REGENERATION OF THE DORSAL ROOT FIBRES OF THE SECOND CERVICAL NERVE WITHIN THE SPINAL CORD.

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INTRODUCTION.

The object of the researches here described was to determine whether there is or is not, within the cord, regeneration of the fibres of the dorsal roots of the spinal nerves following the degeneration caused by injury to the roots between the spinal ganglion and the cord, and also to show the amount of this regeneration, if any should occur.

With this object in view experiments were conducted upon the second cervical nerve in the dog. The selection of this nerve was suggested by the following considerations: In the first place, the posterior root ganglion of the second cervical nerve in the dog lies normally outside the intervertebral foramen, so that experiments upon the roots are much easier and the risk of injuring the cord is much less than it would be were it necessary to open the vertebral canal. Moreover, the second cervical nerve in the dog is connected with the sympathetic system, not by a mixed ramus communicans, but by a gray ramus alone; a fact of some importance, as will be shown later.

Evidences of regeneration were sought for both by physiological and by histological methods. The present article deals with the physiological methods and the results obtained by them, while a discussion of the subject from a histological standpoint will appear later.

The literature of this subject is not extensive, and most of it dates from a period when the ideas concerning the relations of the nerve fibres and cells were less complete than at the present day. In the very brief summary of this literature that is here presented no especial attempt is made to criticise the older results in the light of newer knowledge, since our object is simply to call attention to the work previously done in this field. On the clinical side, so far as the writers can ascertain, no satisfactory cases are reported for man of regeneration and return of function after lesions involving the destruction of any part of the central nervous system. On the experimental side, the subject of regeneration in the cord or brain has been studied more carefully by histological than by physiological methods. The efforts made to prove by physiological means the possibility of regeneration have been limited mainly to observations upon the return of sensation or voluntary movement. The results are therefore less certain and more open to double interpretation than would be the case if more exact experimental methods had been employed.

H. Müller (1) cut off the tails of lizards and tritons and demonstrated that anatomical and physiological regeneration of the spinal cord in the regenerating tail may take place, although incompletely.

Masius and Vanlair (2) also obtained regeneration and return of function in frogs after excising pieces of the spinal cord. In some cases the regeneration was complete.

Voit (3) claimed a regeneration and partial return of function after removal of the cerebral hemispheres of a pigeon. This claim has probably been disproved by later experimenters, and the fact that in Voit's case the animal never ate voluntarily nor showed signs of fear indicates that the return of function was not more complete than in the cases of Schrader, in which the entire cerebrum was undoubtedly lacking.

Brown-Séquard (4) described a return of function after section of the cord in pigeons and guinea-pigs. In the former the return was complete, in the latter only partial.

Dentan (5), Eichhorst and Naunyn (6) and subsequently Eichhorst (7) described voluntary movements in dogs after section of the spinal cord. But viewed in the light of the work of Schiefferdecker (8) and of the careful description of reflex movements furnished by Freusberg (9), it seems not impossible that these movements were of a reflex character.

In connection with his interesting microscopical work, Kahler (10) made a few experimental observations. He crushed the dorsal roots of the sixth and seventh lumbar and first and second sacral nerves in young dogs. The resulting anæsthesia and loss of reflexes persisted, except that, after a few months, a hard pinch of the toes appeared to cause pain. It is difficult to understand this latter result without supposing that the crushed nerves again formed connections in the spinal cord.

It thus appears that in the lower vertebrates a certain amount of return of function can follow a lesion in the central nervous system, while it is not yet decided certainly whether any such return is possible among higher animals.

METHOD OF INVESTIGATION.

In our experiments we made use of the second cervical nerve and a short description of the anatomical relations of this nerve are given first, as it may make clearer the subsequent account of the results of the experiments.

