the uppermost and lowest fila of each nerve—thus omitting some of the cord, where, as is conspicuously the case in the thoracic region, the line of roots is not continuous. A number of fresh observations were therefore made. The measurements to determine the lengths of the segments in the adult human cord were made on one specimen (W)—preserved in normal size in 10 per cent. formalin;—on the two careful delineations (X, Y) published by KADYI (4), and on the photolithographic chart (Z) of RÜDINGER (5). In the three plates the cord is depicted in natural size. The cords in the order named, are designated W, X, Y, Z.

In the cord W, the condition of the specimen did not permit the measurement of the first four cervical segments. In cords X and Y, the first cervical segment could not be measured on the dorsal aspect nor on the coccygeal segment at all. In cord Z, measurements on the dorsal aspect alone could be made, and even these could not be extended below the level of the 12th thoracic segment.

To determine the length of a segment, the distance between the uppermost fila of successive nerves was found, beginning with the uppermost filum of the first cervical nerve.[1] This was done both on the dorsal and ventral aspects of the cord. In making the measurements, the distance was marked off with a pair of spring compasses, and then this distance was measured on a metal scale to the nearest tenth of a millimeter. Each measurement has been separately entered in Table I.

---

[1] This method of measurement credits to any segment the entire "intersegmental space" which lies caudad to it. The method of LÜDERITZ (6) was to credit to any segment one-half the length of the intersegmental spaces lying on either side of it. The difference in the results would be the amount by which, in any instance, the intersegmental space caudad to the part of the segment to which the roots were attached differed in length from the sum of half the intersegmental spaces above and below the same parts. This difference in general would be small.

TABLE I.

Showing in millimeters the lengths of the segments in the adult human spinal cord.

Segment		Cord W		Cord X		Cord Y		Cord Z	Average
Aspect		Dorsal	Ventral	Dorsal	Ventral	Dorsal	Ventral	Dorsal	
Cervical	1				5.9		8.2	7.6	7.23
	2			7.1	12.3	6.0	13.0	10.4	9.74
	3			12.2	11.0	12.0	13.1	13.8	12.40
	4			13.6	11.1	16.1	12.8	18.1	14.34
	5	10.5	11.7	11.9	11.9	14.0	12.6	13.9	12.35
	6	14.3	14.1	13.7	14.0	13.3	13.3	13.5	13.75
	7	12.2	15.4	12.6	15.2	9.8	11.0	13.7	12.85
	8	12.6	15.7	15.6	13.1	10.6	12.7	12.1	13.20
Thoracic	1	12.2	13.3	14.6	13.7	12.9	9.3	13.4	12.80
	2	12.8	14.5	12.9	15.3	13.5	14.1	16.1	14.20
	3	15.4	19.3	18.8	18.8	15.6	16.4	16.6	17.30
	4	16.7	20.2	21.1	19.3	24.6	20.1	24.3	20.90
	5	19.8	19.9	20.3	20.8	23.6	26.0	22.5	21.85
	6	25.8	25.6	24.1	22.2	19.7	25.5	21.9	23.55
	7	28.7	28.8	17.3	20.7	28.4	21.8	23.8	24.22
	8	29.6	28.3	19.8	26.1	23.8	23.8	23.9	25.05
	9	22.8	23.3	19.6	22.4	24.8	26.3	25.7	23.50
	10	23.7	25.4	19.7	21.3	19.6	21.2	26.2	22.50
	11	28.0	20.1	19.1	20.4	23.5	19.3	19.2	21.38
	12	20.2	21.9	20.3	13.9	21.5	19.8		19.60
Lumbar	1	21.3	23.0	15.5	14.7	16.3	19.2		18.30
	2	15.4	13.7	11.0	9.5	15.6	11.9		12.90
	3	13.2	14.0	11.1	9.7	10.8	12.1		11.80
	4	10.8	11.9	10.7	7.8	10.9	11.8		10.64
	5	9.1	7.2	10.5	6.2	9.9	6.1		8.16
Sacral	1	7.5	8.4	10.3	5.5	8.6	6.1		7.74
	2	6.1	6.6	9.6	4.5	13.4	8.3		8.40
	3	6.6	4.4	8.4	4.8	8.3	9.9		7.07
	4	6.1	6.6	5.4	4.7	8.5	8.6		6.65
	5	6.6	4.1	3.3	3.8	4.9	5.9		4.77
Coccygeal	1	2.5							2.50

The last column in the Table (I), gives the average of all the measurements for each segment, and these average lengths were those used for the divisions of the abscissa in the accompanying chart I.

