

THE LOCATION OF THE MOTOR NEURONES INNERVATING
PARTICULAR GROUPS OF MUSCLES IN THE ALBINO RAT.

BY

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CONTENTS

INTRODUCTION

Material and Methods 1.

OBSERVATIONS

Case A: The Distribution of the
Degenerated Motor Cells of
the Sciatic Nerve. 4.

Case B: The Distribution of the
Degenerated Motor Cells of
the Sciatic Nerve. 8.

Case C: Adductor Longus Muscle. 12.

DISCUSSION

Nissl Substance 14.

Muscles Innervated by the Sciatic Nerve 16.

Adductor Longus Muscle 22.

CONCLUSIONS 23.

BIBLIOGRAPHY 25.

FIGURES 27.

INTRODUCTION

A careful examination of the literature accessible to me upon the location of motor neurones innervating the limb muscles, does not reveal the information that is necessary for a satisfactory understanding of the subject. The purpose of this work is, therefore, to determine exactly the position of the motor neurones that innervate certain limb muscles and to interpret the possible significance of such an anatomical arrangement.

The author is indebted to Professor G. E. Coghill and Professor H. C. Tracy for valuable criticism, suggestions, and encouragement given throughout the progress of the work.

Material and Methods

Adult albino rats were used for the experimental phases of the work. In two cases I cut the right sciatic nerves at the point where the nerve passes over the ischium, and in one case I excised the left adductor longus muscle. The nerves and muscles were cut under aseptic conditions. Infections were not encountered.

The degeneration was allowed to proceed fifteen days, which time, according to Nicholson ('25) is adequate for complete disappearance of the Nissl substance. I killed the animals with chloroform, removed the spinal column and exposed the spinal cord by cutting the laminae of the vertebrae. The spinal column and cord were then placed into a small amount of fixative for a few minutes. Under such conditions the tissue soon becomes more rigid and the spinal cord can be removed with least torsion and mutilation. This procedure does not interfere with the proper fixation.

I fixed the tissue in Van Gehuchten's fluid. This fixative affords advantages in that it fixes the cord in rather large pieces, and decalcifies small chips of bone which might be overlooked. The acetic acid has special fixative value for the Nissl substance (Hopkin, '24). I sectioned the cord serially at ten micra, and stained the sections by the erythrosin toluidine blue method.

The cell groups in the lumbar cord were established by the following procedure: a characteristic region was chosen in the lumbar enlargement and the cells of every tenth section were drawn throughout a spinal segment. The drawing was done with the aid of a projecting apparatus upon transparent tracing cloth. The different drawings were then carefully superimposed upon one another, and the cells traced into one com-

posite drawing. The margins of the several groups were then traced in even contours according to figure I.

OBSERVATIONS.

Cell Groups in the Lumbar Cord.

It has long been known that the motor neurones are not distributed at random in the ventral gray of the spinal cord. They group themselves into longitudinal columns. Waldyer ('89) found four groups of motor of motor cells in the anterior horn of the ape. In the lumbar cord of the rat I find four main groups. They are, group C, group D, group E, and group F. There are, however, four other groups of cells; group A, group B, group E, and group J. Group J is in the dorsal horn of the lumbar cord. In the caudal region of the cord, group C and group D shift their position dorsally and group A and group B ventrally. The anatomical contour of the cord must be a contributing factor to the shifting of the cell groups. In reference to the grouping of the motor cells in the ventral gray of the rat, I found in the various lumbar cords that I studied very little deviation as to the position of the groups.

Sciatic Nerve.

The sciatic nerve enters the vertebral canal by three roots; the fifth, sixth, and seventh lumbar. This nerve has long dorsal and ventral roots in comparison to other peripheral nerves. The ventral roots ascend to the level of the fourth lumbar vertebrae. There the fila radicularia diverge as they approach the cord. Upon entering the spinal cord, the fila of each root overlap those of the adjacent root. The component fila radicularia extend over a level of four and a half mm. at the point of entrance to the cord.

CASE A.

The Distribution of the Degenerated Motor Cells of the Sciatic Nerve.

The degenerating cells of the sciatic nerve of Case A group themselves serially according to Figure II, Series I. The numbers of cells in each column are given comparatively in Figure III. There are 57 cells that show chromatolysis in column A; 17 in column B; 399 in column C; 330 in column D; 150 in column E; 50 in column F; and 2 in column G.

The degenerated cells in column A (figure II, series I) show variation as to the number of cells in the different levels of the column. The cells are dis-

tributed throughout the column, but most of the cells are in the lower three-fourths of the column. The lower two divisions are in this level. The second division extends from section 320 to section 360, with fifteen motor cells. The third division (c) extends from section 412 to section 474, with twelve degenerated cells. The first or most cephalad division extends over the upper one-third of the cell column. Its largest number of cells is in its caudal third.

The cell column B shows two very distinct divisions of degenerated motor cells. The first division (a) extends over the upper third of this cell column, and the second division (b) over the lower two-thirds of the cell column. The cells in the most cephalad division extend from section 77 to section 165. There are no degenerated cells from sections 165 to 399. The lower division (b) extends from section 399 to 421; within this group are five cells placed serially (section 299 - 304).