The dorsal and ventral roots of the second cervical nerve, after uniting in the intervertebral foramen, pass together to the ganglion, which lies about 2 mm. external to the foramen. Beyond the ganglion the nerve trunk divides into a dorsal and a ventral branch. The former in turn divides into three main branches. The ganglion and the origin of these three dorsal branches lie on the ventral surface of the m. rect. cap. (posticus) major, and, as they curve around the lower border of this muscle, these branches begin to diverge from one another. The main branch, n. occip. magnus, has the following cephalad course: Over the ventral surface of the m. complexus, through the substance of this muscle, emerging close to the median line of the neck; thence over the superficial surface of the m. temporalis to terminate in the m. levator auris longior and the integument of the region about the ear. A second branch passes beneath the larger branches of the third cervical nerve, but without communicating with this nerve, and enters the m. complexus, where its finer ramifications anastomose with similar branches of the third cervical nerve. The third branch, after passing beneath the m. complexus, enters the m. splenius, where its ramifications also anastomose with those of the third cervical nerve.

The ventral trunk passes between the m. longus capitis and the m. longissimus capitis, and then internal to the m. sternocleido-mastoideus. It gives off communicating branches to the n. accessorius and divides into the n. auric. magnus and smaller branches, which are distributed to the lower part of the neck.

The method employed in experimenting on this nerve was as follows: The continuity of the dorsal root fibres was destroyed by ligation of the roots between the ganglion and the cord. The animals were allowed to live for a variable period after the operation so that the lesion might be followed by degeneration of all the nerve fibres entering the cord by the dorsal root, throughout their whole extent central to the point of ligation. After a period of not less than 88 days (the maximum being 151 days), the nerve was tested for return of function. Such a return would be indicated by the reflex variations in blood pressure, pulse rate and respiration, which might follow stimulation of the nerve in question. The nerve and cord were afterwards studied histologically.

As control experiments kymographic tracings were obtained, showing the variations due to stimulation of the second cervical nerve in two normal dogs. In one of these (Dog B) the roots were then ligated in the usual manner and the nerve again stimulated but with negative results. In all cases both the anterior and posterior roots were ligated, as it was impossible to separate them, a fact without significance in the experiment as only motor fibres occur in the anterior root.

Ligation of the roots.—The dog was etherized, the back of its neck shaved, well scrubbed and then washed with bichloride (1:1000). An incision was made about 8 cm. in length, extending from a point about 2 cm. above the protub. occipit. extern. down the mid-line of the neck. This incision passed through the skin and subcutaneous tissue, which were then retracted, exposing the n. occipit. magnus running to the ear. By separating and retracting the muscles and dividing the m. rect. capitis (posticus) major transversely, both the ganglion and the more central part of the nerve were exposed. After carefully freeing the roots from the surrounding tissue, a white silk ligature was passed around them and tied tightly. After a few moments the ligature was removed with a pair of fine, sharp scissors, leaving a constriction of the roots plainly visible at the point of ligation, the two parts of the nerve being united only by a tube of translucent connective tissue—the epineurium—while the continuity of the enclosed fibres was destroyed. The field of operation was then thoroughly irrigated with warm, sterile salt solution, except in the cases of dogs II and III, in which irrigation with bichloride (1:1000) preceded the use of the salt solution; the muscles were brought together with deep catgut sutures and the skin wound was closed with a continuous silk suture; the wound was painted with collodion and dressed with iodoform gauze and bandaged. In none of the cases did suppuration occur.

Test for regeneration.—No antiseptic precautions were observed. The dog was given a hypodermic injection of 0.05 gramme of the sulphate of morphia, and etherized; the trachea and carotid artery were connected with a tambour and a mercury manometer respectively, and these in turn were arranged to record upon a kymographion. A time recorder and a stimulating key also wrote upon the kymographion, so that the kymographic tracings were made to show four simultaneous records, namely, of the circulation, respiration, time, and duration of the stimulation.

The nerve, ganglion and roots were exposed as in the first operation, but greater difficulty was encountered owing to the presence of a considerable amount of scar tissue. In dogs A, I and II, the entire nerve was exposed before stimulating; in dogs B, III, IV, V, VI and VII, stimulations were made as the dissection advanced towards the ganglion.

The electrical stimulations were faradic and of varying strength; weak, moderate and strong. A weak stimulus was a current just perceptible on touching the electrodes to the tongue; a strong stimulus was a current painful to the tongue, and a moderate stimulus was of intermediate strength. Care was taken at each stimulation to prevent radiation through the surrounding tissues. In some cases mechanical stimulation was employed, which consisted in crushing the nerve with forceps, or in tightly ligating it.

