

AN EXPERIMENTAL ANALYSIS OF THE MOTOR CELL  
COLUMNS IN THE CERVICAL ENLARGEMENT  
OF THE SPINAL CORD IN THE  
ALBINO RAT.

BY

JOSEPH GOERING

A. B. BETHEL COLLEGE, 1923

A thesis submitted to the Department of Anatomy  
and the Faculty of the Graduate School, in par-  
tial fulfillment of the requirements for the  
Degree of Doctor of Philosophy.

Approved \_\_\_\_\_

Henry C. Tracy  
Department of Anatomy.

May 10, 1927.

## CONTENTS

### INTRODUCTION

Literature	1.
Material and Methods	3.
Classification of Cell Groups and Nomenclature	5.

### OBSERVATIONS

A Normal and a Degenerating Motor Cell	8.
Plexus Brachialis	9.
Anatomy of the Fore-limb Muscles	11.
The Motor Cell Columns	15.

### EXPERIMENTAL ANALYSIS

Nervus Radialis	19.
Nervus Medianus	22.
Nervus Ulnaris	24.
Nervus Musculocutaneus	25.
Nervus Thoracalis Anterioris	26.
Nervus Axillaris	27.
Nervus Suprascapularis	28.
Ratio of Motor Cells Showing Chromatolysis to Normal Cells	29.
Segmental Localization of the Motor Cells of Nerves Studied	30.

SUMMARY AND CONCLUSIONS

32.

BIBLIOGRAPHY

36.

FIGURES

38.

AN EXPERIMENTAL ANALYSIS OF THE MOTOR CELL COLUMNS IN  
THE CERVICAL ENLARGEMENT OF THE SPINAL CORD  
IN THE ALBINO RAT.

INTRODUCTION

The morphological arrangement of the motor cells, into linear columns, has been established by various anatomists. However, anatomists, heretofore, have not fully interpreted the significance of such an arrangement. Therefore, this work was undertaken to determine the confinement of the motor cells of various nervi plexi brachialis to specific cell columns, and to interpret the possible significance of the results of such an analysis.

This work was carried on for two years under the direction of Dr. G. E. Coghill, now of The Wistar Institute of Anatomy, formerly of the University of Kansas, and continued under the direction of Dr. H. C. Tracy. To them and to Dr. H. B. Latimer, the author is indebted for valuable suggestions, criticism, and encouragement given during the progress of this work.

Literature

A brief statement of previous analytical work on the spinal motor cells is essential to bring out the different views of the various workers on this subject. According to the different authors, the spinal motor cell columns are variously supposed to represent limb segments, muscles,

nerves, etc. My review of the literature reveals that previous work is not recent, and that it is limited to a large degree to non-experimental observations.

Sano ('97), Marinesco ('98), and Van Gehuchten ('99), were early original workers in this field. Other authors do not differ materially in opinion from the views of these writers.

Sano ('97), was the first to attempt an analysis, by observing chromatolysis of the motor cells in the spinal cord. He constructed a scheme in which each peripheral muscle had a definite motor center.

According to Marinesco ('98), each peripheral nerve is represented in a sharply defined motor center.

Van Gehuchten ('99), advanced the theory that all muscles of a limb segment are represented in a specific cell column. This theory is agreed to by his co-workers, among whom should be mentioned De Buck ('98), Nelis ('99), and Neeff ('00).

Parhon and Goldstein ('01), and Onuf ('89), are of the opinion that muscle groups are represented in the spinal cord by sharply outlined motor centers or columns.

Lapinsky ('03), concludes that the motor cell groups in the spinal cord are not associated with either segments of the extremities, muscles, or nerves. He makes no definite conclusions as to the meaning of the cell columns.

In my survey of the literature on this subject, Knappe ('01) is the only one that states, following experi-

mental observation, that the motor cells innervating flexors and extensors occupy different portions in the spinal cord. He, however, does not analyze specific cell columns, nor does he assign specific functions to the same.

I find no literature more recent than that of Lapinsky ('03), on experimental analysis of the motor cells in the spinal cord employing Nissl degeneration.

### Material and Methods

This work has been confined to the cervical enlargement of the spinal cord in the albino rat, *Mus norvegicus albinus*. This animal submits itself favorably to the necessary experimentation, and possesses a cervical enlargement which can readily be sectioned serially. For all the experimental phases of this work, albino rats between the ages of fifty and one hundred days were used. Various nervi plexi brachialis were cut with the necessary precautions against sepsis. Infections were not encountered. Special precautions were taken in operating, not to injure structures adjacent to the nerve which was cut, and particularly to avoid trauma to all muscles, including the muscles innervated by the resected nerve.

The following nervi plexi brachialis were each cut in separate animals at the point indicated.

The n. radialis was cut posterior to the tendons of the m. latissimus dorsi and of the m. teres major, at its entrance between the medial and lateral heads of the m.

triceps brachii.

The n. medianus was cut at the inferior border of the tendon of the m. pectoralis major.

The n. ulnaris was cut at the point where this nerve pierces the septum intermuscularis medialis.

The n. axillaris was severed through an incision in the m. deltoideus.

The n. suprascapularis was severed through an interval produced between the clavicular portion of the m. deltoideus and the m. pectoralis major.

Access to the n. musculocutaneus was gained by lifting the tendon of the m. pectoralis major, and then passing a forceps beneath the tendon, crushing the nerve at the point just proximal to that part of its course where it pierces the m. caraco-brachialis.

The n. thoracalis anterioris was cut through an incision in the m. pectoralis major.

The degeneration, in each case, was allowed to proceed from ten to twelve days, which is adequate time for chromatolysis of the Nissl substance in the motor cells of the spinal cord of the rat.

The spinal column of chloroformed animals was removed, and the cord exposed by cutting the vertebral laminae. The whole preparation was then placed in a small amount of Van Gehuchtens fluid. The tissue soon became more rigid and the spinal cord could be removed with little torsion and mutilation. This procedure did not interfere with proper

fixation. Van Gehuchters fluid affords advantages in that it fixed the whole cord, and decalcified small chips of bone which might have been overlooked. The acetic acid has special fixative value for the Nissl substance, (Hopkins '24). The whole cervical cord was sectioned serially at ten micra, and stained with erythrosin and toluidine blue.

The motor cell groups were established by reading a number of cervical cord series. The observations were verified by composite drawings. These composite drawings were produced by the following procedure: The cells of every tenth section throughout the cervical enlargement were drawn with the aid of a projecting apparatus upon transparent tracing cloth. The different drawings of each cervical segment were then carefully superimposed upon one another, and the cells traced into one composite drawing.

Photographs were taken of certain characteristic sections of some of the series studied. The photos include projections of entire sections with a low power objective, and also projections with an oil immersion lens of the cells which show chromatolysis. These photos have been a great help in verifying my observations.

#### Classification of Cell Groups and Nomenclature.

The existence of motor cell groups in the mammalian spinal cord is almost universally accepted by anatomists. However, authors differ in opinion in regard to the number, location, and classification of these cell groups. Waldeyer



('88), Kaiser ('91), and Bruce ('01), are among those who have done notable work on this subject. Their classification is based on general topography of the cell group.

Bruce ('01) in his monograph on the motor cells of a human cord indicated the following groupings:

medio-anterior  
 medio-posterior  
 anterio-lateral  
 posterio-lateral  
 post-posterio-lateral

Waldeyer ('88), gives the following grouping of the motor cells in the anterior horn of the spinal cord:

medio-anterior  
 medio-posterior  
 laterio-anterior  
 posterio-lateral

His classification of groups was based on observations made on the motor cells in the spinal cord of a gorilla and a four year old infant.

Kaiser ('91), assigns four groupings in man to the motor cells in the anterior gray horn of the spinal cord in the cephalad portion of the cervical enlargement. They are indicated as lateral, accessory, ventral, and medial. The lateral group is divided into four sub-groups. In the lower cervical enlargement he gives the following grouping: a dorso-lateral group, a ventro-lateral, and a medial group. The dorso-lateral group consists apparently of three sub-

groups, while the ventro-lateral is divided into two sub-groups.

The classification as indicated by these authors is the one most universally accepted. Their classification, however, does not comprise all the cell groups as analysed in the rat. In view of this and of a possible different presentation of cell groups in different species, the author deems it necessary to use another method to indicate the cell group; therefore, letters are used to designate the cell groups in the spinal cord.

The B. N. A. Nomenclature is used wherever possible in the descriptive phases of this work. The anatomical terms, ventral or inferior, dorsal or superior, anterior or cephalad, posterior or caudal, are employed on a comparative anatomical basis.

## OBSERVATIONS

### A Normal and a Degenerating Motor Cell

My observation of the characteristic degenerating nerve cell is in accord with those of previous workers. Therefore, chromatolysis, as such, need be described only briefly.

Mention must here be made of the valuable studies of Nicholson ('23). According to his work, the normal Nissl substance disappears from the cell in a progressive manner; this process varies with the degree of injury, the greater the injury, the greater the cellular reaction. Chromatolysis starts in the cytoplasmic mass and moves toward the periphery. The whole cell shrinks and the nucleus becomes eccentric, moving away from the source of injury, that is, away from the axone hillock.

Figure 15, (A) and (B), are camera lucida drawings at the same magnification of a characteristic normal and a degenerated motor cell, as they appear in my preparations. In Figure 15, (A), is given the details of the normal motor cell. The Nissl bodies are uniformly distributed in the cytoplasmic mass. As to the structure of the individual Nissl bodies there is variation, but in general they are large, angular, cytoplasmic aggregates which stain deep blue. Erythrosin stains all the cytoplasm uniformly except the basophilic substance. The cytoplasm has a reddish-blue appearance. There is uniformity of the nuclear structure. The nucleus has an even contour. Within the nucleus there is a large deep-blue

staining nucleolus, located near the center of the nuclear mass. The cell processes stand out prominently.