The cells in column C (figure II) group themselves into two large divisions and two smaller divisions. The first division (a) begins at the main sciatic grouping, and extends to section 72. This division is distinctly marked off from the adjacent division (b), by complete absence of cells from section

79 to section 86. The second division (b) begins in section 85 and extends to section 170. The degenerated cells have the largest number of cells in the upper two-thirds of this division. The third division (c) of cells comprises two-fifths of the whole cell column, and extends from section 189 to 375. This division contains 271 cells and has the largest number of degenerated cells in series I. The cells in this division are distributed uniformly, but are most numerous in the middle third of the group.

The fourth division (d) begins at the section 375 and ends with the sciatic grouping. The cells are uniformly distributed in linear order.

In cell column D are three divisions of cells. The first division (a) is marked off from the adjacent group by the absence of degenerated cells for twenty sections. This division extends over a level of forty-seven sections, and is represented by twenty degenerated cells. The second division (b) extends over eighty-five sections, from section 75 to section 172. The cells are not uniformly distributed in this group. In the upper third of this division, cells are not present for five sections. The degenerated cells first increase and then decrease. In the middle third the cells are more numerous, and

the number of cells decreases gradually caudalward. The third division (c) is marked off from the second division by a few scattered cells at the level of section 172 to section 192. This division of cells is the largest in column D and extends over its lower two-thirds. The middle third of this cell division contains the largest number of cells.

In cell column E, the degenerated cells are not uniformly distributed. There are numerous small divisions. However, these small divisions can be divided into three larger divisions. The first division (a) extends to section 72. It has the largest number of cells in the middle third. This division is marked off from the adjacent group by the absence of degenerated cells, for nineteen sections. The second division (b) of cells extends from section 89 to section 171. Most of the cells are located in the upper fourth of this division. The third division (c) of cells extends from section 191 to section 455. This division of cells comprises the middle third of column E. Within this group the cells aggregate into three distinct sub-divisions. The first (r) of these is in the upper half of this division, the lower half contains both the second (s) and the third (t) sub-divisions. The third sub-di-

vision contains the most of the cells; the cells are uniformly distributed, except at the lowest point where there are seven cells placed serially.

Cell column F presents only two distinct divisions of degenerated motor cells. The highest division (a) begins near the cephalic end of the sciatic grouping and extends to section 250. The degenerated cells are most numerous in the middle third of this division. The lower division begins at section 299 and continues to the end of the series. There are only a few cells in the lower division of this column, but the distributions of the cells is regular.

Column G has only two degenerated cells in the lower two-fifths of the sciatic grouping.

CASE B.

The Distribution of the Degenerated Motor Cells of the Sciatic Nerve.

The degenerated motor cells of the sciatic nerve, Case B, group themselves serially according to figure II. The number of cells in each column are given comparatively in figure IV. There are 66 cells that show chromatolysis in column A; 24 cells in column B; 450 cells in column C; 300 cells in column D; 130 cells in column E, and 45 cells in group F.

In the cell column A (figure II, series II) there are three distinct divisions of cells. The first division (a) extends from section 50 to section 117. The second division (b) continues from section 330 to section 380. There are only two cells located between these divisions. The third division (c) extends from section 458 to section 525. Only one degenerated cell is located between divisions two and three. The cells are for the most part arranged serially from section to section except at the cephalic end of the first division and second division, where there is a relatively larger number of cells than in the rest of the respective divisions.

The cells in column B show no pronounced grouping into divisions. The cells are distributed throughout the sciatic nerve grouping. The only possible divisions are from section 104 to section 388 and from section 481 to section 524. In the first division there are twenty-one cells and in the second only three.

The cells in column C place themselves into four divisions. The first division begins with the general sciatic nerve cells. The cells in this division are aggregated into clusters, some sections contain two or three cells while some of the other sec-

tions do not contain any. The second division (b) is marked off from the first by the absence of degenerated cells in seven serial sections. This division begins at section 115 and continues to section 220. In the upper one-fourth there is a relative larger number of cells than in the remainder of the division. The cells in the lower three-fourths are very regular in their distribution. The third division (c) of cells is located in the lower two-thirds of the cell column. It begins at section 230 and is prolonged to section 460. The degenerated cells are most numerous in the upper half of this division. Almost all of the sections of the lumbar cord at this level are represented with one degenerated cell. The fourth division (d) extends from section 460 to the end of the sciatic grouping. This division is made up of four sub-divisions, which are distributed at regular intervals.

The column D is represented by four divisions of cells. The first (a) begins near the beginning of the sciatic groupings and extends to section 100. The cells are mainly in the middle third of this division. The second division (b) of cells continues from section 100 to section 200. The cells are more abundant in the middle third. The cells are distributed quite uniformly; however, not all sections

in this division contain cells. In the third division (c) the cells of column D are uniformly distributed. It is continuous from section 200 to section 538, and embraces one-third of this column. The largest number of cells are in the middle two-fourths. The distribution of cells is marked by continuous serial grouping, and omission of cells in intermediate sections. The fourth division (d) is in the lower sixth of column D. The cells are divided into three sub-divisions with only a few cells in each.

The cell column E included three definite divisions. The first division (a) commences near the beginning of the sciatic grouping and continues to section 195. Not all of the sections contain degenerated cells, but their distribution is uniform and in linear arrangement. The second division (b) extends from section 203 to section 350. In the upper third of this division the cells are more abundant. The third division contains cells distributed more or less at random. There are only comparatively few degenerated cells from section 350 to the end of the sciatic grouping.

The cell column F has no distinct division of cells. The cells are located in the lower two-thirds of the sciatic grouping. In the lower half of this column of cells the cells are uniformly distribu-

ted, while in the upper half the cells are grouped into clusters of three to five cells, placed serially.