After the desired data had been obtained, the animal was killed; the vertebral canal and cranial cavity were laid open with bone forceps; the brain and spinal cord, as far caudally as the sixth cervical nerve, were removed for histological examination. Great care was taken not to injure the brain and cord. The right second cervical nerve with its ganglion and roots was also removed for histological examination.

For the sake of clearness and convenience the results of the kymographic tracings have been tabulated (Table I). The table does not include the results of every stimulation, for where several stimuli in the same region gave identical results only one or two have been taken as examples. Also, all results have been discarded where it seemed possible that they were influenced by any accidents, such as bad electrodes, imperfect isolation of the nerve, etc. The results obtained with the two normal dogs (A and B) are so nearly identical that it has been considered sufficient to insert a single record (Dog A).

EXPLANATION OF TABLE I.

The figures in the column on the extreme left give the order of sequence of the stimuli. The second column states the part of the nerve stimulated. The third column gives the greatest amplitude of the respiratory curve in millimetres: (1) during the period of 10 seconds preceding stimulation, (2) during the period of stimulation, (3) during the period of 10 seconds immediately following the stimulation, and (4) during the succeeding period of 10 seconds. The fourth column gives the rate of respiration per 30 seconds during the same periods of time.

As it is often impossible to appreciate the relative values of small variations in the blood pressure, the approximate *average size* of the pulse waves for the period of 10 seconds preceding stimulation is given in column five. In columns six and seven the blood pressure in millimetres of mercury and the pulse-rate per 30 seconds have been recorded in the same manner and for the same periods as with the respiration. Columns eight, nine and ten state some of the characteristics of the stimuli. Sometimes it was impossible to determine the duration of a mechanical stimulus, and, in such cases, four periods, each of ten seconds duration, were taken in such a manner that stimulation begins with the first second of the second period. Such a procedure is denoted by an asterisk (*) in column ten. In column eleven the results of the stimulations are summed up; "positive" indicating that the stimulation produced reflex changes similar to those obtained with a normal dog; "negative" meaning that there were no appreciable reflexes.

From inspection of the table it appears that a more or less complete return of function occurred in every case, although in dogs IV and VI the reflex effects were very slight. Such an apparent return of function might be accounted for in several ways:

(1) *Imperfect destruction of continuity in the first operation.*—The possibility of this source of error is removed by the following experiments. After obtaining the usual effects of stimulation of the second cervical nerve of a normal dog (Dog B), the roots were ligated in the usual manner. Subsequent stimulation produced no effect whatever. Again in the case of Dog III, after giving the routine stimulations, the roots were ligated in the usual manner. Subsequent stimulations were without effect, and microscopical examination of the nerve showed a complete break in the continuity of the fibres at the point of ligation.

TABLE I.—Dog A. (Normal.)

No.	Part of nerve stimulated.	Respiration: Amplitude.	Respiration: Rate.	Circulation: Amplitude of Pulse wave.	Circulation: Blood pressure.	Circulation: Rate.	Stimulus: Kind.	Stimulus: Strength.	Stimulus: Duration.	Result.
1	*Occipitalis magnus.*	5 41 44 11	7 50 39 22	36	130 145 148 123	47 55 45 44	Electrical.	Moderate.	7 sec.	Positive.
2	Base of skull.	14 47 44 20	16 40 39 35	24	124 148 150 126	52 64 56 48	do.	do.	5 sec.	do.
3	2 mm. from ganglion.	4 34 32 2	6 53 68 11	30	120 150 151 131	36 57 49 37	do.	do.	4 sec.	do.
5		3 13 12 3	10 53 52 32	18	121 140 156 100	52 65 56 48	do.	Strong	7 sec.	do.

Dog I.