(*a*) *Total Length of the Spinal Cord.* The lengths of all the segments taken together, should, of course, equal the length of the entire cord. The average length obtained for the segments will therefore depend on the lengths of the cords. But before presenting the lengths of the cords which were here examined, it will be best to state what is already known concerning the length of the human spinal cord.

The correlation in development between the medulla spinalis and the columna vertebralis indicates that the longer columna vertebralis would contain the longer medulla spinalis.

The observations of RAVENEL (7) on the length of the adult human spinal cord, show in 11 adult males, a range in length of 390-480 mm., with an average of 448 mm. In 11 adult females, the range is from 370-460 mm., with an average of 413 mm. These results plainly exhibit the greater average length of the medulla spinalis in the male. The measurements were made on fresh material from the level of the upper edge of the atlas to the lowest filum of the coccygeal nerve on the conus medullaris.

The cords examined for the length of the segments in the present investigation give the following lengths:

TABLE II.

Cord	Sex	Length in mm.
W	Male	458
X	?	403
Y	?	453
Z	Male	448
Average,		440.5

It is thus seen that this average length lies between the average length for the males and that for the females, though rather nearer the former, as determined by RAVENEL (7). It concerns us here, however, merely to show that the average length obtained is a medium one—differences according to sex being disregarded. The average lengths of the segments determined from the several cords (W, X, Y, Z) are presented in Table I. When these average lengths are summed, they give 441.6 mm., for the length of the cord, against 440.5 mm., as determined by direct measurements. The former number is the one employed in the construction of the chart.

LÜDERITZ (6) is the only investigator who has made a detailed study of the length of the segments of the spinal cord.

On comparing the results just given (Table I), with those obtained by LÜDERITZ (6), it appears that the averages of the sums of the segments in his two men—33 and 37 years of age —show the total to be 450.5 mm., or about 2% more than the total sum in our case. This is a difference which is well within normal limits, since the measurements of RAVENEL (7) show for the male cord a range in length from 390–480 mm. At the same time, the lengths of the segments as determined by LÜDERITZ, agree substantially with our own, when the differences in the total length of the cord and the great individual variations in the lengths of the segments are both taken into account.

This can be shown by the accompanying Table (III), in which the percentage values of the lengths of the different regions of the cord as determined from our own Table (I), and from the observations of LÜDERITZ on two male cords, are compared with the range in the lengths in these regions, as found by RAVENEL in 11 male cords.

TABLE III.

To show the percentage value of the lengths of the spinal cord within the regions named in the table, as compared with the range in these percentages as determined by RAVENEL.

Region.	From Table (I) 2 males, 2?	Lüderitz 2 males, p. 460	Ravenel 11 males, p. 348
Cervical	21.7%	24.1%	19.8–25.0%
Thoracic	55.8%	54.9%	53.2–65.4%
Lumbar	13.9%	11.3%	9.1–13.6%
Sacral and Coccygeal	8.4%	9.6%	1.8–15.2%

For these reasons we are justified in employing our own data in marking off the abscissa for the curve showing areas, since, in so doing, we shall give an approximately true picture of the relations in the human cord of medium size.

For the abscissa, it was decided therefore to take 441.6 mm. and this base line was divided into lengths equal to the average lengths of the segments as recorded in Table I.

II. Areas of Cross-Sections.

In the first instance charts were drawn life size, so to speak, with the abscissa 441.6 mm. long. The ordinates were drawn on a scale of one linear millimeter for each square millimeter in the area of the transverse section of the cord. The original charts thus made, were too large to publish, and have therefore been reduced photographically to exactly one-third their linear dimensions. As a consequence of this reduction, multiplying the length of the ordinates in the accompanying chart by three, will give a line as many millimeters long as the section has square millimeters of area, and multiplying the length of any segment in the chart by three will give the length of the segment as represented in the column of averages in Table I.

The data for the areas of the cross sections represented by the ordinates were taken from STILLING (3) and comprise his measurements on four adult cords.

TABLE IV.