Group G is represented with one cell in the lower third of the sciatic grouping.

There are no cells in column J.

The two sciatic nerve series I and II have an out-standing similarity. They, however, differ in both columns B and F. In series I, the cells of column B are in two distinct groups, while in series II they are not distributed so. Column F in series I has the cells mainly in the upper third, and series II has the cells in the upper fourth. The cell columns of series I extend over ninety-five sections more than series I. The division of cells into groups, both Case A and Case B, have corresponding grouping of cells in their respective columns.

CASE C.

Adductor Longus Muscle.

The degenerating cells of the adductor longus muscle group themselves serially according to Figure V. The numbers of cells are given comparatively in Figure VI. There are 40 cells in group D, 2 cells in group A, 1 cell in group B, and 3 cells in

group C. The degenerated cells extend in the cord over a level of 1.35 mm. The cells are, for the most part, in the dorsomedial area of Group D.

The motor cells of the adductor longus muscle are for the most part in column D. The cells place themselves into divisions with various numbers. The largest number of the cells are in the lower fourth of the column. The several clusters of cells are uniformly distributed. The first (a) contains three cells and is separated from the second by six sections. The second division contains four cells. The third and second divisions are separated by nine sections. In the third division are seven cells. The fourth division contains four; the fifth only two cells, and the sixth only three. The seventh division is the largest, extending over thirty-six sections. The cells of the several divisions are distributed uniformly in column D. The two cells of column A are in the lower third of the serial grouping. The degenerated cells in column C are in the lower half of the serial grouping. Column B contains one cell in its lower third.

DISCUSSION.

Nissl Substance.

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. The progression varies with the degree of injury, the greater the injury, the greater the cellular reaction. Chromatolysis starts in the center of the cell and moves toward the periphery. The whole cell shrinks and the nucleus becomes eccentric. I have noticed in addition, that the nucleus moves away from the source of injury, that is, away from the axone hillock.

Figure VII, A and B, are camera lucida drawings at the same magnification of the normal and degenerated motor cells as they appeared in my preparation. In figure A are given the details of the normal motor cell. The Nissl bodies (a) 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, deep blue staining, cytoplasmic aggregated. Eryth⁷osin stains all the cytoplasm (b) uniformly, except the basophilic substance. The cytoplasm has a reddish-blue appearance. There is uniformity of the nuclear structure and the nucleus (c) has an even contour. Within the nucleus there is a large deep blue staining nucleolus (e) located near the center of the nuclear mass. The cell processes stand out prominently.

In figure B are given the characteristics of a degenerated cell. The whole cell is shrunken, with the Nissl bodies (a') limited to the periphery of the cytoplasm (b'), and to the region adjacent to the nuclear wall (d'). The Nissl substance or bodies are irregularly distributed. They are not so abundant and much smaller than in the normal cell. The normal cytoplasm is not so deeply stained by eryth⁷osin as the chromatolytic area (f') of the degenerated motor cell. 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 (c') is eccentric and is located in the periphery of the cell. The nucleolus (e') is smaller than in the normal and is not in the center of the nuclear mass.

The Muscles Innervated by the Sciatic Nerve.

Functional Classification of Muscles Innervated
by Sciatic Nerve.

Muscle	Flexors.			
	Hip	Knee	Ankle	Phlanges
Biceps	-	+	-	-
Semimembranosus	-	+	-	-
Semitendinosus	-	+	-	-
Gastrocnemius	-	+	-	-
Soleus	-	-	-	-
Popliteus	-	+	-	-
Plantaris	-	+	-	-
Tibialis anterior	-	-	+	-
Extensor digitorum longus	-	-	+	-
Flexor digitorum longus	-	-	-	+
Peroneus Tertius	-	-	+	-
Peroneus Longus	-	-	-	-

Extensors.

Muscle	Hip	Knee	Ankle	Phlanges
Biceps	/	-	-	-
Semimembranosus	/	-	-	-
Semitendinosus	/	-	-	-
Gastrocnemius	-	-	/	-
Soleus	-	-	-	-
Popliteus	-	-	-	-
Plantaris	-	-	/	-
Extensor digitorum longus	-	-	-	/
Flexor digitorum longus	-	-	/	-
Peroneus tertius	-	-	-	-
Peroneus longus	-	-	/	-
Peroneus breves	-	-	/	-

Rotators

Medial

Muscle	Hip	Knee	Ankle	Phalanges
Semitendinosus	-	+	-	-
Semimembranosus	-	+	-	-
Peroneus tertius	-	-	+	-
Extensor digitorum longus	-	-	+	-

Lateral

	Hip	Knee	Ankle	Phalanges
Biceps	-	+	-	-
Peroneus longus	-	-	+	-
Peroneus brevis	-	-	+	-

The muscles which extend the hip are innervated by the sciatic nerve. Here are to be enumerated the following muscles: biceps, the semitendinosus and the semimembranosus.

The movement of the knee joint by muscles innervated by the sciatic nerve is mainly flexion. The muscles which function in this action are: biceps, semimembranosus, semitendinosus, gastrocnemius, popliteus, and plantaris. There is only a limited amount of rotation in the knee joint. The biceps rotates the tibia slightly laterally, while the semimembranosus and semitendinosus rotate the tibia somewhat medially.