No.	Part of nerve stimulated.	Respiration: Amplitude.	Respiration: Rate.	Circulation: Amplitude of Pulse wave.	Circulation: Blood pressure.	Circulation: Rate.	Stimulus: Kind.	Stimulus: Strength.	Stimulus: Duration.	Result.
1	*Occipitalis magnus.*	2 31 32 10	.. 52 44 47	54	136 176 136 120	40 55 48 54	Electrical.	Weak	5.2 sec.	Positive.
2	Top of skull.	3 4 4 ..	31 25 24 ..	38	131 122 125 ..	45 43 43 ..	do.	do.	4.3 sec.	do.
3	Base of skull.	4 13 9 10	24 37 37 29	38	125 140 128 124	42 47 42 44	do.	do.	9.1 sec.	do.
5		10 32 13 10	21 40 48 48	30	122 138 132 118	48 56 49 54	do.	Strong	8.4 sec.	do.
6	15 mm. from ganglion.	7 9 9 9	27 30 27 29	26	131 132 128 127	53 52 47 52	do.	Weak	8.9 sec.	do.
7		8 10 9 6	26 29 28 21	24	126 132 128 126	50 50 48 48	do.	do.	9.3 sec.	do.
8		5 11 10 9	23 30 30 28	30	126 134 128 129	49 50 47 50	do.	Strong	9.1 sec.	do.

TABLE I.—*Continued.* Dog II.

No.	Part of nerve stimulated.	RESPIRATION. Amplitude.	RESPIRATION. Rate.	CIRCULATION. Amplitude of pulse wave.	CIRCULATION. Blood pressure.	CIRCULATION. Pulse rate.	STIMULUS. Kind.	STIMULUS. Strength.	STIMULUS. Duration.	Result.
13	*Occipitalis magnus.*	0 2 2 2	6 7 7 7	20	130 128 130 132	39 39 38 37	Electrical.	Moderate.	12 sec.	Negative.
14	Base of skull.	2 2 2 2	7 7 6 7	24	128 126 126 127	37 37 36 36	do.	do.	14 sec.	do.
11	3 mm. from ganglion.	0 3 3 2	9 8 6 3	14	106 109 114 117	45 45 45 45	do.	do.	12 sec.	do.
10	*Ganglion.*	3 13 16 10	8 25 34 18	16	122 131 132 110	42 41 45 47	do.	do.	12 sec.	Positive.
17		1 19 19 10	5 31 15 9	20	104 115 116 107	41 41 44 45	do.	do.	8 sec.	do.
18		2 22 22 12	8 39 24 8	16	114 124 106 114	41 42 41 40	do.	do.	8 sec.	do.
16	*Roots.*	2 15 15 6	7 23 12 5	20	116 124 122 114	39 39 40 41	do.	do.	10 sec.	do.

Dog III.

No.	Part of nerve stimulated.	RESPIRATION. Amplitude.	RESPIRATION. Rate.	CIRCULATION. Amplitude of pulse wave.	CIRCULATION. Blood pressure.	CIRCULATION. Pulse rate.	STIMULUS. Kind.	STIMULUS. Strength.	STIMULUS. Duration.	Result.
1	*Occipitalis magnus.*	1 1 2 2	6 6 7 7	22	126 121 120 119	59 53 53 52	Electrical.	Weak.	10 sec.	Negative.
2	Top of skull.	3 2 1 2	7 7 7 9	22	120 120 120 123	54 52 51 51	do.	Strong.	18 sec.	do.
19	25 mm. from ganglion.	15 28	42 47	7	115 166 142 100	90 84 89 95	Mechanic'l	Crush.	9 sec.	Positive.
21	15 mm. from ganglion.	11 36 30 18	19 44 48 52	7	126 164 110 94	89 . . 91 94	do.	do.	8 sec.	do.
6	4 mm. from ganglion.	4 3 4 4	12 12 12 12	18	95 97 97 97	57 60 55 57	Electrical.	Weak.	8 sec.	Negative.
8		4 4 5 5	11 12 12 12	14	103 107 106 106	66 68 69 67	do.	Strong.	7 sec.	. . ?
7	*Ganglion.*	4 4 5 5	11 12 12 12	20	96 97 97 97	59 60 60 62	do.	Weak.	10 sec.	Negative.
9		5 12 12 8	11 23 37 30	14	104 118 124 114	67 76 79 81	do.	Strong.	8 sec.	Positive.
10		4 22 15 4	19 40 36 41	8	118 123 120 102	89 87 87 92	do.	do.	5 sec.	do.

TABLE I.—*Continued.* DOG IV.