Giving the pages in STILLING's "Neue Untersuchungen über den Bau des Rückenmarks"—1859, where the records are to be found.

Designation of Curve.	Sex.	Age.	Pages.
A	Male	45 years	Page 1098
B	Woman	35 years	Page 1100
C	Woman	25 years	Page 1099
D	Male	25 years	Page 1097

The sections from each segment of these cords are also depicted in Table XXVIII of STILLING's Atlas (1859).

This is the place to call attention to the condition of the cords measured by STILLING. All of the measurements of areas used in this present article—including those on the immature cords to be mentioned later on—were made on material hardened in chromic acid and preserved in 97% alcohol. STILLING makes a statement of his method on pp. 1032 and 1033, but it appears to be erroneous in that it calls for so large an amount of chromic acid, practically an 8% solution. Preliminary observations made on the spinal cord of the white rat, hardened in chromic acid 0.6%, followed by 97% alcohol, indicate a slight increase in the volume of the cord after this treatment. This suggests that these measurements by STILL-

ING may give a somewhat greater area than would appear in the fresh cord.

Although the exact effect of STILLING'S treatment has yet to be determined, it is not to be anticipated that more than a small correction will need to be made for it, and as the several cords used were all treated by the same method, they are comparable among themselves.

In accordance with the measurements of STILLING, three curves were constructed for each individual. These curves represent his determinations for the total areas of each section, as well as the areas of the white and the gray substance, taken separately; all *measured at the most caudal level of each segment.*

To obtain a general expression for these several measurements, a composite curve—the first on the chart—was made from the averages of the four individual records.

This composite curve shows the maximal total area of the cord to occur at the VI cervical segment, the next greatest areas being at the III lumbar and V Lumbar, a result dependent on the large area of the white substance in C VI, of both gray and white in L III; and of the gray in L. V.

B. ON THE VOLUME OF GRAY MATTER IN THE SEVERAL SEGMENTS OF THE CORD.

A special feature of this chart as now plotted, is that it enables us to estimate the volume of gray substance belonging to the several segments. This volume was determined as follows:

For the first segment we multiply the number of square millimeters represented by the ordinate, by the number of millimeters representing the length of the segment. In the case of the first segment of the cord, the result is probably a trifle too large. Below the first, we can make a more accurate determination of the volumes by using to represent the area one-half of the sum of the two ordinates limiting each segment; this area being multiplied by the length of the segment intervening. Working in this way, the following results have been obtained for the average volumes of gray substance in the segments of the cord as exhibited in the composite curve on Chart I.

TABLE V.

Giving in cubic millimeters the volume of the gray substance in each segment of the mature human spinal cord. With the exception of the first cervical segment, the volume is obtained by multiplying one-half the sum of two limiting ordinates by the length of the intervening segment, based on the data used for the composite curve in Chart I.

	Segment	Volume in cubic mm.	Volume in cubic mm.
Cervical	I	129	
	II	157	
	III	178	
	IV	220	Cervical segments IV-VIII 1220
	V	224	
	VI	275	
	VII	261	
	VIII	240	
Thoracic	I	177	
	II	147	
	III	141	
	IV	148	
	V	171	
	VI	198	
	VII	180	
	VIII	159	
	IX	156	
	X	169	
	XI	178	
	XII	187	
Lumbar	I	216	Lumbar segments I–V. 1086
	II	184	
	III	228	
	IV	256	
	V	202	
Sacral	I	192	
	II	176	
	III	105	
	IV	67	
	V	34	
Coccygeal	I	12	

An examination of the foregoing Table V shows some relations worthy of remark. In the first place, the greatest volume of gray substance is here found in the segment C VI. In the last five of the cervical segments, the total volume of gray substance is 1220 cubic millimeters, being thus decidedly greater than the volume of substance in the five lumbar segments, which contain but 1086 cubic millimeters.

Between the two intumescentiae of the cord, the segment with the smallest volume of gray substance (T III) contains 141 cubic millimeters, which is more than half that in the largest segment, C VI, which contains 275 cubic millimeters.

This shows first, that there is much less difference in the total amount of gray substance in the successive segments of the spinal cord, than would appear by comparison of the areas of their cross sections alone (see composite curve in Chart 1); second, that as a matter of fact, it is the cervical enlargement which contains the greatest volume of gray substance although the area of the gray reaches its maximum in the lumbo-sacral region. It may not be out of place to again call attention to the fact that the division of the base line into equal intervals for the successive segments of the cord, as in the charts based on WOROSCHILOFF's curves, gives a set of relations which are misleading; for it necessarily suggests that the volumes of the segments are proportional to the areas of their cross sections.

