to X-rays at temperatures up to a dull red heat. There is usually color change as mentioned under (6) and a distinct maximum of brightness at some intermediate temperature.

1 In this statement reference is to established cases of luminescence. Exception is made of the rather numerous instances in which radiation of an unusual character is ascribed to luminescence without actual demonstration of the fact. The present author more than once has made such assumptions and believes them likely to be verified.


FUNCTIONAL REGULATIONS IN ANIMALS WITH COMPOSITE SPINAL CORDS

By S. R. Detwiler

Peking Union Medical College, Peking, China

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In several recent series of experiments,1 involving the transplantation of the forelimb in Amblystoma embryos, a number of points were brought out by the author bearing upon the question of the functional readjustment of the peripheral nervous system in response to the altered conditions. The cardinal points may be summarized as follows:

(1) When the limb is transplanted to an abnormal (heterotopic) position, there is a striking tendency for its innervation to be derived from the original limb level of the cord, and only when this is totally or in part accomplished, is the limb capable of movements which are well coordinated with those of the opposite intact appendage.

(2) Transplanted limbs which are not supplied by the normal limb nerves exhibit a degree of function which is directly correlated with the region of the spinal cord from which the nerves are derived. The motility of the appendage is more perfect when its nerves come from segments of the cord adjoining those which contribute the normal limb nerves.

(3) The gradual loss of function as limbs are transplanted further and further away from the normal situation is attributed to increased defective connections within the central nervous system and not to a corresponding decrease in effective peripheral efferent innervation nor to deficiencies in in the skeleto-muscular mechanism of the limb and the shoulder girdle.

(4) Peripheral nerves supplying a transplanted limb are larger than their counterparts which have no connection with a limb. Critical examination has shown this enlargement to be due to a hyperplasia of the afferent neurones with no evident over-production of cells on the motor side.

The fact that structurally complete transplanted limbs with an adequate peripheral nervous mechanism, derived from the extra-limb level
of the cord, are capable of adaptive movements led to the inference above
given, namely, that the defective motility is due to a corresponding in-
adegacy of central connections and not to any rigid specific relation be-
etween certain nerves and a given group of muscles. Further, the general
failure of the motor centres to undergo hyperplastic regulation such as
occurred in the sensory centres under the conditions of increased func-
tional demands at the periphery, led to the view that factors other than the
peripheral requirements must be sought for in the solution of motor read-
justment.

In the light of these considerations, the experiments which are herewith

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**Explanation of Figures**

(1) Reconstruction model showing the sensory (sr) and motor (mr) roots of the right
eighth spinal nerve, the spinal ganglion (sg), and the corresponding level of the spinal
cord (sc) × 180. Nerve not connected with limb. Case TrSc 137.

(2) Reconstruction model showing the enlarged senso-motor apparatus of the right
fourth spinal nerve (originally eighth of another animal and transplanted into the limb
level of the host) × 80. Nerve connected with limb. Case TrSc 137.

briefly reported were carried out. They consisted in removing that
portion of the spinal cord from which the normal brachial plexus is derived
(third, fourth and fifth segmental nerves) and transplanting into the ex-
cised area a more posterior portion of the spinal cord of another embryo
that normally gives origin to the seventh, eighth and ninth segmenta
nerves. These latter nerves, in their normal position, are capable of pro-
ducing but very limited movements when innervating transplanted
limbs. The limb rudiments were left intact.

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In the present experiments the grafted unit of spinal cord, carrying with it the neuroblastic forerunners of the seventh, eighth and ninth peripheral nerves, is subjected to all the factors which normally produce the increased proliferation of nerve cells in the limb region, and the resultant degree of development of its neurone components under these conditions can be compared directly with the undisturbed seventh, eighth and ninth segments of the host.

The experiments were carried out on Amblystoma embryos ranging in age from those with completely closed medullary folds (stage 21) up to those with a prominent tail bud (stage 33), a stage just preceding that in which primary reactions first appear. Although the survival of the embryo appears to have no correlation with its age at the time of the operation, the percentage of normal results, both structural and functional, is clearly a function of the age of the embryo and the most normal results were obtained from embryos in the stage of closed neutral folds (table 1). The operated animals were reared in individual aquaria and the majority were kept under daily observations for from 60 to 75 days.