The movements of the ankle joint are both flexion and extension of the foot. The extension is occasioned by the following muscles: gastrocnemius, soleus, plantaris, flexor digitorum longus, peroneus longus, and peroneus brevis. There is a slight medial and lateral rotation of the foot. The tibialis anterior, peroneus longus, and peroneus brevis, rotate the foot laterally while the peroneus tertius and extensor digitorum longus rotate the foot medially.

The lumbricales flex the toes and the inter-
ossei flex the phalanges at the tarsal joints.

The chief muscles innervated by the sciatic nerve do not have much variation as to function. They are mainly extensors and flexors, with only a very limited amount of rotation. The muscles which are concerned with flexion of knee and ankle predominate, while muscles which extend the hip and ankle are next in order. There is more medial rotation than lateral rotation.

The similarity of the arrangement of the motor neurones of the sciatic nerve, of both Case A and B, into specific longitudinal cell columns in the lumbar cord of the rat, places a functional value on the cell columns. Parhon and Goldstein ('01) do not assign specific functions to the cell columns in the spinal cord, but they favor the idea that motor cell columns are specific functional centers of the muscles.

Placing a functional value on the motor cell column, and taking into account the classification of the limb muscles innervated by the sciatic nerve and the number of cells in individual cell columns, one might conclude that the neurones of the flexor muscles would fall in cell column C, and those of the extensor muscle in cell column D. Some of the minor actions

occasioned by the muscles of the sciatic nerve innervation, are probably represented in cell columns which contain fewer degenerated cells. These minor functions are probably located in cell columns E, F, and A. The neurones of specific functional action probably arrange themselves in their respective cell columns at definite levels of the lumbar cord according to the segment of the limb in which they are located. For instance, flexors of the thigh might be located more cephalad than the flexors of the leg.

According to Onuf ('99) there is a sympathetic motor cell column in the lumbar cord of man. If there is similarity between the cell columns of man and other vertebrates, cell column B may be considered sympathetic. This interpretation would suggest evidence of preganglionic sympathetic motor neurones to the limb muscles. Iden ('20) finds post-ganglionic fibers to limb musculature and states "whether there are also preganglionic nerve fibers to striated muscles is a question on which my researches throw no light."

Adductor Longus Muscle.

The adductor longus muscle in the rat is a pure muscle as regards its specific function. The degenerated cells of this muscle are, with the exception of five, in one column. This is evidence of a specific functional value for the linear cell column provided due account is taken of the fact that adduction of the thigh in the rat must necessarily be allied with extension in the support of the extension thrust of the limb in locomotion.

The five cells of this series which are not in column D may be concerned with other actions in which the adductor muscle participates in a minor degree.

According to Wilson ('23) and Iden ('19), a single muscle is commonly supplied by more than one segmental nerve. The motor cells to the adductor longus do not extend over a segment. If this muscle is supplied by more than one segmental nerve the arrangement of the primary motor cells must be such that the axones diverge from the cord in the adjacent fila radicularia of the segmental nerves. I find no evidence of motor cells to the adductor longus segmentally placed.

Much more can be done regarding the locali-

zation of motor cells in the anterior gray by cutting particular types of muscles and muscle groups. Individual muscles of the fore limbs have much variety of function (deltoid muscle), and, according to the results of this investigation, they would undoubtedly be innervated by neurones located in several cell columns. Similar studies upon certain of longitudinal muscles of the back, which are functionally comparatively simple and are innervated by many segmental nerves, should give valuable information upon the question as to whether a given cell column represents the same type of functions in all levels of the spinal cord.

CONCLUSIONS.

1. The lumbar cord of the rat contains seven columns of motor cells in the ventral gray.

2. The degenerated cells of the sciatic nerve are located in the following motor cell columns: dorsolateral, dorsomedial, intermediolateral, ventrolateral, ventromedial, and median.

Intermedio-ventral

3. The motor neurones to the adductor longus muscles are for the most part in the dorsomedial portion of cell column D, and arranged in linear order.

4. Analysis of the grouping of the motor neurones as related to particular muscles, strongly suggests that each cell column represents a unit of function, such as flexion and extension.

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Figure I -

The outlines of the motor cell groups in the lumbar enlargement of the rat.

- A. Dorsolateral.
- B. Dorsomedial.
- C. Intermedio lateral
- D. Ventrolateral.
- E'. Intermediomedial.
- E. Intermedio-ventral
- F. Ventromedial.
- G. Median.
- J. Dorsal horn group.

Lumbar Cord - Cell Groups .