C. RELATION BETWEEN THE AREA OF THE CROSS SECTION OF EACH SEGMENT OF THE CORD OR THE VOLUME OF GRAY MATTER IN IT, AND THE AREA OF THE CROSS SECTION OF ALL THE NERVE ROOTS BELONGING TO THE SEGMENT.

LÜDERITZ (6), p. 478, has published a chart based on STILLING's measurements, which shows the relations between the combined areas of the cross sections of each of the four spinal nerve roots, and that of the cross section of the gray substance of the segment to to which they belong. The two curves representing the two series of areas run nearly parallel to one another. The data, however, on which the curves are based, are not exactly comparable, for a reference to STILLING (p. 392), shows that the areas of the cross sections of the nerves were taken from measurements in the case of a woman of 26 years; whereas the areas for the cross sections of the gray matter of the cord were from a five-year old child. We have drawn a second curve in which the areas of the gray matter for the mature cord as represented in Table VI, are used. This curve does not fit quite so closely that for the areas of the nerves, as does the curve based on the areas of the gray substance in the five-year old cord. Especially in the thoracic and lumbar regions, the area of the gray substance is larger in proportion to the cross sections of the nerves than in the case of the young cord. In general there appears to be in the mature cord, as contrasted with that of the child, a shift of the larger areas of the gray substance one or two segments cephalad. As a consequence, therefore, using data derived entirely from mature individuals, the curves are less similar than the figure of LÜDERITZ (Fig. 2, p. 478) would indicate.

If we now compare the relative development of the volumes of the successive segments of the cord, with the areas of the cross sections of the spinal nerves, we find that while there is a fair correspondence in the cervical and in the sacral regions, that in the thoracic and upper lumbar regions, where the segments have grown most in length, a great disparity exists between the volume of the gray substance and the area of the cross sections of the nerves, the gray substance being much more abundant than we should expect. This suggests that in these localities, the lengthening of the segments, and consequent increase in the volume of the gray substance, is merely one of adaptation to the elongation of the vertebrae, and not accompanied by any corresponding increase in the complexity of its structure.

D. GROWTH CHANGES.

I. On the Areas of the Cross Sections of the Several Segments of the Spinal Cord at Different Ages.

For this comparison we have used as a standard the records which were employed for the composite curve in Chart I. As previously explained, the data for this composite curve were obtained by taking the average of the observations on the four individuals used for the construction of curves A, B, C, D respectively of Chart I. The numerical data are given in the column headed "Mature" in Table VI.

To compare with the composite curve we have from

STILLING a series of measurements of the areas of the gray and white substance at the level of the several segments of three immature spinal cords: from a child at one year, from one at two years, and from one at five years. STILLING's tables containing these records are found on pages 1101, 1102, 339 and 343 of his "Neue Untersuchungen über den Bau des Rückenmarkes." 1859.

In the following Table (VI) which contains STILLING's measurements, it is at once seen that certain segments in the five-year old child were not measured. In order to make this table comparable with the others, an interpolation for the missing records, C I and C II and L I and L II, has been made on the assumption that in the five year old cord the areas of the unmeasured segments would form the same fraction of the sum of all the areas that they do in the one and two year old cord. At the foot of the five year old columns in Table VI, the total given is the one obtained after the above interpolation. Moreover, it will be noted that in this cord identical measurements are given for the thoracic segments T.III-VIII and T.IX-XI.

Individual measurements for these several segments would, of course, have been preferable, but there is no reason to suspect that any serious error has resulted from the method here employed by STILLING.

TABLE VI.

Areas of Cross-Sections of the Human Spinal Cord at Different Ages. The records for the cords at 1, 2 and 5 years are copied from STILLING. The record for the cord at maturity gives the averages of his four tables of measurements on adults.