In Figure 15, (B), is given the characteristics of a degenerated cell. The whole cell is shrunken, with the Nissl bodies limited to the periphery of the cytoplasm, and to the region adjacent to the nuclear membrane. The Nissl substance or bodies are irregularly distributed. They are not so abundant and are much smaller than in the normal cell. The chromatolytic area takes a deeper Erythrosin stain than the adjacent cytoplasm. The chromatolysis includes all of the cytoplasm except a small area adjacent to the nuclear and cellular wall. There is no uniformity of nuclear structure. The nucleus is eccentric and located in the periphery of the cell. The nucleolus is smaller than in the normal and is not in the center of the nucleus.

#### Plexus Brachialis

The plexus brachialis in the rat is formed from the anterior rami of the sixth, seventh, eighth, and first thoracic nerves, together with a slender ramus of the fifth cervical nerve.

The position of the plexus appears to be fairly constant and uniform in all the cases examined. The segmental nerves entering into the formation of the plexus brachialis first appear between the m. scalenus anticus and the m. scalenus medius, under cover of funiculus adiposis and fascia cervicalis. The plexus is crossed by the v. jugu-

laris externa, m. omohyoideus, and nn. cutanei. In the apex of the axilla, the plexus passes caudalward, dorsal to the clavicle. The a. axillaris lies caudal to the plexus brachialis throughout their course in the axilla, never entering between the rami of the plexus. Thus, there does not exist in the rat, the three typical fasciculi (medialis, lateralis, and posterior) of the plexus brachialis, as in the human.

The first thoracic and eighth cervical nerves unite and form a common trunk which upon receiving a ramus from the seventh cervical nerve, divides into two portions; the most ventral division continues as the n. ulnaris and n. medialis, the dorsal division constitutes the main tributary to the n. radialis trunk and receives rami from the sixth and seventh segmental nerves. The n. axillaris is formed from rami from the sixth and seventh segments. The n. musculocutaneus is formed by the sixth and seventh cervical nerves. The n. thoracodorsalis is given off from the trunk of the n. radialis. The n. thoracalis anterioris is derived from the common trunk of the seventh, eighth, and first thoracic segmental nerves. The n. suprascapularis is formed by the common trunk of the sixth and the fifth cervical nerves.

The Figure 2, represents a dissection showing segmental origin of individual nerves of the plexus brachialis. The dissection was done under water with the aid of a dissecting microscope.

### Anatomy of the Fore-limb Muscles

The anatomy of the forelimb musculature of the rat offers advantages for the experimental analysis of the cell columns because of the fact that each group of muscles is well defined, both structurally and functionally. The muscles of the arm and fore-arm are mainly either flexors or extensors. The only exception to this arrangement, so far as my observations show, is in the case of the m. brachioradialis, which has a combined flexion and extension action, flexing the elbow but extending the carpus. The muscles which will either flex or extend the elbow will condition the same action upon the carpus. A few muscles, such as the m. triceps brachi medialis, may extend the elbow and also the shoulder if not fixed, and under similar conditions, the m. biceps brachii may flex the elbow and the shoulder.

The extensors of the arm and fore-arm predominate in number and volume over the flexors.

The shoulder joint is constructed to permit considerable movement. The main movements of this joint are extension and flexion. However, there is some adduction, but only a very limited amount of abduction. The shoulder girdle muscles are mainly rotators, functioning also in maintaining the integrity of the scapulae-humeral articulation.

The ulnar humeral articulation allows flexion and extension only, while the proximal radial articulation allows pronation and supination. However, the two muscles primarily

involved in this action are, in principal action, flexor and extensor.

The action of muscles was determined by taking into consideration muscle mechanics and animal progression. Although mechanically a single muscle is a unit, little can be ascertained as to what each muscle contributes in action, to groups of muscles. The simplest act is exceedingly involved and cannot occur without the co-ordination of many muscles.

The primary actions, extension, flexion, and adduction, predominate in progression. Rotation and abduction is developed to a lesser degree. Rotation, pronation, and supination function somewhat in feeding. In the rat, most acts are for progression, beyond which, it is capable of only a few. Therefore, I have classified the muscles according to their simple fundamental action.

A functional classification of the muscles of the upper extremity innervated by the nerves which were studied in this investigation.

<u>Flexors</u>	Artic. humeri	cubitus	carpus	phalanges
m. biceps brachii	*	*	*	-
m. brachialis	-	*	-	-
m. coracobrachialis	*	-	-	-
m. palmaris longus	-	*	*	-
m. flexor digitorum sublimis		*	*	*
m. flexor digitorum profundus		*	*	*
m. flexor carpi radialis		*	*	-
m. flexor carpi ulnaris		*	*	-
m. pronator teres		*	*	-
m. lumbricales		*	-	*
m. deltoideus	*	-	-	-
<u>Extensors</u>				
m. triceps longus	*	*	-	-
m. triceps lateralis	-	*	-	-
m. triceps medialis	-	*	-	-
m. anconeus	-	*	-	-
m. epitrochlearis	-	*	-	-
m. extensor digitorum communis		*	*	*
m. extensor carpi radialis I.		*	*	-
m. extensor carpi radialis B.		*	*	*
m. extensor carpi ulnaris		*	*	*
m. supinator		*	-	-



	Artic.			
	humeri	elbow	carpus	phalanges
m. extensor pollicis	-	-	*	*
m. extensor indicis	-	-	*	*
m. extensor quinti	-	-	*	*
m. deltoideus	*	-	-	-

Rotators

m. supra scapularis	*	-	-	-
m. infra scapularis	*	-	-	-

### The Motor Cell Columns

The motor cell columns, as they occur in the various segments of the cervical enlargement in the rat, are indicated diagrammatically in Figure 1. A brief description of their position and contour will greatly add to the interpretation of individual nervi plexus brachialis motor cell distribution and confinement to specific motor cell columns.

The cell column C, in the ventral horn, is dorso-lateral in the sixth and the cephalad two-thirds of the seventh segment; and dorso-medial in the caudal one-third of the seventh, and in the eighth and first thoracic segments. This column, somewhat compressed dorso-ventrally, is uniform throughout, except for a slight increase in the number of cells in the eighth segment. However, in one series, an interruption of this column was noted in the caudal third of the sixth segment.

Cell column C', lateral to cell column C, is present in the eighth and first thoracic segments. Following a progressive increase there is a rapid decrease in the number of cells in the cephalad two-thirds of the first thoracic segment.

The position of cell column D, intermedio-lateral, is ventral to cell columns C and C'. This column, containing the largest number of cells, is uniform in the sixth and seventh segments, much enlarged in the eighth and cephalad one-third of the first thoracic segment, but decreases rapidly in the caudal two-thirds of the first thoracic segment. The general contour of this column is oval, with its long axis

disposed horizontally.

The intermedio-medial cell column M extends throughout the sixth, seventh, eighth, and first thoracic segments. This column is occasionally interrupted in the sixth and seventh segments, but it is persistent in the eighth and cephalad two-thirds of the first thoracic segment.

The position of cell column S, ventro-lateral, is most pronounced in the caudal portion of the seventh, and throughout the eighth and first thoracic segments. However, it is present intermittently in the sixth and upper portion of the seventh segment.

Cell column M', adjacent and medial to cell column S, consists of only a few cells. Its functional significance is not brought out in this work.

The cell columns under consideration in this work are not present as such, in other segments than those mentioned, of the cervical and thoracic cord.

In the various series studied of the cervical enlargement, but little variation in the motor cell groups can be noted. The cell columns in the right and left anterior cornu of the cord appear bilaterally symmetrical.

The shifting of cell column C, dorso-medially in the seventh, eighth, and first thoracic segment can be accounted for by the increased number of cells in this level.

Only the motor cell columns which contain motor cells innervating the fore-limb were included in the previous description.

The most universally accepted grouping of the motor cells of the spinal cord is that of Bruce ('01), Waldeyer ('88), and Kaiser ('91). Therefore, a comparison of their work with this present analysis of the motor cell groups in the rat will give the reader a comparative basis upon which to homologize the topography and classification of this, and that of previous contributions on cell groupings.

Bruce ('01), illustrated with micro-photographic plates the motor cell groups of the various segments in a human cord. In comparing the topography of the cell group as represented in this work, with the grouping of the motor cells in the rat as described in this paper, a great degree of similarity is noted. The important difference appears to be that the rat presents two groups not indicated by Bruce ('01); these are groups M and S. As shown by Bruce's figures, there is some evidence that groups are present in the anterior lateral gray cornu of the human cord, not discussed or figured by him, but which correspond to columns M and S. If these groups exist as such in the human cord, they are apparently in closer proximity to the intermedio-lateral, or cell column D, than in the rat. The group lateral and inferior to the post-posterior lateral group in his figures, perhaps corresponds to the column indicated in this paper as C', if due account is taken of the possible shifting medially of the dorso-lateral group in the fifth and sixth segments.

The motor cell groups of the spinal cord as classified by Waldeyer ('88), do not differ greatly from the cell

groups as indicated in the figures of Bruce ('01), which show a post-posterioro-lateral group in the cervical enlargement of the spinal cord. This group is not definitely indicated by Waldeyer ('88). The latter author, however, states that the posterioro-lateral group divides into two or more groups. Perhaps one of these groups would correspond to the post-posterioro-lateral groups mentioned in the work of Bruce ('01).