No.	Part of nerve stimulated.	RESPIRATION. Amplitude.	RESPIRATION. Rate.	CIRCULATION. Amplitude of Pulse wave.	CIRCULATION. Blood pressure.	CIRCULATION. Pulse rate.	STIMULUS. Kind.	STIMULUS. Strength.	STIMULUS. Duration.	Result.
1	*Occipitalis*	1 2 3 3	8 8 12 8	14	98 104 103 97	67 57 56 57	Electrical.	Weak.	5 sec.	Positive.
2	*magnus.*	3 2 4 3	8 9 9 11	14	100 105 106 111	53 59 51 51	do.	Strong.	6 sec.	do. ?
3	Base of skull.	2 2 1 1	13 14 10 11	16	104 108 109 106	53 53 49 51	Mechani'l.	Ligation.	10* sec.	do. ?
8	2 mm. from	1 1 1 1	17 17 15 16	7	56 58 58 58	98 96 95 96	Electrical.	Strong.	8 sec.	Negative.
19	ganglion.	1 1 1 1	18 17 18 16	6	63 61 61 60	89 90 90 90	do.	do.	7 sec.	do.
12	*Ganglion.*	1 1 1 1	16 18 19 18	6	58 57 59 61	94 95 93 95	Mechani'l.	Crush.	6 sec.	do.

DOG V.

No.	Part of nerve stimulated.	RESPIRATION. Amplitude.	RESPIRATION. Rate.	CIRCULATION. Amplitude of Pulse wave.	CIRCULATION. Blood pressure.	CIRCULATION. Pulse rate.	STIMULUS. Kind.	STIMULUS. Strength.	STIMULUS. Duration.	Result.
1	*Occipitalis*	1 1 1 1	32 32 33 30	38	132 133 132 133	35 35 38 33	Electrical.	Weak.	8 sec.	Negative.
2	*magnus.*	1 1 1 1	30 30 30 31	34	133 135 134 134	33 30 36 36	do.	Strong.	9 sec.	do.
3	Top of skull.	2 3 3 3	31 36 48 45	36	136 142 134 122	35 41 48 50	Mechani'l.	Crushing.	10 sec.	Positive.
4		3 8 14 4	45 48 57 52	20	122 142 130 ..	50 53 66 ..	do.	Ligation.	10* sec.	do.
5		1 1 1 1	26 28 25 24	64	154 155 154 153	31 32 32 30	Electrical.	Weak.	12 sec.	Negative.
6	Base of skull.	1 2 2 1	24 32 36 33	60	154 155 146 144	30 34 36 34	do.	Strong.	10 sec.	Positive.
9		1 1 1 1	23 21 25 23	56	143 140 140 140	30 31 30 30	Mechani'l.	Crush.	11 sec.	Negative.
18	2 mm. from	4 3 4 4	20 22 20 20	5	98 92 96 94	83 80 83 81	Electrical.	Strong.	11 sec.	Positive.
19	ganglion.	2 2 4 4	19 22 19 21	6	91 93 94 98	82 76 79 80	do.	do.	9 sec.	do.
17	*Ganglion.*	3 10 11 4	19 57 18 20	5	100 103 80 86	85 85 84 83	do.	do.	7 sec	do.
20		4 19 11 3	19 62 24 22	5	94 106 84 86	81 79 81 83	do.	do.	6 sec.	do.
25	*Roots.*	2 2 2 2	18 20 19 19	4	94 94 95 95	67 67 68 69	do.	Moderate.	9 sec.	Negative.

TABLE I.—*Continued.* Dog VI.

No.	Part of nerve stimulated.	Respiration. Amplitude.	Respiration. Rate.	Circulation. Amplitude of pulse wave.	Circulation. Blood pressure.	Circulation. Pulse rate.	Stimulus. Kind.	Stimulus. Strength.	Stimulus. Duration.	Result.
1	*Occipitalis*	2 2 2 2	15 17 17 17	14	118 119 119 119	60 59 59 59	Electrical.	Weak.	18 sec.	Negative.
3	*magnus.*	2 2 2 1	17 17 15 17	14	123 124 122 122	58 58 59 60	do.	Strong.	8 sec.	do.
4	Top of skull.	1 1 1 1	17 18 17 18	14	126 126 128 125	54 59 56 56	Mechani'l.	Crushing.	10 sec.	do.
7	2 mm. from	3 4 3 4	15 15 15 15	8	100 101 98 102	65 65 67 69	Electrical.	Strong.	5 sec.	do.
14	ganglion.	3 4 4 5	19 18 12 18	3	103 99 99 106	101 100 92 92	do.	do.	13 sec.	Positive.
15		4 4 4 3	18 18 19 18	3	107 107 107 107	96 98 93 95	Mechani'l.	Crushing.	10* sec.	Negative.
8	*Ganglion.*	4 4 4 3	15 17 17 15	5	102 97 106 106	78 78 81 71	Electrical.	Weak.	10 sec.	Positive.
13		4 4 4 4	20 20 20 18	3	101 92 100 103	100 98 98 99	do.	Strong.	16 sec.	do.
18	*Roots.*	6 4 6 7	15 12 14 13	2	111 111 106 114	102 90 89 85	do.	Weak.	14 sec.	do.
19		7 4 5 6	20 16 16 15	2	114 103 113 115	90 91 96 84	do.	do.	13 sec.	do.