	Areas of White Substance. sq. mm.				Areas of Gray Substance. sq. mm.			
	Age.				Age.			
Segment.	1 yr.	2 yrs.	5 yrs.	Mature.	1 yr.	2 yrs.	5 yrs.	Mature.
Cervical.								
I	31.46	30.75	{ 58.04	62.03	7.07	7.42	{ 12.37	17.85
II	28.98	30.04		68.57	4.60	4.60		14.49
III	22.62	23.33	32.75	72.37	4.60	4.60	11.25	14.14
IV	48.08	41.36	34.65	74.94	18.03	16.26	12.73	16.52
V	45.60	41.36	42.02	73.97	21.21	16.26	19.67	19.70
VI	46.31	37.12	42.02	79.18	20.86	20.85	19.67	20.32
VII	47.37	43.83	40.39	71.84	18.03	14.14	18.24	20.38
VIII	39.24	46.66	33.99	65.30	16.97	12.37	13.68	15.99
Thoracic.								
I	30.75	30.04	28.59	63.65	6.01	6.36	6.97	11.66
II	26.51	26.51	24.12	53.64	6.72	7.78	5.32	9.01
III	20.85	28.99	24.12	52.23	4.95	6.36	5.32	7.24
IV	21.56	26.16	24.12	52.22	5.30	4.95	5.32	6.89
V	22.98	20.50	24.12	50.10	5.30	6.01	5.32	8.74
VI	21.56	22.98	24.12	45.20	4.60	6.36	5.32	8.04
VII	19.44	24.04	24.12	47.43	5.66	5.30	5.32	6.80
VIII	20.86	20.50	24.12	45.1[illegible]	6.01	5.30	5.32	5.92
IX	20.15	20.85	23.83	40.74	5.66	7.78	4.56	7.33
X	23.68	16.97	23.83	43.05	4.95	7.07	4.56	7.71
XI	23.68	23.33	23.83	41.40	6.36	7.07	4.56	8.92
XII	22.62	20.85	21.74	44.18	7.42	7.07	6.44	10.14
Lumbar.								
I	22.98	23.33	{ 46.30	44.00	7.42	9.54	{ 20.06	13.51
II	22.62	23.68		49.6[illegible]	10.96	9.90		15.08
III	22.98	19.09	21.15	48.0[illegible]	14.85	16.61	13.26	23.59
IV	23.33	22.62	22.34	43.30	15.20	15.91	21.02	24.48
V	20.15	19.80	17.07	43.40	17.68	19.80	24.89	25.01
Sacral.								
I	22.62	20.86	17.18	32.34	15.91	21.56	23.53	24.47
II	20.85	13.79	17.26	19.44	18.38	22.62	23.22	17.41
III	10.61	10.61	9.87	12.25	15.20	13.43	17.21	12.19
IV	10.61	5.66	5.97	8.30	9.19	8.84	10.81	7.86
V	3.89	4.59	2.18	4.77	4.60	3.89	6.01	6.36
Coccygeal.								
I	1.06	1.77	.96	2.38	2.83	2.47	2.70	3.18
Total	766.00	741.97	734.80	1455.07	312.53	318.48	334.65	410.93

In order to compare the records in Table VI, we use the sums of the total areas of the section, obtained by adding the sums of the areas of the gray and white substance, which are tabulated separately.

TABLE VII.

Showing the sums of the total areas in the three immature and one (composite) adult cord, as tabulated in Table VI.

Age.	Sum of 31 Areas.
1 year	1078.53 sq. mm.
2 years	1060.45 sq. mm.
5 years	1069.45 sq. mm.
Maturity	1866.00 sq. mm.

These figures show that from one to five years, there is very little variation in the sum of the total areas. It ranges from 1078.53 sq.mm. to 1060.45 sq.mm. Since this difference appears as a deficit in the two year cord, it is probably the expression of an individual variation. The extreme cases, 1 and 3 years, differ by less than 2%, whereas between five years and maturity, there is an increase in the total area of the sections of nearly 74%. From this it is inferred that the growth changes leading to the larger area at maturity occur at some time subsequent to the fifth year of life.

The analysis can be carried a step further by comparing the relative areas of gray and white substance in the several cases.

TABLE VIII.

To show the percentage values of the sums of all the areas occupied by gray and by white substance at different ages.