The motor cell groups of the cervical enlargement of the spinal cord in man, as indicated in the figures of Kaiser ('91), differ markedly in classification and general topography from the grouping of the motor cells mentioned in the work of the authors referred to in this paper.

His classification differs in the same degree from the motor groups as indicated in this work.

EXPERIMENTAL ANALYSISNervus Radialis

## Specimen One

The distribution of the motor cells in this specimen, in which the n. radialis was cut, was found to be as follows: This radial nerve, Figure 3, presents its motor cells mainly in cell columns D and C'. There are, however, a few cells in columns C and M. The motor cells in column D have an extensive but definite distribution, cephalo-caudal; the cells of this column first appearing in the cephalad portion of the sixth segment and extending caudally as far as the caudal one-third of the first thoracic segment. The number of cells gradually increases, reaching a maximum in the caudal third of the seventh segment, near the level of section 290. The increased number of cells is maintained to section 450, which is located in the caudal portion of the eighth segment. From this level caudad, the number of cells rapidly decreases. The total number of cells in cell column D is 398, of which 50 are in the sixth, 116 in the seventh, 170 in the eighth, and 62 in the first thoracic segment.

The cells of this nerve in column C' make their appearance in the caudal third of the eighth segment and extend through the cephalad third of the first thoracic segment. The cells located in the eighth cervical segment are much scattered. Those in the first thoracic segment are of regular distribution with a pronounced increase followed by a decrease in

number of cells.

Comparatively few cells are present in cell column C and M. The total number of cells in column M is 10, of which 4 are in the seventh and 6 are in the eighth segment.

The cells in column C, located in the eighth and first thoracic segments, number 14, of which 12 are in the seventh segment, and 2 in the first thoracic segment.

#### Specimen Two

The distribution of the motor cells in the spinal cord in the second specimen studied, was essentially the same; as shown in Figure 4. The motor cells in specimen one extend over a level of 400 micra more than in specimen two. The cells in column D, in both specimens, show a corresponding increase in number in the seventh and eighth segments. The distribution of the cells in column D is more irregular than in specimen one. Specimen one presents distinct grouping of motor cells in each segment.

The cells in column C', of both specimens, are located at approximately the same level, that is, the caudal one-third of the eighth and cephalad two-thirds of the first thoracic segments. The cells are most numerous in the first thoracic segment.

The localization of the motor cells in column M is in the seventh and eighth thoracic segments. The comparative number of cells in specimen two is much greater than in specimen one. The sequence of cells in specimen two is uniform,

first increasing and then decreasing in number, while the cells in this column in specimen one are few and much scattered.

The comparatively larger number of cells in column M of specimen one is an irregularity, which at present cannot be accounted for.

The motor cells in column C, of both series, are located in specimen one in the seventh and eighth segments, and in specimen two in the seventh segment, and are of regular distribution, but few in number.

The following table compares, by segments, the number of cells showing chromatolysis in the various motor columns in the two specimens.

	Cell Col. D		Cell Col. C'		Cell Col. M		Cell Col. C	
	Specimen One	Specimen Two	Specimen One	Specimen Two	Specimen One	Specimen Two	Specimen One	Specimen Two
6 C	50	62	—	—	—	—	—	—
7 C	116	114	—	—	—	—	—	2
8 C	170	160	8	18	4	26	12	5
1 T	62	70	50	42	6	30	2	—



Nervus Medianus

## Specimen One

The motor cells showing chromatolysis, following the resection of the n. medianus, confine themselves, with the exception of six cells in cell column C', entirely to cell column C, as shown in Figure 5. The cells are located in the lower two-thirds of the seventh, and in the eighth and first thoracic segments. The seventh segment extends to section 436, the eighth between the levels of section 436 to section 543, and the first thoracic segment from this level caudalward. The cells occur in regular sequence, presenting only one main grouping. There is an increase in the number of cells to the level of section 460, in the cephalad portion of the eighth segment; this increase is maintained to the level of section 556, which is in the middle third of the first thoracic segment. From this level caudalward, there is a decrease in the number of cells per section. Both cephalad and caudal to the main grouping is found a few cells, somewhat scattered.

The sum total of the number of cells in cell column C is 198, of which 20 are in the seventh, 118 in the eighth, and 60 in the first thoracic segment.

The six cells in cell column C' are located in the seventh and eighth segments.

## Specimen Two

Figure 6, shows the distribution of the motor cells of the n. medianus, in specimen two as compared to specimen

one. In these there exists a definite mode of distribution and confinement of the motor cells to specific cell columns. The motor cells of the n. medianus in specimen one extended over a larger segment of the cord.

Both specimen one and two exhibit, in cell column C, one pronounced grouping. The curve in specimen two is somewhat more smooth than that of specimen one. The cells increase progressively to section 500. This increase is maintained to the level of section 560, and from this level the number of cells per section rapidly decreases. The cells in specimen one increase to section 460, and the increased number of cells is maintained, with irregularities in the curve, to section 560, from which there is a gradual decrease.

The cells of the median nerves are located in the caudal two-thirds of the seventh, and in the eighth and first thoracic segments.

The cells in column C' are located in the eighth cervical segment.

The following table compares the number of cells showing chromatolysis in specimen one and two in the various spinal segments.

		Cell Column C		Cell Column C'	
		Specimen		Specimen	
		One	Two	One	Two
7	C	20	16	—	—
8	C	118	110	2	—
1	T	60	50	4	5

Nervus Ulnaris

Specimen One

Figure 7, shows the serial distribution of the motor cells of the n. ulnaris. The motor cells of this nerve showing chromatolysis, are located in the caudal two-thirds of the eighth, and in the cephalad two-thirds of the first thoracic segments. The eighth cervical segment extends to section 479. The cells of this nerve are, with the exception of three cells in column C', exclusively situated in cell column C. The cells in column C number thirty-five.

Nothing striking is noted in the distribution of the cells in column C. The number of cells at first increases and then decreases, being most numerous from section 466 to section 490. Of these, 20 are in the eighth, and 15 are in the first thoracic segment. The cells in column C' are in the eighth and first thoracic segments.

Specimen Two

Figure 8, shows essentially the same distribution of the motor cells as specimen one. The number of cells in column C of specimen one is slightly larger. The cells in column C' of specimen one extend over a longer segment of the cord; the cells in this column are too few to make a definite comparison of their distribution.

The following table compares, by segments, the number of cells showing chromatolysis in the various motor columns in the two specimens.

		Cell Column C		Cell Column C'	
		Specimen		Specimen	
		One	Two	One	Two
8	C	20	26	1	2
1	T	15	22	2	6

### Nervus Musculocutaneus

#### Specimen One

Figure 9, shows the distribution of the motor cells of the n. musculocutaneus as confined to column C. The sixth segment extends to section 167. The cells present two major groupings. The first group in the sixth and cephalad one-fourth of the seventh segment, extends from section 38 to section 118, and the second group in the caudal one-fourth of the sixth and seventh segments extends from section 151 to section 256.

The cells in the first group increase gradually, being most numerous from section 66 to section 100. The number of cells from this section caudal-ward decrease abruptly. The second group is most pronounced from section 167 to section 230. The total number of cells of the n. musculocutaneus is 219, of which 108 belong distinctly to the first group, and 87 to the second group. There are a few scattered cells located between the two groups and caudally to the second group.

Nervus Thoracalis Anterioris

## Specimen One

Figure 10, shows that the motor cells of the n. thoracalis anterioris are most numerous in column S. There are, however, a few cells in column M and subjacent to M, in column M'. The motor cells of this nerve are located in the caudal one-half of the seventh, and in the eighth and first thoracic segments. The seventh cervical segment extends to section 455, and the eighth to section 570.

The motor cells in column S are of regular distribution. Cephalo-caudally, the number of cells first increases, and then decreases. The cells in column M are confined to the lower half of the motor distribution of this nerve. The cells in column D are scattered. Two of these cells are located in the cephalad portion, and five in the caudal portion of the motor distribution of this nerve.

The following table gives the number of motor cells showing chromatolysis in the various columns.

	Cell Col. S	Cell Col. M	Cell Col. D	Cell Col. M'
7 C	13	—	2	—
8 C	31	4	1	1
1 T	6	7	4	3

## Nervus Axillaris

## Specimen One

The motor cells of the n. axillaris are located in columns C, D, and M, as shown in Figure 11. Cephalo-caudally they first appear in the cephalad third of the sixth cervical segment, and extend to the caudal third of the seventh cervical segment. The sixth cervical segment extends to the level of section 138.

The motor cells of this nerve in column M, are located in the sixth and seventh segments. This distribution of motor cells in this column extends from section 51 to section 118. The number of cells is slightly increased in the level of section 61 to 82 and from section 140 to section 155.

Column D in this series contains a few cells. Three cells are located in the cephalad third of this series, and thirteen cells are distributed in the caudal fourth of this series.

Column C contains ten cells, aggregated in groups which are located in the caudal third of the axillary nerve motor cell distribution.

The following table compares, by segments, the number of cells showing chromatolysis in the various motor columns.

	Cell Column M	Cell Column D	Cell Column C
6 C	15	3	—
7 C	17	13	10

## Nervus Suprascapularis

### Specimen One

The n. suprascapularis presents on examination of serial sections, its motor cells showing chromatolysis exclusively in cell column M, as shown in Figure 12. The cells are definitely located in the caudal one-third of the fifth segment, and in the sixth cervical segment. The fifth cervical segment extends to section 56.

The cells do not follow a definite sequence, but are grouped to a minor degree. The first group is from section 1 to section 56; the second group from section 92 to section 142; and the third group from section 177 to section 200. An occasional cell is present between these groups.