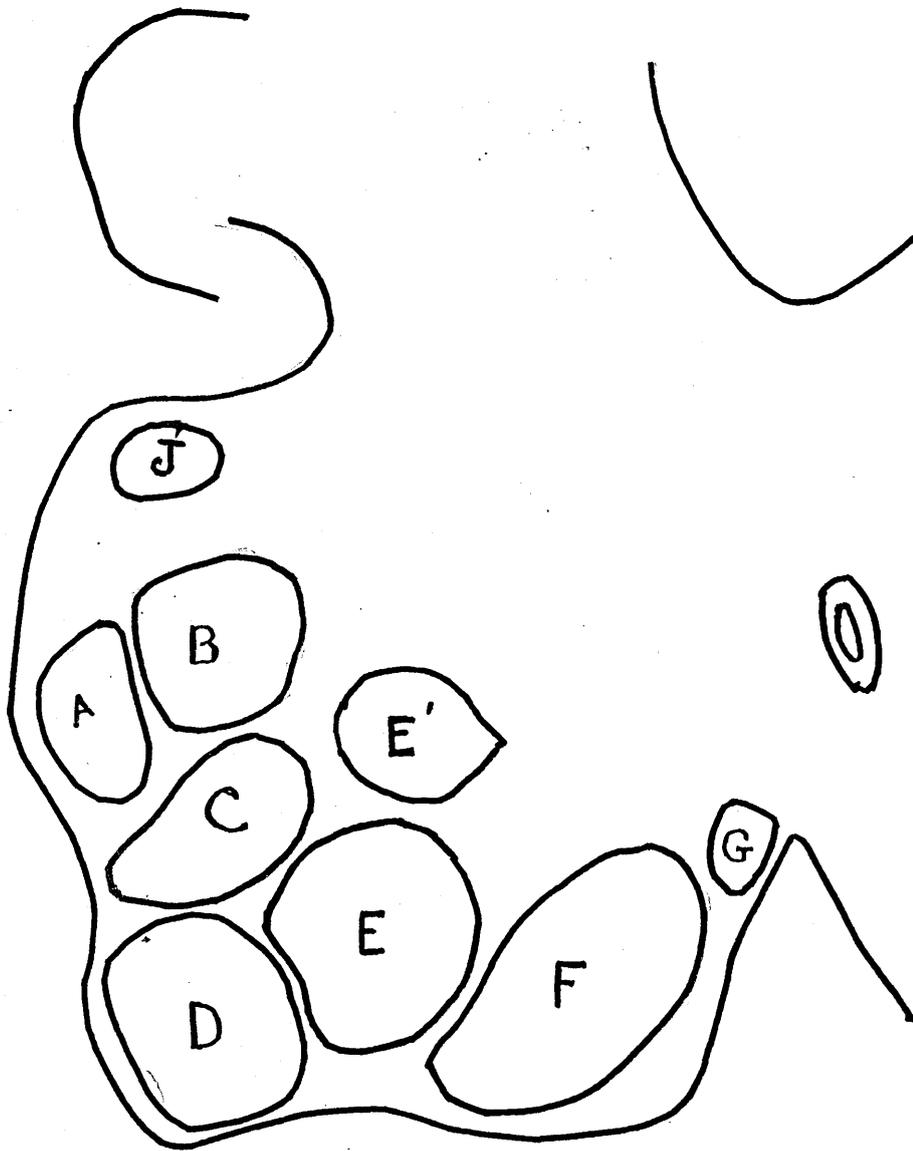


Figure 1

Figure II.

Each mm. square of the photographed chart represents, vertically, a section of the lumbar cord, and, horizontally, one degenerated cell in their respective column.

CASE A - SERIES I.

Column A -

- (a) Upper third; (b) section 320 - 360;
- (c) Section 412 - 474.

Column B -

- (a) Upper third; (b) Lower third.

Column C -

- (a) To section 72; (b) Section 86 - 230;
- (c) Section 189 - 375; (d) Section 375 --

Column D -

- (a) To section 47; (b) Section 75 - 172;
- (c) Section 192 ----.

Column E -

- (a) To section 72; (b) Section 89 - 171;
- (c) Section 191 - 460. Sub-divisions
- (r) Upper half; (s and t) Lower Half.

Column F -

(a) Section -- to 250; (b) Section 299 ---

Column G -

Two cells in lower two-fifths.

CASE B - SERIES II.

Column A -

(a) Section 50 - 170; (b) Section 330 - 380;

(c) Section 458 - 525.

Column B -

(a) Section 164 - 388; (b) Section 481 - 524;

Column C -

(a) To section 108; (b) Section 115 - 213;

(c) Section 215 - 460; (d) Section 460 ---

Column D -

(a) To section 100; (b) Section 100 - 200;

(c) Section 200 - 528; (d) Lower sixth.

Column E -

(a) To section 195; (b) Section 230 - 350;

(c) Section 364 ---

Column F -

(a) Lower two-thirds.