	White Substance		Gray Substance	
Age.	Sums of Areas in sq.mm.	Percentage of sums of total areas	Sums of Areas in sq.mm.	Percentage of sums of total areas
1 year	766.00	71%	312.53	29%
2 years	741.97	70%	318.48	30%
5 years	734.80	69%	334.65	31%
Maturity	1455.07	78%	410.93	22%

A glance at this table shows that during the first five years, the proportional value of the white substance in the section is about 70%, whereas at maturity it reaches 78%, the gray substance of course showing a correlated variation.

It appears then that from the first to the fifth year, there is little variation in the relation between the gray and white, and that the change in this relation must occur at some period after the fifth year.

In this connection, it is of interest to determine whether the growth changes leading to the greater total area of the cord segments at maturity are the result of a proportional enlargement in the different regions of the cord. In order to determine this, it is necessary to compute the percentage values of the total areas in the different regions. The results of this computation are shown in the following table:

TABLE IX.

Showing for both the mature and immature cords the percentage value which is represented by the total areas of the segments that constitute the cervical, thoracic, lumbar and sacral and coccygeal regions respectively.

Region.	Age.			
	1 year.	2 years.	5 years.	Maturity.
Cervical	39.05	36.86	36.60	37.92
Thoracic	31.85	33.86	33.18	36.30
Lumbar	16.52	17.02	17.42	17.69
Sacral and Coccygeal	12.58	12.26	12.80	8.09
	100%	100%	100%	100%

From the foregoing Table IX, it appears that after the fifth year, the proportional growth in area has been slightly more rapid in the thoracic region, and less rapid in the sacral and coccygeal, while in the two intumescentiae, the relations at maturity are similar to those found during the first to the fifth year of life. From the end of the first year then, the relative areas of the different regions of the cord change but slightly during subsequent development. The statements which have been made on the basis of the total area can also be repeated for both the gray and the white substance separately, though it is not deemed necessary to publish the computations, as the data for them are found in Table VI.

It must be remembered, however, that from the first to the fifth year of year of life, the medulla spinalis is growing rapidly in length. From the measurements of RAVENEL (p. 350), we have calculated that the length of the medulla spinalis at one year of age would be about 200 mm., whereas he found in a five-year old boy the length to be 300 mm. Yet, despite this increase in length, the measurements just given show that the transverse diameters remain practically constant. Apparently we have here another example of the tendency of structures to grow first in their long axis before enlarging at right angles to it. It must be remembered, however, that we are without observations on the changes which occur within the limits of the first year.

On looking at Table VI, it is to be noted that the area of the white substance at maturity is nearly 95% greater than it was at five years, while the gray substance is only 23% greater, thus showing the much more rapid enlargement of the white substance. This being the case, it is evident that the curves of WOROSCHILOFF, based on a five-year old child exhibiting in cross section hardly more than half of the white substance in its cord than is present in the adult, necessarily give a false notion of the relations at maturity.

II. Comparison of a Curve, Representing the Areas in the Child's Cord, with the Corresponding Curve for the Cord of the Adult.

It has just been shown that from the first to the fifth year, the areas of the cross sections of the spinal cord remain the same size. It is therefore only necessary to obtain the measurements of the lengths of the segments at some period within these ages in order to construct a curve for the child's cord that may be compared with that for the adult.

LÜDERITZ (p. 471) gives the length of the segments in the cord of a female child of three and a half years. His measurements are presented in the following Table X.

TABLE X.

Lengths of Segments of the Cord as Determined by LÜDERITZ in the Case of a Girl of Three and a Half Years.

	Segment.	Length in mm.		Segment.	Length in mm.
Cervical	I	4.7[1]	Lumbar	I	8.25
	II	5.5		II	6.25
	III	7.0		III	4.5
	IV	7.2		IV	4.1
	V	8.6		V	2.9
	VI	6.8			
	VII	6.3	Sacral	I	3.5
	VIII	6.3		II	3.4
				III	3.8
Thoracic	I	5.8		IV	3.5
	II	7.25		V	3.0
	III	7.0			
	IV	8.9			
	V	10.3	Cocc.	I	3.0
	VI	11.9			
	VII	13.3			
	VIII	11.75			
	IX	11.5			
	X	9.6			
	XI	9.3			
	XII	7.75			

As will be seen from examining the table, the measurement for the first cervical segment is lacking in the original record, but it has been interpolated here on the assumption that it would have the same proportional value as in the cord at seven weeks. The measurements for a cord at this latter age being given by LÜDERITZ (p. 470), it is possible to make a calculation on this basis, and the result is the number which appears in the Table X. Upon adding the lengths of all the segments together, we find the length of this cord at three and a half years, to be 212.95 mm. For comparison with this result, there is available RAVENEL'S table (p. 550), giving the following individual measurements for the length of the cord in children.