The total number of cells in the fifth cervical segment is 4, and those in the sixth cervical segment number 17.

### Specimen Two

Figure 13 compares the serial distribution of the motor cells of specimen 1 and 2 and presents a some-what corresponding grouping of cells in the sixth cervical segment and a lesser congruent grouping in the fifth cervical segment. The serial distribution of the motor cells of specimen 1 and 2 is occasionally interrupted in sequence. The motor cells in specimen one extend over a level of 40 sections more than specimen two.

The following table compares, by segments, the number of cells showing chromatolysis in the various motor columns in the two specimens.

	Cell Column M	
	Specimen	
	One	Two
5 C	4	8
6 C	17	23

Ratio of Motor Cells Showing Chromatolysis  
to Normal Cells

This ratio has been quantitatively determined for the n. musculocutaneus. Figure 16 represents a smoothed curve comparing the serial distribution of chromatolytic and normal cells in column C, after sectioning the n. musculocutaneus. This nerve is the only one, with the exception of the n. axillaris, in which motor cells are confined to column C in the level of the sixth and cephalad two-thirds of the seventh spinal segments. Eighty-three percent of the cells show a Nissl degeneration. As the number of chromatolytic cells increases, the number of normal cells also increases. Column C is partly interrupted in this series from section 115 to section 149 in the caudal one-third of the sixth segment.

The full significance of this anatomical feature presented here, cannot be ascertained with certainty. Perhaps not all the motor cells react to the sectioning of a



nerve, or perhaps the non-chromolytic cells are not component parts of the nerve trunk, having an entirely different meaning; possibly these unaffected cells are concerned with association, functioning in muscle co-ordination.

The total number of normal cells is 36.

The total number of degenerated cells is 199

The cells were not read from section 242 caudalward, because of the fact that some of the motor cells belonging to the n. medianus appeared in this series at this level.

Work is in progress to determine quantitatively the ratio of chromatolytic to normal cells of the other nerves studied in this work.

### Segmental Localization of the Motor

#### Cells of Nerves Studied

In comparing the segmental localization of the motor cells of the individual nerves, according to the table following this description, certain anatomical features are brought into view. First, the motor cells innervating flexors of the arm are located more cephalad than those innervating the flexors of the forearm. Second, the motor cells innervating muscles which have a trunk, axial, or pectoral girdle origin, have an extensive segmental distribution.

The preceding statements are in accord with Sherrington's view on spinal localization of limb muscles; and are based on the following table, which was constructed from

data of this work, to show the segmental localization of the motor cells of the various nerves studied.

N. musculocutaneus

6 C

7 C (cephalad two-thirds)

N. medianus

7 C (caudal one-third)

8 C

1 T

N. radialis

6 C

7 C

8 C

1 T

N. thoracalis anterioris

7 C (caudal one-half)

8 C

1 T

N. suprascapularis

5 C (caudal one-fourth)

6 C

### SUMMARY AND CONCLUSIONS

To cell column C are confined the motor cells of the n. musculocutaneus, n. medianus, and the n. ulnaris. There are, however, a few cells of the n. medianus and of the n. ulnaris located in cell column C'. The n. axillaris, also, has some cells represented in this column.

The motor cells of the n. radialis are, for the most part, located in cell columns D and C'. The n. axillaris and the n. thoracalis anterioris each have a number of cells in column D.

The n. suprascapularis confines its motor cells entirely to cell column M. The cell column M also contains a large percentage of n. axillaris and the n. thoracalis anterioris motor cells. Comparatively few cells of the n. radialis are located in cell columns M and C.

In cell column S are located the largest number of motor cells of the n. thoracalis anterioris. The functional significance of this column cannot at present be definitely stated. Perhaps this column is functionally correlated with adduction.

It will be noted that in cell column C are located the motor cells of nerves innervating muscles which are in principal or part, flexors; in cell column D and C' the motor cells of nerves innervating muscles which are in principal or part, extensors; and in cell column M the motor cells of nerves innervating muscles which are in principal or part, rotators.

This confinement of motor cells of individual nerves into special linear cell columns, which varies directly as the action of the muscles innervated by them, places a functional value on the cell columns.

The motor cells of nerves in other cell columns not correlated directly with the action of the muscles innervated by the nerve, may function in muscle co-ordination. The writer especially refers to the motor cells of the n. radialis in cell column C and to the motor cells of the n. medianus in cell column C'.

I have constructed a scheme, Figure 14, in order to place emphasis on the functional value strongly indicated in this experimental analysis. In this figure, cell column C is to represent the motor cells functionally correlated with flexion; columns D and C' those with extension; and column M, those with rotation. Column S probably is functionally correlated with adduction. The functional value of this column is not fully brought out in the present experimentation.

The homology of this work to that of previous authors, on the analysis of the motor cell groups, can well be viewed by comparison.

First, mention must here be made of the work of Sano ('89) who constructed a scheme in which each peripheral muscle had a definite motor center. This scheme was based on observations made on three human cords obtained from autopsy of men with amputations of the inferior extremity, and on a limited number of muscle resections in animals. The degree

with which the theory advanced by this author coincides with the present work cannot be definitely stated, as he did not analyze nerves as a whole.

In the rat, I do not find as many cell columns as there are muscles, nor do I find as many cell columns as there are groups of muscles in the extremities. External differentiation into many muscles, of course, does not necessarily mean an internal differentiation of motor centers equally numerous.

The theory advanced by Van Gehuchten ('99), and his co-workers, De Buck ('98), Nelis ('99), and Neeff ('00), in which limb segments are confined to specific spinal motor centers, does not appear in accord with my experimental analysis. For, according to data presented in this work, amputation of either the arm or forearm would produce chromatolysis of motor cells in various cell columns. However, flexors and extensors of limb segments may be confined somewhat to the same level in the spinal cord.

According to the theory of Marinesco ('98), each peripheral nerve is represented in a sharply defined motor center. It is very evident in this analysis, that several nerves may be confined to one specific cell column and that the motor cells of a single nerve may be located in various cell columns, dependant upon the function of the muscle or muscles innervated by the nerve.

Parhon and Goldstein ('01), and Onuf ('89), concluded that muscle groups are represented in the spinal cord

by sharply outlined motor centers or columns. Their contentions coincide somewhat with those of Sano ('89), in which each peripheral muscle has a definite spinal localization. In view of the present analysis, the motor cells of a single group of muscles may be confined to one cell column or several, depending on the action of the muscles involved.

Knappe ('01), following experimental analysis, definitely states that the motor cells innervating flexors and those innervating extensors occupy different positions in the spinal cord. There is a similarity in his and the present work, in that a functional segregation of the motor cells is merely indicated by his data. He, however, does not analyze specific cell columns, nor does he assign specific function to the same.

The part that the functional motor cell column, as analyzed, contributes to the volitional and reflex movements cannot be definitely ascertained. Activation of motor impulses, perhaps is facilitated by linear confinement of the motor cells into specific columns. Such an arrangement may be necessary for a high gradient of a physiological act, in which voluntary and reflex of the vestibular, visual, and auditory impulses, find expression.

BIBLIOGRAPHY

- BRUCE. 1901. Atlas of the spinal cord. Edinburgh
- HOPKINS, A. E. 1924. The appearance of the Nissl substance in the nerve cell following variation in fixation. Anat. Rec., vol. 28, no. 2.
- KAISER. 1891. Die funktionen der ganglienzellen des halsmarkes. Haag.
- KNAPPE. 1901. Experimentelle untersuchungen uber die motorischen kerne eines spinalen nerven der hinteren extremitaten des hundes. Deutsche Zeitschr. F. Nervenheilk. S 116.
- LAPINSKY. 1903. Zur frage d. fur die einzelnen segmente der extremitaten u. d. muskelgruppen bestimmten ruckenmarkscentren beim hund. Arch. F. (Anat. u.) Physiol., Suppl. p. 427.
- LENHOSSEK, Von M. 1895. Der feinere bau des nervensystems. 2. Aufl., Berlin, Taf. vi. (Cited by Barker)
- MARINESCO. 1898. Contribution a l'etude des localizations des noyaux moteurs dans la moelle epiniere. Jour. de Neurologie.
- NICHOLSON, F. M. 1923. The changes in amount and distribution of iron containing protein of the nerve cells following injury to their axones. Comp. Neur., vol. 36, no. 1, October '15.

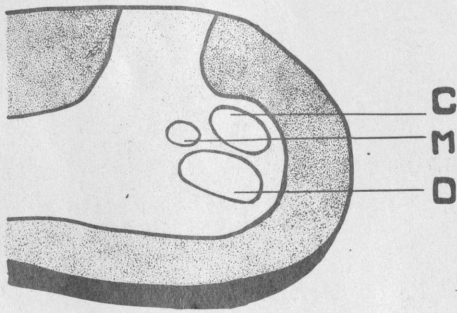
- ONUF. 1889. On the cell groups of the lumbo-sacral region in man. Jour. Nervous and Mental Diseases, 26.
- PARHON and GOLDSTEIN. 1901. Zur kenntniss der langerung der motorischen hirnnerven im hirnschenkelfuss. Neurol. Zentralblatt, no. 20.
- SANO. 1897. Resume de la communication de M. le Docteur Fritz Sano. Jour. de Neurologie, p. 404, d'Anvers.
1897. Les localizations motrices dans la moelle lombo-sacre. Jour. de Neurologie.
1898. Les localizations des fonctions motrices de la moelle epiniere. Anvers, Bruxelles, p. 32.  
(Cited by Barker, p. 912.)
- VAN GEHUCHTEN and NEEFF. 1900. Les noyaux moteurs de la moelle lombosacree chez l'homme. L. E. Nevraxe I.
- VAN GEHUCHTEN and De BUCK. 1898. Contribution a la l'etude des localization des noyaux moteurs dans la moelle lombo sacree et la vacuolasation des cellules nerveus. Jour. de Neurologie.
- VAN GEHUCHTEN and NELIS. 1899. La localization motrice medullaire est une localization segmentaire. Jour. de Neurologie.
- WALDYEYER. 1888. Das gorilla ruckenmark. Berlin. (Cited by Gehuchten and Neeff).