Figure 11

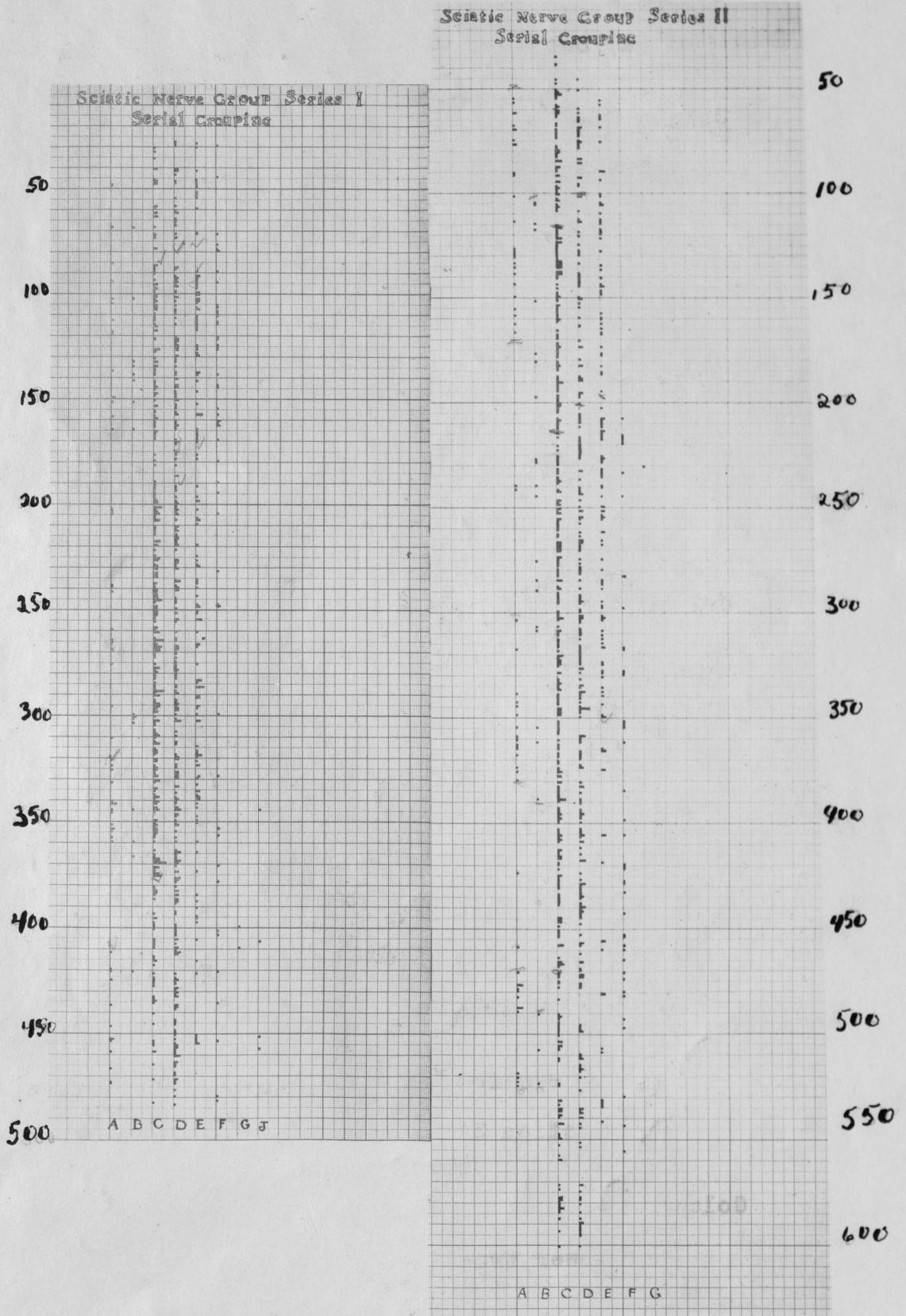


Figure III

Case A; Motor Cells of the Sciatic Nerve.

The number of degenerated motor cells in each column is given comparatively. Each mm. square of the chart represents two cells.

Figure III

Sciatic Nerve Group Series I. Number Cells in Groups.