Dog VII.

No.	Part of nerve stimulated.	Respiration. Amplitude.	Respiration. Rate.	Circulation. Amplitude of pulse wave.	Circulation. Blood pressure.	Circulation. Pulse rate.	Stimulus. Kind.	Stimulus. Strength.	Stimulus. Duration.	Result.
1	*Occipitalis*	10 9 7.5 6	30 27 28 25	2	169 169 175 173	75 72 75 76	Electrical.	Weak.	14 sec.	Negative.
2	*magnus.*	7 7 8 6	21 22 23 21	2	172 173 171 173	76 78 73 73	do.	Strong.	14 sec.	do.
3	Base of skull.	6 7 6 ..	23 18 18 ..	2	173 174 174 ..	75 71 70 ..	*Mechanical*	*Forceps.*	14 sec.	do.
5	2 cm. from ganglion.	8 14 14 12	12 17 19 18	2	140 152 156 152	93 92.1 93 96	Electrical.	Weak.	14 sec.	Positive.
12	1 cm. from	1 28 16 0	13 54 39 ..	1	156 184 118 146	117 117	do.	do.	47 sec.	do.
7	ganglion.	13 32 46 33	9 74 43 38	1	142 146 144 138	.. ..	do.	do.	9 sec.	do.
10	*Ganglion.*	3 33 38 29	12 70 45 34	1	149 172 122 127	.. ..	do.	do.	12 sec.	do.
11		1 27 23 0	13 71 24 0	1	142 181 112 131	117 .. 115 117	do.	do.	7 sec.	do.

(2) *Anastomosis with neighboring nerves.*—The above mentioned experiments on Dogs B and III also show that although the finer ramifications of the second cervical anastomose with the third cervical and with the accessorius, still, it is not possible for impulses to pass from the second cervical nerve to the cord through either of these connections.

(3) *Radiation to the cord through the surrounding tissues.*—This also appears highly improbable, for in every case the nerve was dissected out and retracted from the surrounding tissues before the electrodes were applied; and in the case of the ganglion, where such retraction was impossible, many of the stimulations especially with strong currents were accompanied by control stimulations of the surrounding tissues, and always with negative results.

(4) *Transmission of the impulses through the dorsal root of the nerve stimulated.*—This is considered the only possible explanation for the results obtained. Such a return of function in the dorsal roots can occur only in two ways. The root may be regenerated by fibres having their trophic centres within the cord; or secondly, by fibres having their trophic centres outside the cord. It is the usually accepted view that no sensory fibres are derived from cells within the cord, nevetheless it seems advisable to call attention to the work which goes to prove that the dorsal root of the nerve in question does not contain such fibres. This will be especially useful for reference in the section on histology.

In the chick of four to eleven days' incubation, it has been abundantly proved by von Lenhossék (12), Cajal (13), van Gehuchten (14) and Retzius, that fibres arising from a group of cells situated in the ventral horn, after running dorsally and entering the dorsal root, pass directly through the root ganglion without communicating in any way with the ganglion cells. Kölliker (15) is of the opinion that they are vaso- and viscero-motor fibres on their way to the sympathetic system. Up to the present time, however, no observer has been able to demonstrate microscopically the occurrence of such fibres in the mammalia.