[1] The length for the first segment is interpolated, being given the value of 4.7 mm.

TABLE XI. (From RAVENEL).

Number.		Total Length.
3	Boy of 2 years	245 mm.
4	Boy of 5 years	300 mm.
5	Girl of 9 years	280 mm.

From this comparison it appears that the cord here chosen is short, the child evidently being under size even for a female. However, the length 212.95 mm., is well within the probable limits of normal variability as judged from the variations in the length of the spinal cord in the adult. In using the curve, however, it must be remembered that in this case, the lengths of the segments are from a female cord that is probably short even for this age and sex. This is all that need be said about the base line of curve E. Since the measurements for the areas of the sections of the cord were so similar from the first to the fifth year, it was thought best to choose those made on the two-year old child (Table VI). This record of STILLING was taken because the measurements for all the areas are given, and because it is the middle one of the series of three, and hence we know the form and size of the cord before and after this period.

On examining curve E in chart I, it will be noted that the intervals on the axis of ordinates *are equal to and have the same value*, as in all the other curves in this chart.

Special emphasis is to be placed on this point, and attentention is particularly directed to it, since the designating numbers are smaller in size than those used for the other curves, in which a number is given for each twenty units only. These peculiarities create the illusion that the intervals on the axis of ordinates in curve E are smaller than in the case of the other curves, and for this reason, attention has been called to this point.

On comparing curve E with the composite curve in chart I, some interesting differences appear. If the composite curve be taken as the standard, the following statements may be made. The base line, or length of cord, in E is a little less than half as long. The total area (called *entire section* in chart) at no point rises above 60 sq.mm., whereas in the composite curve, it runs above 100 sq. mm. The intumescentiae are more abrupt. The enlargements of the areas in the intumescentiae as compared with the areas in the thoracic region, are greater. The maximum total areas in both the cervical and lumbar intumescentiae are further caudad, and the absolute area of the white substance is much less than at maturity. The most marked deficiency in the areas of both gray and white substance occurs in the first three cervical segments, and especially in the third cervical segment. That this last feature is not an individual peculiarity, is indicated by the fact that the one year cord in Table VI (the only cord available for comparison) shows a similar relation. As the curve E is based on a single individual, no significance can be attached to minor peculiarities in it, but enough has been shown by the comparison just made, to indicate that the cord of the child differs from that of the adult in a number of its characters, and that the curves showing the areas in childhood cannot be properly used to show the relations obtaining at maturity.

Conclusions.

The foregoing observations warrant the following conclusions:

The chart given in this article is more correct than that based on the curves of WOROSCHILOFF, since the areas of the gray and white substance are taken from measurements on the mature spinal cord, and are plotted on a base line, the divisions of which are proportional to the lengths of the spinal segments. These curves show the greatest areas at the level of C. VI, L. III, and L. V. The curves, however, are generalized, and apply to a cord of medium size, the differences due to sex being disregarded.

Moreover, the measurements of the areas are from cords which had been hardened in chromic acid, and preserved in alcohol. This treatment has certainly altered the size of the cord, but control experiments indicate that the alteration in size has probably been slight. A study of chart I (see Table V) shows that the volume of gray substance in the intumescentia cervicalis is greater than that in the intumescentia lumbalis.

There is a general correspondence between the area of a cross section of the gray substance at the level of any segment and the area of the cross sections of all the spinal nerves belonging to the segment. When, however, the volume of the gray substance, instead of the area, is used for the comparison, a disproportionately large amount of gray substance is found in the case of the thoracic and upper lumbar segments. This is interpreted as indicating a passive enlargement of the gray substance in these segments of the cords which have been most elongated.

When the cords of immature individuals are compared with those from adults, several important relations are brought to light. In the first place, the sum of the total areas of the cross-sections of the cords, from one to five years, is practically the same (see Table VII), although during the period, a considerable growth in length has occurred. During this time, therefore, growth in the long axis has taken place without any corresponding growth at right angles to the long axis.