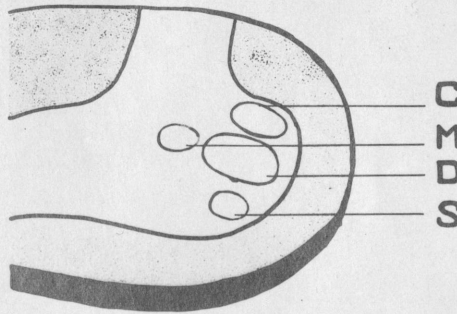
Figure 1.

A diagrammatic presentation  
of the cell groups in the cervical en-  
largement of the spinal cord in the  
albino rat.

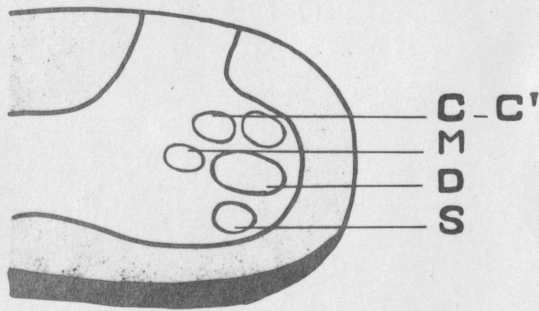
6C.



7C.



8C.



1T.

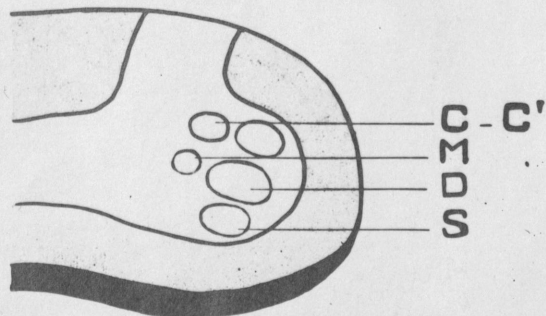
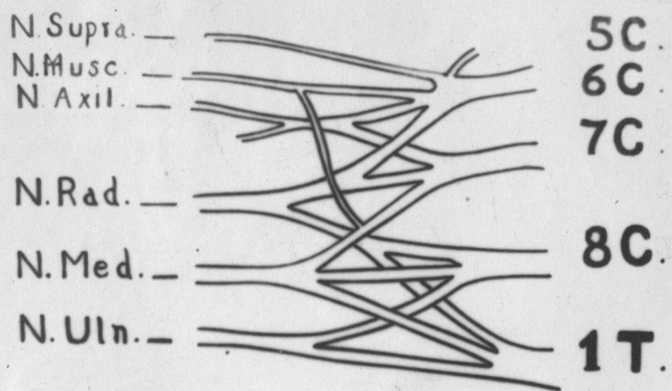


Fig. 1.

## Figure 2.

Photograph of a drawing made  
from a dissection of the plexus  
brachialis.

N. Uln.	-----	Nervus Ulnaris
N. Med.	-----	Nervus Medianus
N. Rad.	-----	Nervus Radialis
N. Musc.	-----	Nervus Musculocutaneus
N. Axil.	-----	Nervus Axillaris
N. Supra.	-----	Nervus Suprascapularis



**Fig. 2.**

Figure 3.

The serial distribution and confinement in specific cell columns of the motor cells of the nervus radialis, in specimen one. Four vertical one-tenth inch squares is a unit for one degenerating motor cell. Each horizontal one-tenth inch square represents one section of the series.

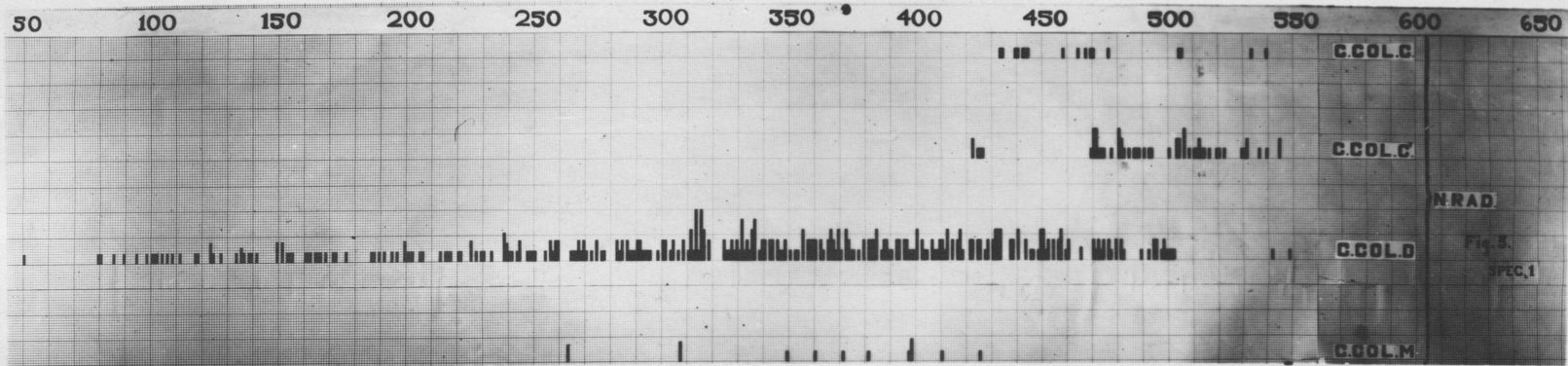


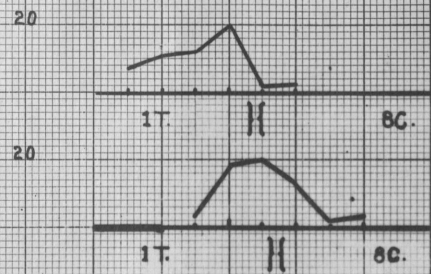
Figure 4.

The serial distribution and confinement in specific cell columns of the motor cells of the nervus radialis, in specimen one and specimen two. The curves are plotted to the sums of the motor cells which show chromatolysis in every twenty sections.

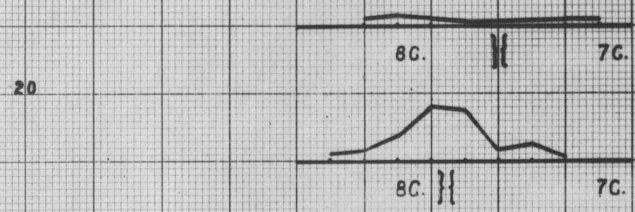
N. Rad.



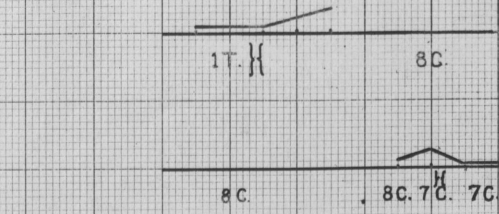
Spec. 1  
C.Col.D.  
Spec. 2



Spec. 1  
C.Col.C'  
Spec. 2



Spec. 1  
C.Col.M.  
Spec. 2



Spec. 1  
C.Col.C.  
Spec. 2

Fig. 4.



Figure 5.

The serial distribution and confinement in specific cell columns of the motor cells of the nervus medianus, in specimen one. Four vertical one-tenth inch squares is a unit for one degenerating motor cell. Each horizontal one-tenth inch square represents one section of the series.

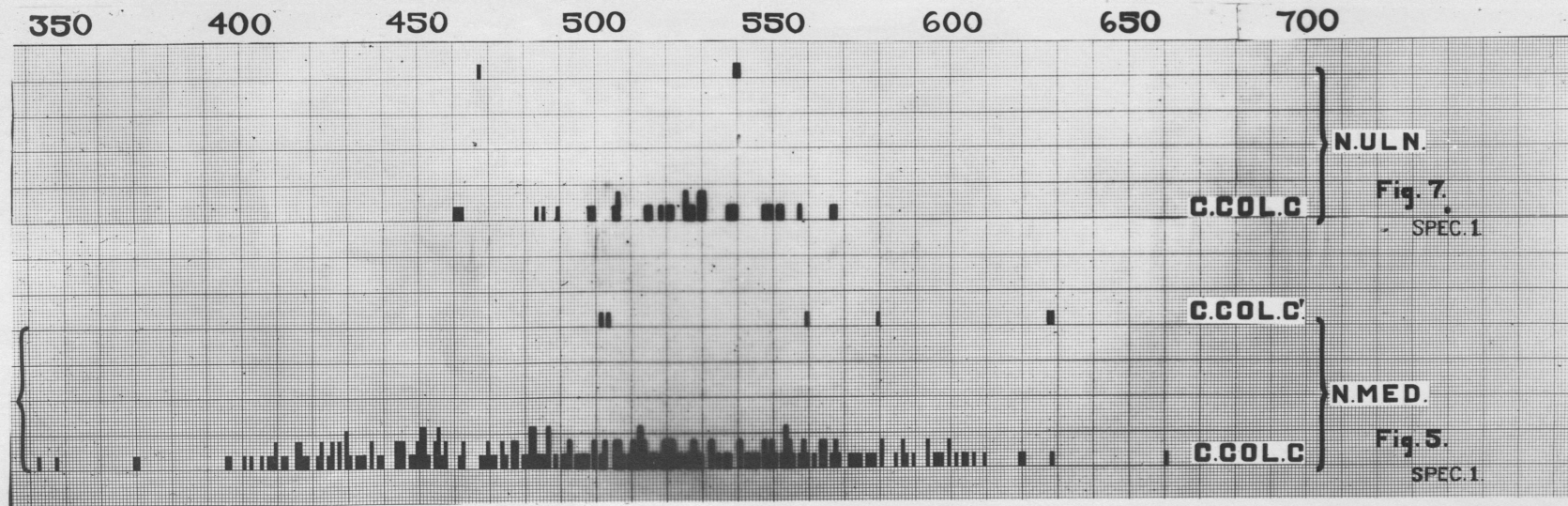


Figure 6.