According to the original observations of Waller (16) the trophic centres of all the fibres of the dorsal root are the spinal ganglion cells. Vejas (17) and Joseph (18) stated that they found undegenerated fibres in the proximal part of sectioned dorsal roots, but no one has been able to confirm their observations. On the contrary, Waller's experiments have been repeated and his results confirmed by Bernard (19), Kahler (20), and more recently by Singer and Münzer (21). Sherrington (22) observed such "undegenerated fibres" in the cat, but he gives excellent reasons for believing that they are "embryonic fibres" (23) and not undegenerated fibres.

It might be claimed that splanchnic efferent fibres occur in the dorsal root (24, 25) of the second cervical nerve, as is probably the case with some of the lumbar and sacral nerves. It has been demonstrated, however, by Gaskell (26) and Langley (27) that the splanchnic efferent fibres traverse the white and not the gray rami communicantes. They have also shown that the second cervical nerve in the dog is connected with the sympathetic system (sup. cerv. gang.), not by a mixed ramus communicans, but by a gray ramus alone (28), the rami viscerales of the upper cervical nerves (as well as of the vagus) being represented by the internal branch of the accessorius.

With regard to the occurrence in the second cervical nerve of trophic fibres to the skin, it may be stated that although ligation was performed on both roots of the nerve in seven dogs, no trophic disturbances resulted in the area supplied by the nerve such as Joseph (29) has described in the cat.

Such fibres, moreover, whether splanchnic-efferent or trophic, would not give reflex effects on stimulation, inasmuch as they would be efferent fibres, and the fact that they probably do not exist is therefore of importance only in relation to the subsequent histological study of the cord and nerve.

Hence it is a justifiable conclusion that this dorsal root contains only such fibres as have their trophic centres situated outside the cord, and consequently the presence of root fibres on the central side of the point at which the continuity of the fibres has been destroyed is proof of a regeneration from the ganglion to the cord, and any return of function is a proof of regeneration of those fibres, both in the root and within the cord itself.

As has been said, a more or less complete regeneration occurred in every case. The character of the regained functional activity varied considerably in the different cases. In some the respiratory effects preponderated, in others the circulatory.

As a commentary to the tables and as a means of calling attention to numerous interesting facts shown by them, the following summary of results is given:

Dog. A (normal). The *amplitude* and *rate of respiration, blood pressure,* and *pulse rate* were in all cases markedly *increased* by stimulation of the second cervical nerve.

Dog I. The *increase* in the *amplitude* of the respiratory curve was as great as in the normal dog (Dog A). The effect on the *rate of respiration* was *variable,* but usually an acceleration was observed. There was a *rise of blood pressure* during the period of stimulation and the *pulse rate* was, in general, *accelerated,* especially during the earlier stimulations.

Dog II. The respiration was but little affected by stimulation of the peripheral nerve, but stimulation of the ganglion and roots caused about as great an *increase* in the *amplitude* as in Dog A, while the *acceleration of rate,* although marked, was proportionally less than in A. Stimulation at the periphery caused very little change in the *blood pressure;* nearer the ganglion a slight *rise,* while at the ganglion and roots the *rise* was pronounced. The *pulse rate* showed little or *no variation.*

Dog III. A *rise* of *blood pressure* occurred with mechanical stimulation of the peripheral nerve and with strong electrical stimulation at and near the ganglion (No. 8), the last being the least marked. Other stimulations caused no variation in blood pressure. The effect on the *pulse rate* was *inconstant.* The *amplitude* and *rate of respiration increased* with the blood pressure, except in case of No. 8, in which no variation occurred.

Dog IV. The *respiration* remained throughout *unaffected.* The *blood pressure* was *slightly raised* by the first three stimulations, after which stimulation produced no effect. The *pulse rate* was altered in the first three cases only. These were stimulations of the peripheral nerve, of which two caused a *slowing* and one an *acceleration* of the pulse rate.

Dog V. The *rate* of respiration was *increased* by mechanical stimulation of the peripheral nerve near its distal end, strong electrical stimulation of the same at the base of the skull, and strong electrical stimulation at the ganglion. In the two last cases the *amplitude,* which elsewhere remained unaffected, was *increased.* The *blood pressure* varied under the same conditions as the rate of respiration, this variation consisting in a *fall* or less frequently a *rise.* The *pulse rate* was affected (*accelerated*) only in the cases of mechanical and strong electrical stimulation of the peripheral nerve.