The form of the cord from one to five years is nearly like that at maturity, the difference being that in the mature cord the relative enlargement of the areas of the cross-sections has become greater in the thoracic region, but less in the sacral and coccygeal (see Table IX). At maturity, the relative enlargement of the two intumescentiae is practically the same as at the fifth year. From the fifth year to maturity, both the length and the weight of the entire cord as well as the area of the cross-sections at the level of the several segments are increased. The sum of the areas of the white substance at maturity is 98% greater than at five years, and that of the gray substance 23% greater (see Table VIII). This absolute increase must represent either enlargement of elements already completely developed, or the development of elements still immature at the earlier age, or some combination of both of these processes. Yet the failure of the intumescentiae to increase in their relative area in the mature cord (see Table IX), or in their proportional length (RAVENEL, p. 350), would seem to indicate that during this period there was no increase in their relative complexity; a result, which, to say the least, was unexpected.

On comparing the curves for the areas of the cord at 3½ years (curve E), with the composite curve for the adult, in order to determine the change in the form of the cord due to growth, several important differences appear. In the child's cord, the total areas of the sections are of course less than in the adult; the greater deficiency appearing in the substantia alba. In the child's cord, the intumescentiae are developed more abruptly than at maturity, and the maximal areas appear further caudad; yet, despite this, the sums of the total areas in the cervical and lumbar portions of the cord have almost the same relative values (see Table IX). The most marked deficiency in the child's cord appears in the areas of the first three segments of the cervical region and especially in that of the third cervical segment, while the entire thoracic region is less developed than it will be at maturity. On the other hand, the sacral region is arrested in its later growth and becomes relatively smaller.

BIBLIOGRAPHY.

(1) KRAUSE, R und AGUERRE, J:
Untersuchungen über den Bau des menschlichen Rückenmarkes mit besonderer Berücksichtigung der Neuroglia. *Anatomischer Anzeiger.* Bd. 18, 1900.

(2) WOROSCHILOFF:
Der Verlauf der motorischen und sensiblen Bahnen durch das Lendenmark des Kanninchens. *Berichte über die Verhandlungen der Königlich Sächsischen Gesellsch. der Wissenschaften zu Leipzig.* Bd. 26, 1874.

(3) STILLING, B:
Neue Untersuchungen über den Bau des Rückenmarkes. *Cassel,* 1859.

(4) KADYI, H:
Ueber die Blutgefässe des menschlichen Rückenmarks. Lemberg, 1889.

(5) RÜDINGER, T:
Atlas der peripherischen Nervensystems der menschlichen Körpers *Stuttgart,* 1872.

(6) LÜDERITZ, C:
Ueber das Rückenmarkssegment. Ein Beitrag zur Morphologie und Histologie des Rückenmarks. *Archiv f. Anatomie u. Entwickelungsgeschichte.* Anat. Abtheil. Jahrgang, 1881. p. 423–495.

(7) RAVENEL, M:
Die Maasverhältnisse der Wirbelsäule und des Rückenmarkes beim Menschen. *Zeitschrift f. Anatomie u. Entwickelungsgeschichte.* Bd. II. 1877. p. 334–356.

EXPLANATION OF CHART I.

This chart represents by curves, the areas of the cross-sections of several human spinal cords, as well as the areas of the gray and white substance as they appear in each section. The base line in all the charts is just one-third the length of the spinal cord for which it stands, and is divided into lengths proportional to those of the spinal cord segments of which it is composed. For the adult cord, the lengths of the segments given in Table I were used in making the original drawings. On the ordinates one linear millimeter corresponds to one square millimeter of area. In all cases the measurement of the area was made up at the caudal end of the segment. In the order from above downwards, the curves are as follows:

Composite Curve—Based on A, B, C, and D, to give the average of the several areas in the curves named. The curves are generalized and apply to a cord of medium length—441.6 cm. long. The influence of sex is neglected. The average age of the four cases would be 33 years.

Curve A. Man of 45 years. Data for areas from STILLING.

Curve B. Woman of 35 years. Data for areas from STILLING.

Curve C. Woman of 25 years. Data for areas from STILLING.

Curve D. Man of 25 years. Data for areas from STILLING.

Curve E. Child—data for areas from STILLING'S observations on the cord of the two-year old child. Length of segments from LÜDERITZ'S observations on the cord of a three and a half year old girl. Cord rather short.