The serial distribution and confinement in specific cell columns of the motor cells of the nervus medianus, in specimen one and specimen two. The curves are plotted to the sums of the motor cells which show chromatolysis in every twenty sections.

N. Med.

640 600 560 520 480 440 400 360

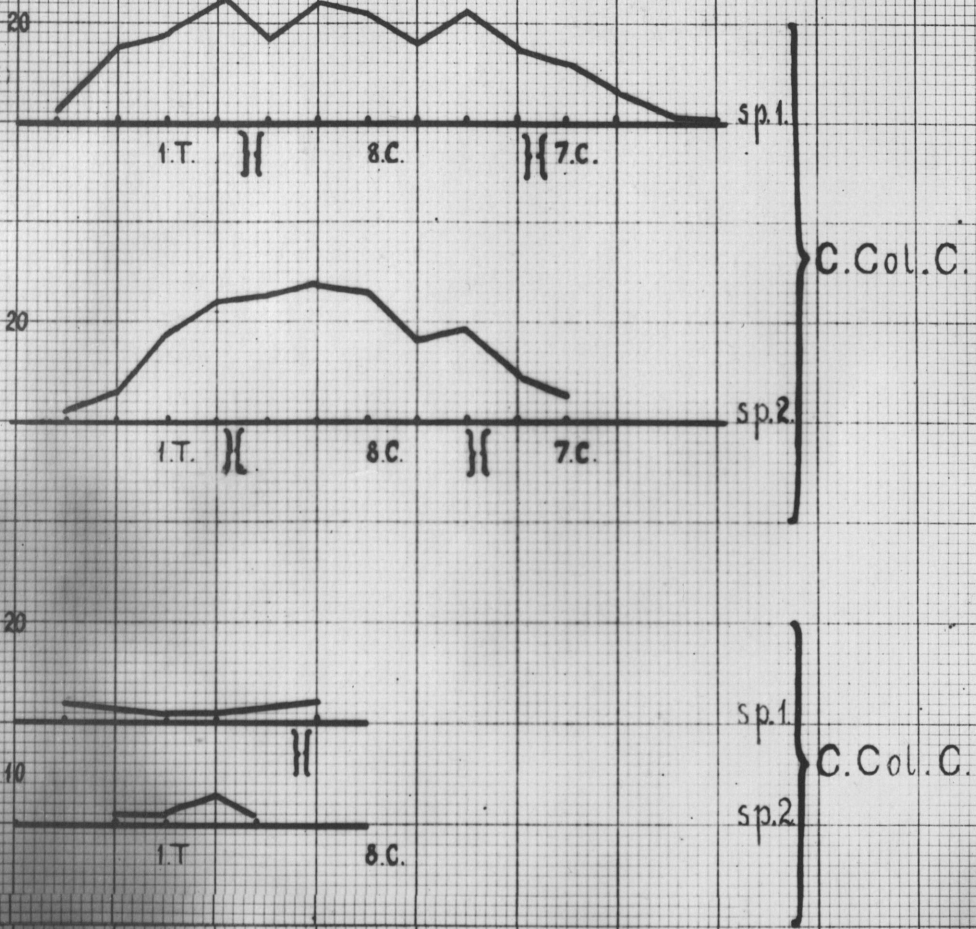


Fig. 6.

Figure 7.

The serial distribution and confinement in specific cell columns of the motor cells of the nervus ulnaris, in specimen one. Four vertical one-tenth inch squares is a unit for one degenerating motor cell. Each horizontal one-tenth inch square represents one section of the series.

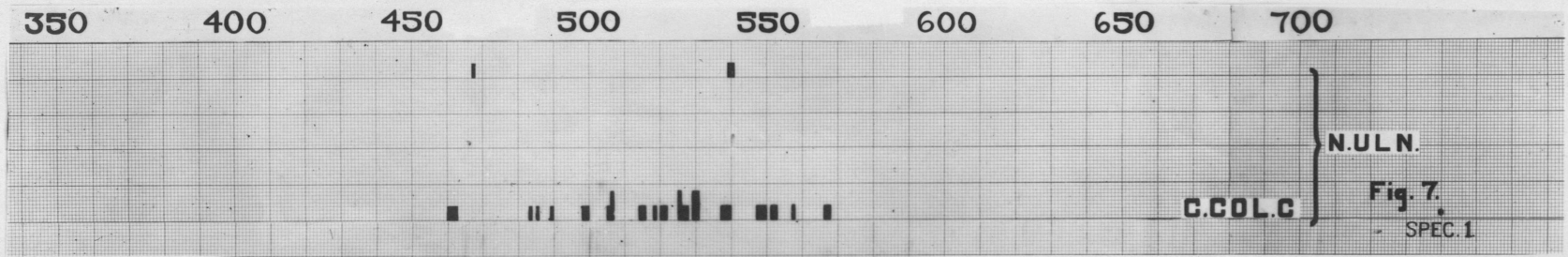


Figure 8.

The serial distribution and confinement in specific cell columns of the motor cells of the nervus ulnaris, in specimen one and specimen two. The curves are plotted to the sums of the motor cells which show chromatolysis in every twenty sections.

N. Uln.

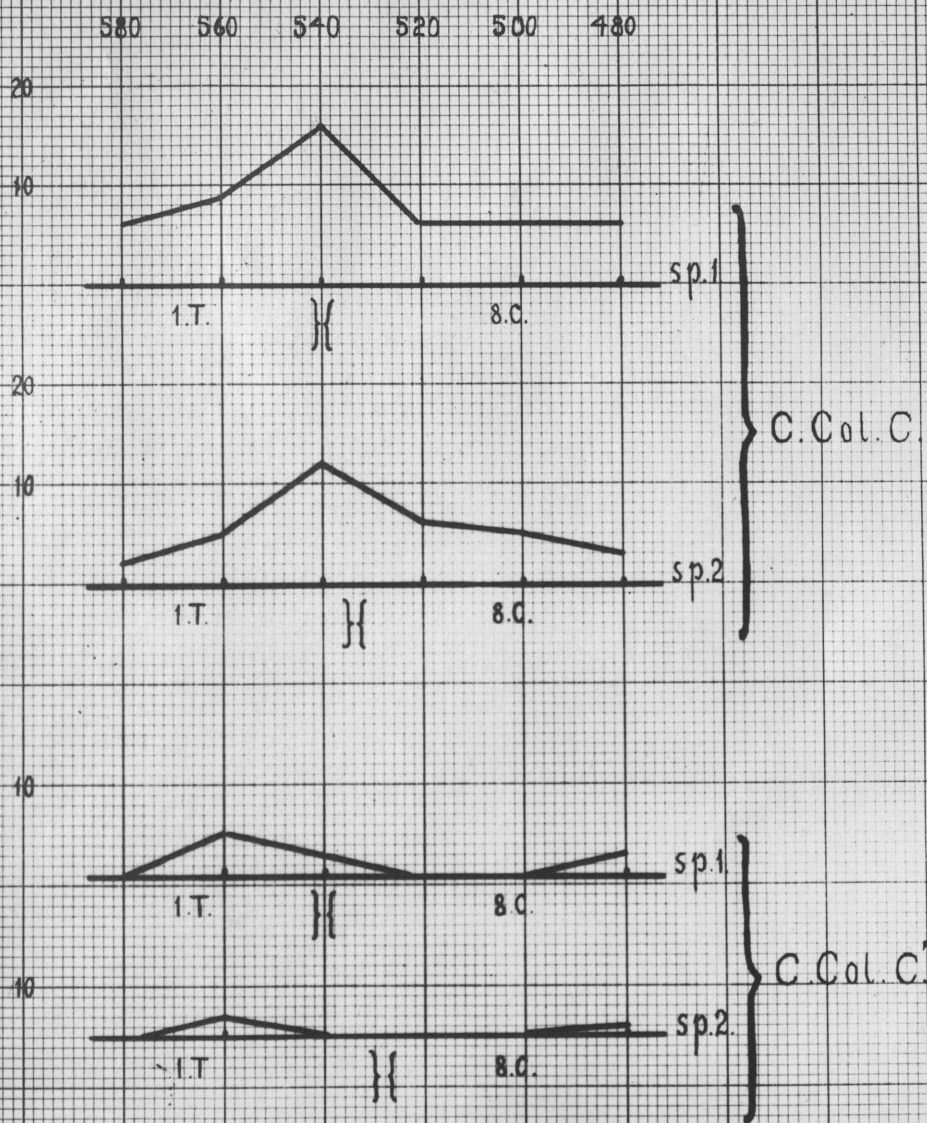


Fig. 8.



Figure 9.