Dog. VI. The *respiration* remained *unchanged,* except in No. 14. The *blood pressure* was not appreciably influenced by stimulation of the peripheral nerve except in one case (No. 14), but stimulation of the ganglion and roots caused a *fall followed by a rise* to or above the normal. There was a *slowing* of the *pulse* in two cases (Nos. 14 and 18), but otherwise no change occurred.

Dog VII. Stimulation of the more peripheral part of the nerve produced no effect. Stimulation of the nerve near the ganglion, of the ganglion itself and of the roots, caused a marked increase in the *amplitude* and *rate* of respiration. The rise of *blood pressure* was in some cases very marked and usually followed by a fall. The counting of the pulse rate was prevented by the fact that the great oscillations in pressure caused by the violent respirations obscured the pulse record.

The condition of the nerve trunk peripheral to the ganglion was in several instances abnormal, especially in the more peripheral parts of its course. (1) It was in some cases of a dull, opaque, grayish-white appearance (Dogs II, III and VI), and in one case (Dog VI) the ganglion was swollen, elongated and bound down by adhesions. (2) It often responded, not to electrical, but only to mechanical stimuli (Dog III, Nos. 19, 20; Dog V, Nos. 3, 4). (3) It often responded only to the first few stimulations, soon losing its irritability (Dog V, Nos. 3, 4, 9).

All these facts point to a recent regeneration of the peripheral nerve (30). The primary degeneration in the nerve trunk peripheral to the ganglion, which this implies, was considered to be due to the contraction of the scar tissue following the first operation, for this scar tissue, as has been stated, was often quite abundant in the region of the old wound.

When the stimulus was applied to the nerve peripherally to the ganglion, it was often impossible to distinguish between the effects due to recent regeneration of the peripheral nerve and those due to recent regeneration of the root. If, however, a comparison be made of these results with those obtained by stimulating the ganglion or roots, there will be no chance of confusing results due to peripheral with those due to more central regeneration. The condition of the peripheral nerve and of the root, their reaction to stimuli and certain other data of interest and importance are stated in the following table (Table II).

TABLE II.

Dog.	Approximate age.	Intervals between first and second operation.	Scar tissue found at second operation.	Appearance of peripheral nerve.	RESULTS OF STIMULATION.			
					Peripheral.	Nearer ganglion.	Ganglion.	Roots.
		Days.						
I.	Adult.	90	Much.	Normal.	+ e	+ e	..	..
II.	About 6 mo.	92	Much.	Abnormal.	— e	— e	+ e	+ e
III.	About 6 mo.	88	Much.	Abnormal.	+ m, — e	— e	+ e	..
IV.	Adult.	90	Moderate.	Normal.	— m, — e	— m, — e	— e	— e
V.	Young adult.	89	Moderate.	Normal.	+ m, — e	— m (later)	+ e	— e (later)
VI.	About 6 mo.	151	Moderate.	Abnormal.	— m, — e	— m, — e	+ e	+ e
VII.	About 6 mo.	109	Much.	Normal.	— m, — e	+ e	+ e	+ e

e = with electrical stimuli.

m = with mechanical stimuli.

— = negative results.

+ = positive results. For example: + e = positive results with electrical stimuli.

From the results of the experiments described above we feel justified in concluding, that *after severance of the fibres of the dorsal root of the spinal nerves between the ganglion and the cord, regeneration of the fibres into the cord will take place under proper conditions, so that normal reflexes through the respiratory, cardiac and vasomotor centres may be obtained.*

As to the completeness of the regeneration and the average time necessary for the restoration of function, it is not possible for us to speak positively, owing to the small number of our experiments. The results of the seven experiments indicate that there may be great individual differences in the rapidity of regeneration. In some cases the return of functional activity in the dorsal root fibres seemed to be nearly complete at the end of 90 days, while in one case the return was far from complete after an interval of 151 days.

We may add in conclusion that if the posterior root fibres can thus be regenerated in the posterior columns of the cord, there seems reason to hope that the fibres in other tracts may possess the same property, and that therefore it is not impossible that with the proper technique a severed spinal cord might be made to regenerate its broken tracts both ascending and descending.

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