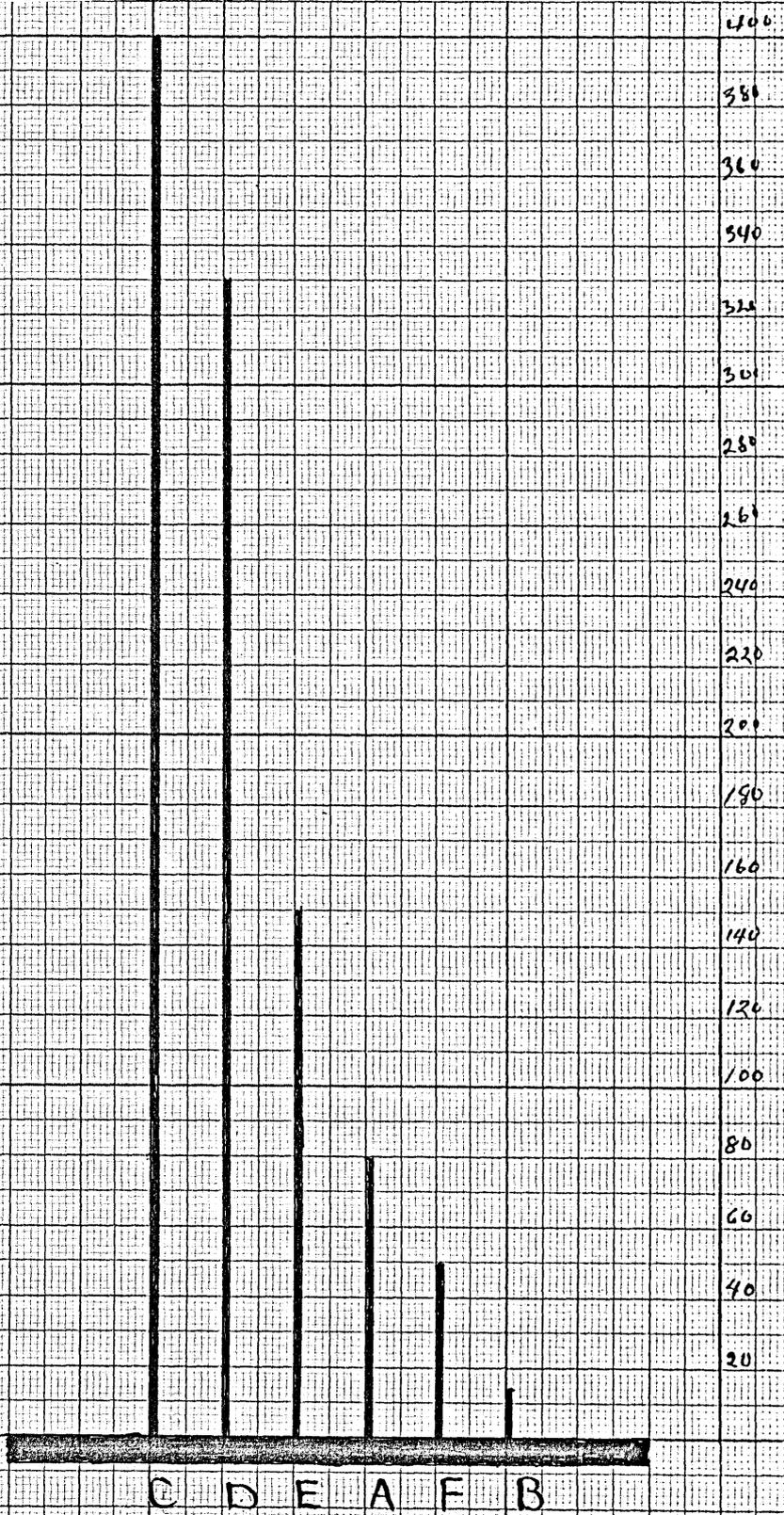


Figure IV

Case B: Motor Cells of the Sciatic Nerve.

The number of degenerated motor cells in each column is given comparatively. Each mm. square of the chart represents three cells.

Figure IV

Sciatic Nerve Group Series II

Number Cells in Groups

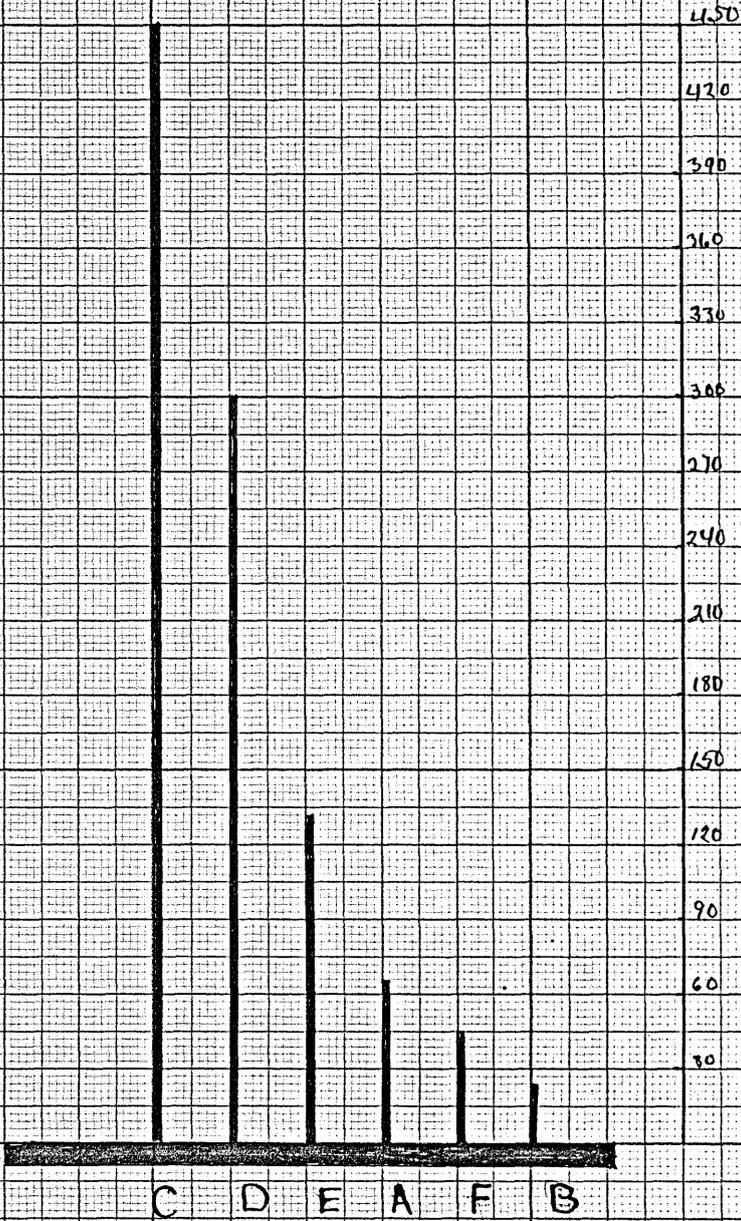


Figure V -

Adductor Longus Muscle.

Each mm. square of the chart represents, vertically, a section of the lumbar cord and, horizontally, one degenerated motor cell in their respective cell columns.

Column D -

First division - section 18-24.

Second Division - section 30-38.

Third division - section 49-61.

Fourth division - section 71-78.

Fifth division - section 81-83.

Sixth division - section 93-103.

Seventh division - section 126-148.

Figure V

Adductor longus Muscle Serial Grouping

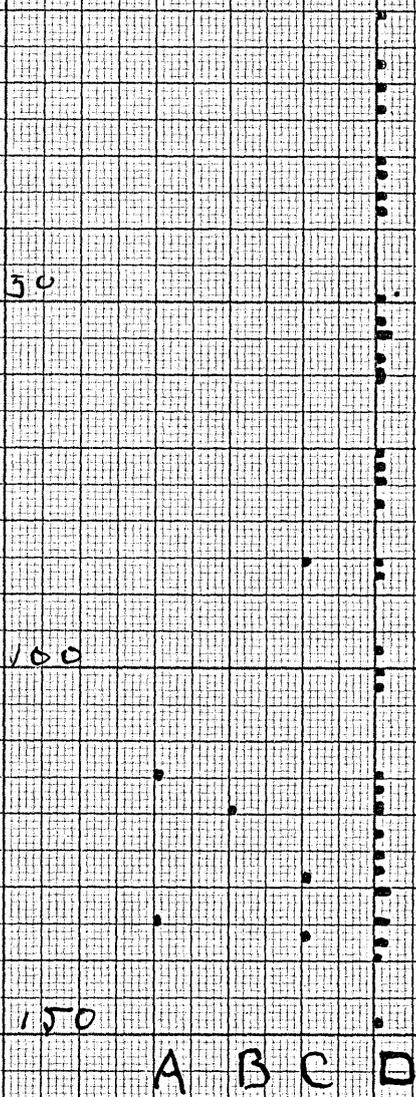


Figure VI

Adductor Longus Muscle.