The serial distribution and confinement in specific cell columns of the motor cells of the nervus musculocutaneus, in specimen one. Four vertical one-tenth inch squares in a unit for one degenerating motor cell. Each horizontal one-tenth inch square represents one section of the series.

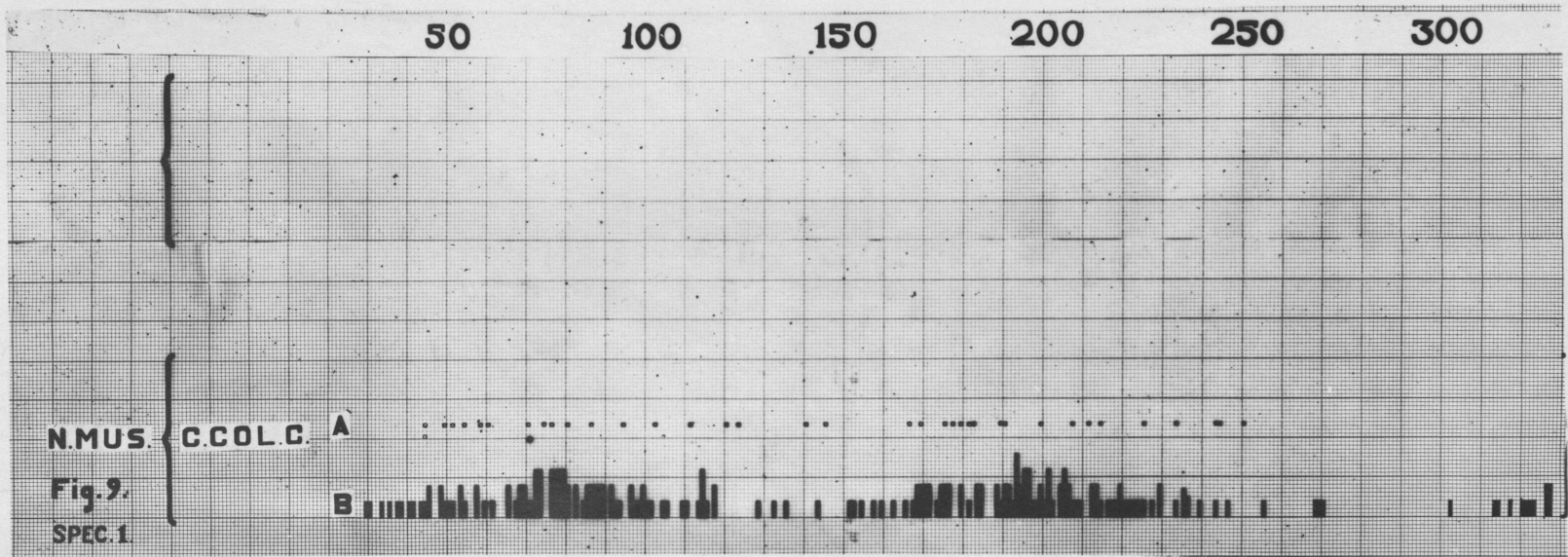


Figure 10.

The serial distribution and confinement in specific cell columns of the motor cells of the nervus thoracalis anterioris, in specimen one. Four vertical one-tenth inch squares is a unit for one degenerating motor cell. Each horizontal one-tenth inch square represents one section of the series.

400

450

500

550

600

650

700

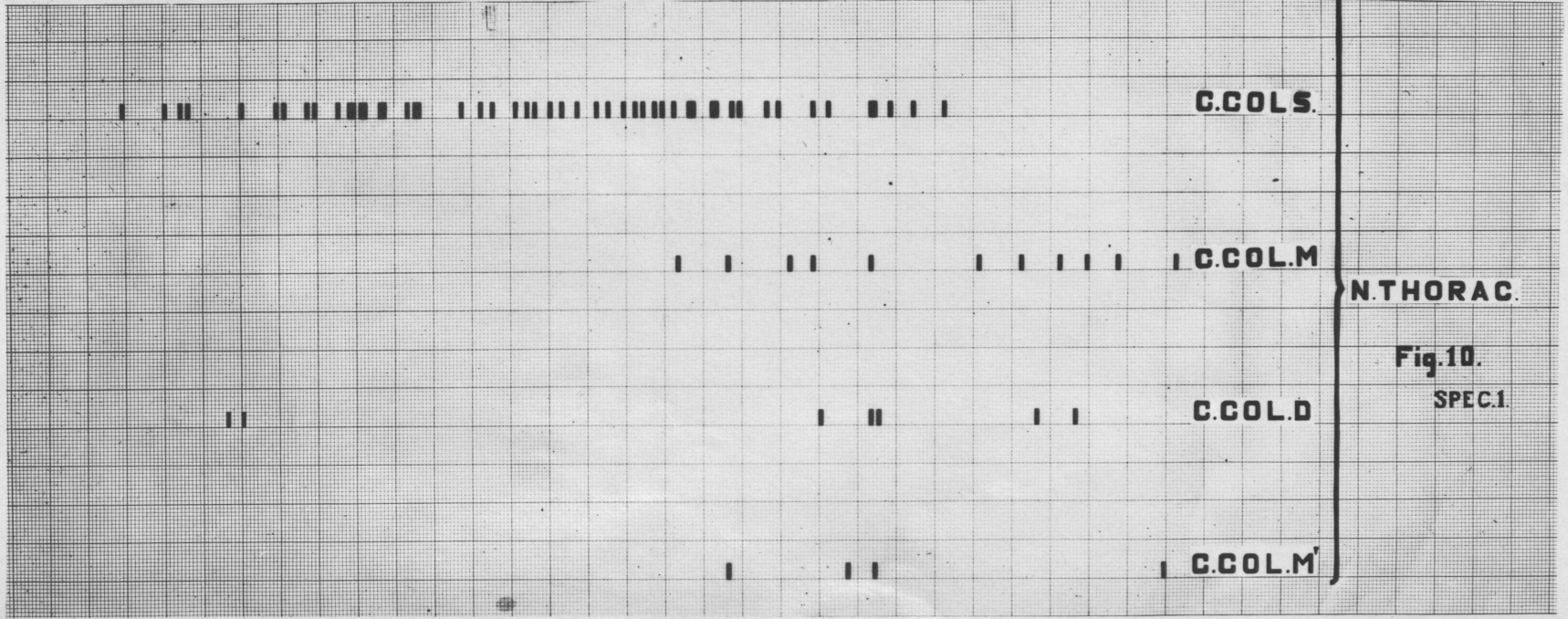


Figure 11.

The serial distribution and confinement in specific cell columns of the motor cells of the nervus axillaris, in specimen one. Four vertical one-tenth inch squares is a unit for one degenerating motor cell. Each horizontal one-tenth inch square represents one section of the series.

Figure 12.

The serial distribution and confinement in specific cell columns of the motor cells of the nervus suprascapularis, in specimen one. Four vertical one-tenth inch squares is a unit for one degenerating motor cell. Each horizontal one-tenth inch square represents one section of the series.

50

100

150

200

250

C.COL.D



N.AXIL.

C.COL.M

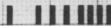


Fig. 11.

SPEC. 1.

C.COL.C



N.SUPRAS.

Fig. 12 C.COL.M.



SPEC. 1.

Figure 13.

The serial distribution and confinement in specific cell columns of the motor cells of the nervus suprascapularis, in specimen one and specimen two. The curves are plotted to the sums of the motor cells which show chromatolysis in every twenty sections.



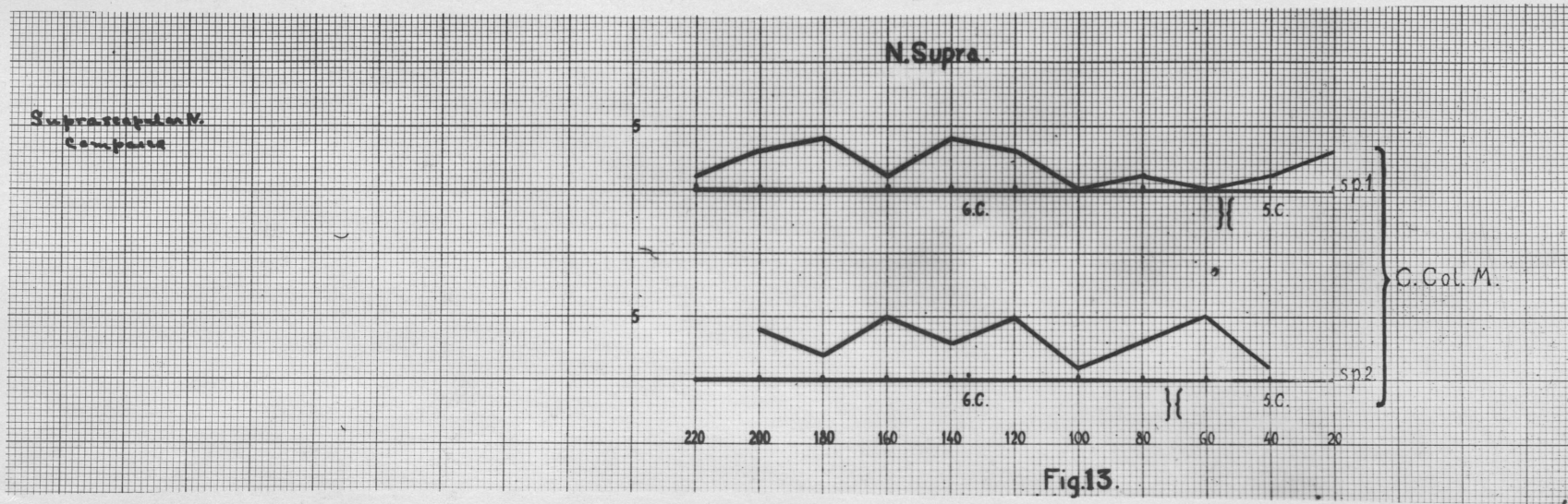


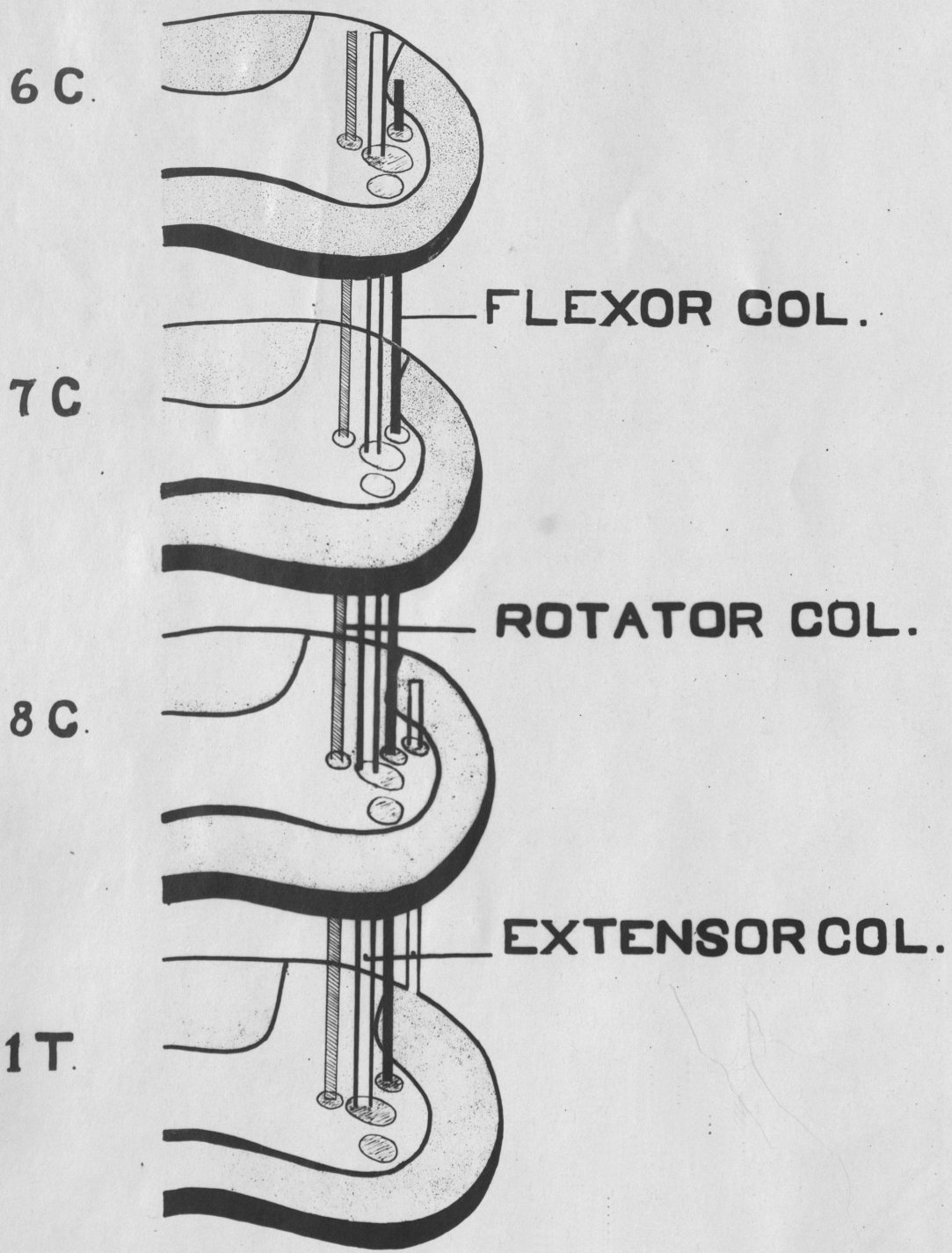
Figure 14.

A schematic presentation of the indicated functional value of the motor cell columns in the cervical enlargement of the spinal cord in the albino rat.

Cell Column C ----- Flexor

Cell Columns D and C' ----- Extensor

Cell Column M ----- Rotator

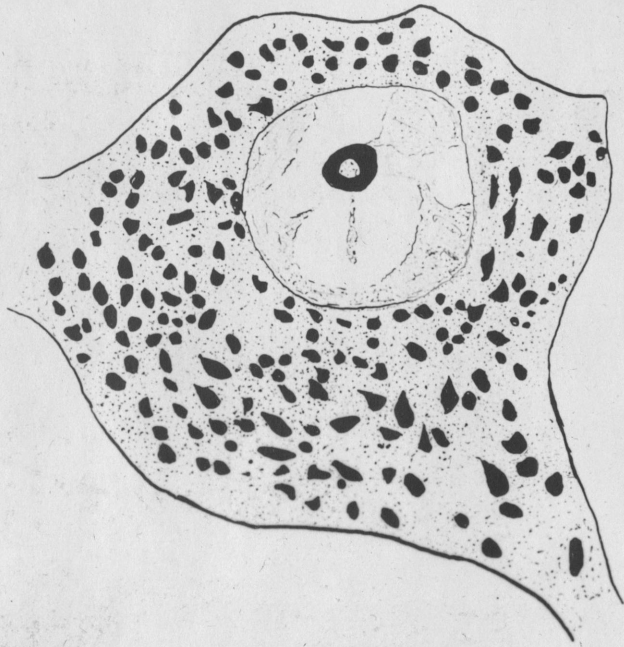


**Fig. 14.**

Figure 15.

Normal and Degenerating Motor Cell.

- A ----- Normal
- B ----- Degenerating



A.



B.

Fig. 15.

Figure 16.

The ratio of motor cells showing chromatolysis to normal motor cells, in cell column C, following resection of the nervus musculocutaneus. The unbroken line represents the motor cells which show chromatolysis, and is plotted to the sums of these motor cells in every ten sections. The dotted line represents the normal motor cells, and is plotted to the sums of these motor cells in every ten sections.

20 40 60 80 100 120 140 160 180 200 220 240 260

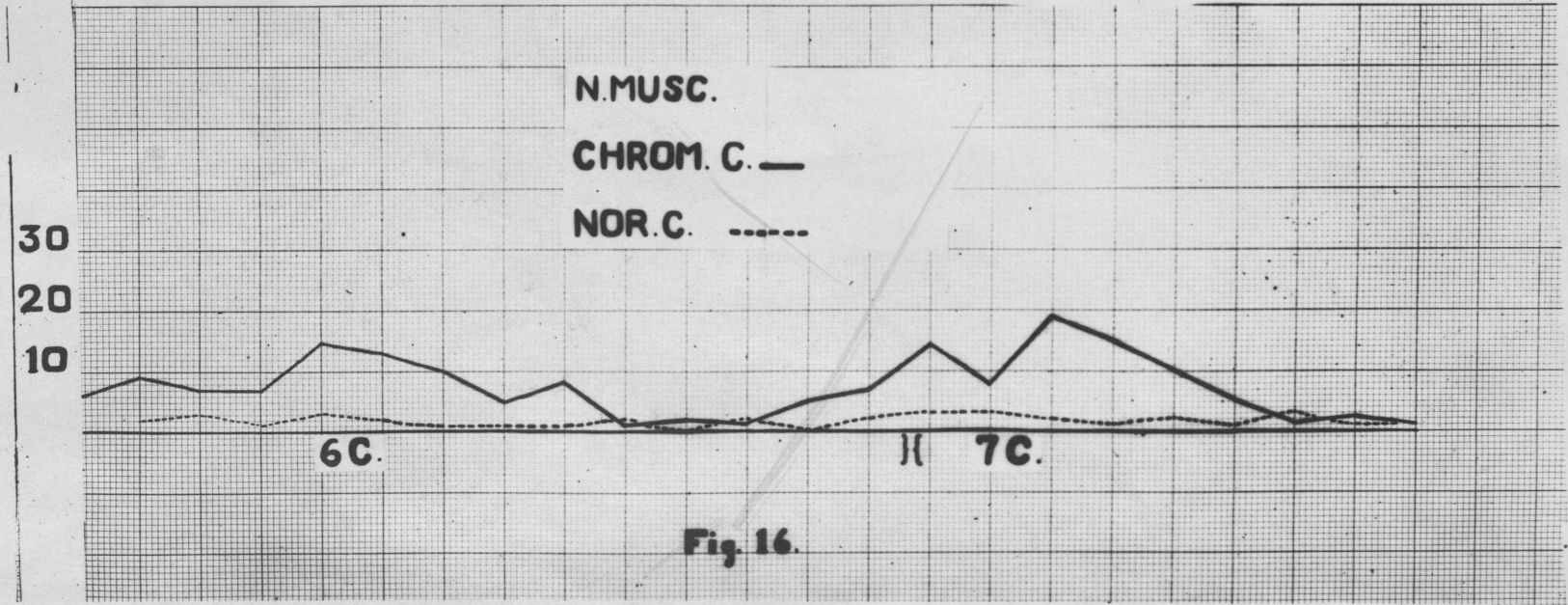


Fig. 16.

Figure 17.

Micro-photographs of sections in some of the series studied, presenting motor cells showing chromatolysis, following nerve resection.

A ----- Nervus radialis

B ----- Nervus medianus

C ----- Nervus ulnaris