The number of degenerated motor cells in each column is given comparatively. Each mm. square of the chart represents one cell.

Figure VI

Adductor Longus muscle

Number cell in groups

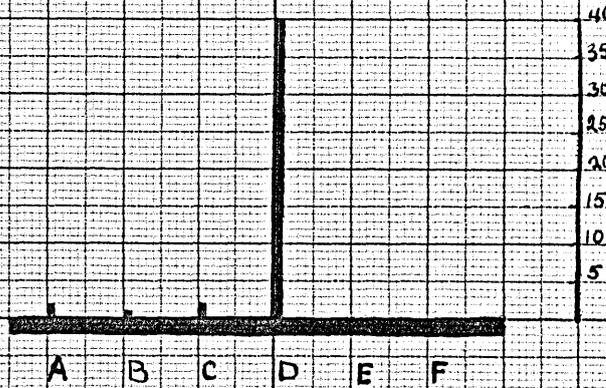


Figure VII -

Normal and degenerated motor cells.

A.

Normal Cell.

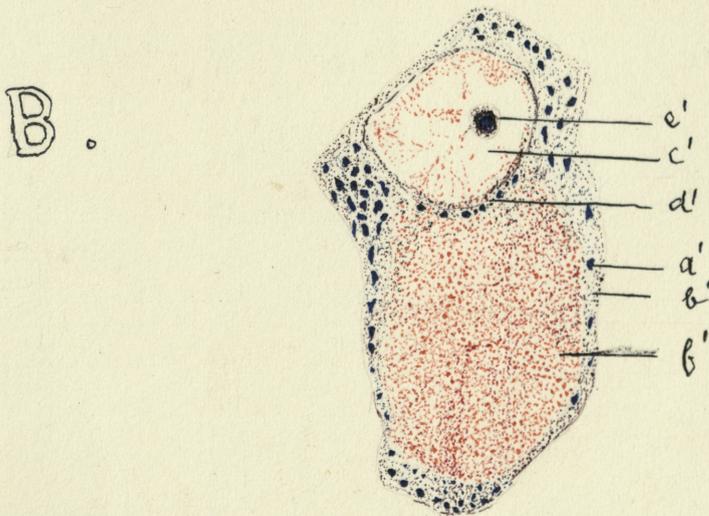
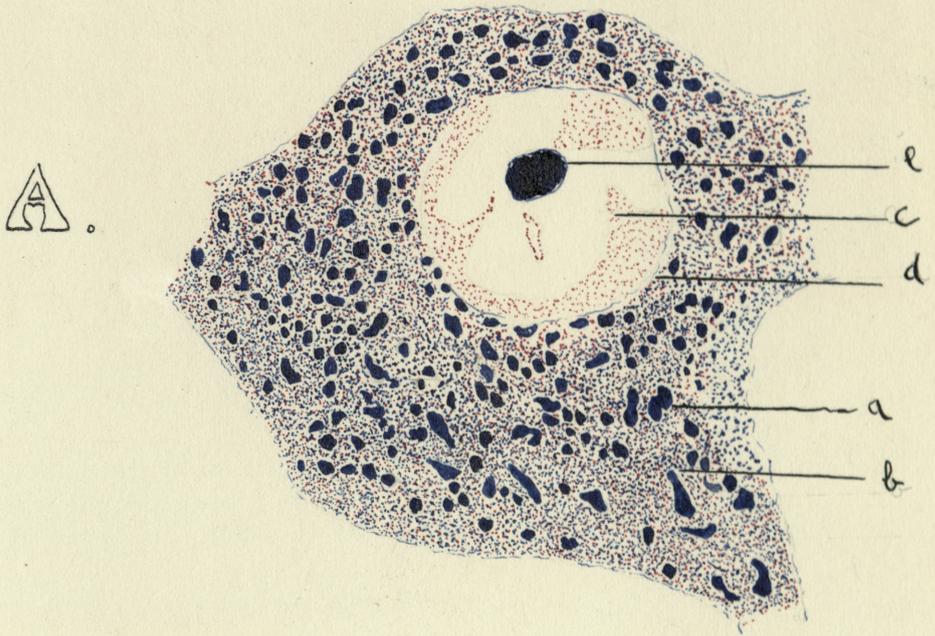
- (a) Nissl bodies.
- (b) Cytoplasm.
- (c) Nucleus.
- (d) Nuclear membrane.
- (e) Nucleolus.

B.

Degenerated motor cell.

- (a') Nissl bodies.
- (b') Cytoplasm.
- (c') Nucleus.
- (d') Nuclear membrane.
- (e') Nucleolus.
- (f') Chromatolytic area.

Figure VII



A Normal motor cell.

B Degenerated motor cell.