The effects of the transplantation upon the development of the embryo, the initial swimming reactions, and the functional behavior of the limbs are given in table 1. The bearing of these experiments upon the question of healing and regeneration of the spinal cord, and upon the development of the primary swimming reflexes in the light of the work of Herrick and Coghill, will be considered later.

The observations made on the living operated animals showed that the limbs in fifty per cent of the cases performed normal adaptive and coordinated movements (table 1). The movements of the remainder were partially impaired. The defects in these consisted mainly of (1) imperfect flexion of both arm and forearm, and (2) extensor paralysis of the wrist. Only two animals of the series have been sectioned thus far (cases TrSc 90 and TrSc 137), in both of which the limbs functioned normally. A microscopic study of sections from these animals showed the presence of a perfectly developed brachial plexus with normal intrinsic nerve distribution, derived from the grafted portion of the spinal cord (seventh, eighth and ninth segments). Not only were the transplanted segmental nerves found to be larger than the undisturbed seventh, eighth and ninth nerves of the host, with which they can be directly compared, but also the cord itself and the spinal ganglia showed distinct hyperplasia of the nerve cells (table 3, A2 and B2), thus indicating that the hypertrophic development was due to excessive proliferation of the neuroblasts rather than to a compensating increase in the volume of a specific number of cell bodies and their axones.

The increased development of the motor and sensory contributions to the fourth nerve (originally the eighth) is shown in figure 2 and also in table 2. In the latter are given the weights and the weight ratios of unas-
### Table 1

<table>
<thead>
<tr>
<th>STAGE OF DEV. WHEN OPERATION WAS PERFORMED</th>
<th>NO. OF OPERATIONS</th>
<th>POSITIVE EXPERIMENTS</th>
<th>NORMAL RESULTS</th>
<th>ABNORMAL RESULTS</th>
<th>INITIAL REACTION</th>
<th>LIMBS WITH PERFECT FUNCTION</th>
<th>LIMBS WITH IMPERFECT FUNCTION</th>
<th>LIMBS WITHOUT FUNCTION</th>
<th>AV. NO. OF DAYS AFTER REACTION BEGAN</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cases</td>
<td>%</td>
<td>Cases</td>
<td>%</td>
<td>Cases</td>
<td>%</td>
<td>Cases</td>
<td>%</td>
<td>Cases</td>
</tr>
<tr>
<td>21–23</td>
<td>40</td>
<td>6</td>
<td>15</td>
<td>0.0</td>
<td>11</td>
<td>6</td>
<td>9</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>25–27</td>
<td>100</td>
<td>14</td>
<td>14</td>
<td>0.0</td>
<td>7</td>
<td>8</td>
<td>4</td>
<td>73</td>
<td>4</td>
</tr>
<tr>
<td>29–33</td>
<td>60</td>
<td>9</td>
<td>15</td>
<td>0.0</td>
<td>2</td>
<td>33</td>
<td>2</td>
<td>33</td>
<td>0</td>
</tr>
<tr>
<td>29*</td>
<td>60</td>
<td>9</td>
<td>15</td>
<td>0.0</td>
<td>2</td>
<td>33</td>
<td>2</td>
<td>33</td>
<td>0</td>
</tr>
</tbody>
</table>

* Nine cases of the positive experiments were preserved before the period when limb reactions normally begin.
### TABLE 2
Showing the Relative Weights of the Sensory and Motor Components of the 4th and 8th Segmental Nerves (Weight of Model in Grams)

<table>
<thead>
<tr>
<th></th>
<th>Sensory Root</th>
<th>Motor Root</th>
<th>Spinal Ganglion</th>
<th>Total</th>
<th>Cell Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fourth nerve* (connected with limb)</td>
<td>1.3</td>
<td>4.3</td>
<td>14.5</td>
<td>209.6</td>
<td>97.3</td>
</tr>
<tr>
<td>Eighth nerve (not connected with limb)</td>
<td>0.3</td>
<td>1.1</td>
<td>5.1</td>
<td>121.5</td>
<td>50.9</td>
</tr>
<tr>
<td>Weight ratios</td>
<td>3.5</td>
<td>3.7</td>
<td>2.8</td>
<td>1.7</td>
<td>1.9</td>
</tr>
</tbody>
</table>

* The fourth nerve was developed from a transplanted portion of the spinal cord which normally gives rise to the eighth nerve.

### TABLE 3
Showing the Number of Cells Counted in (a) 10 Consecutive Transverse Sections in the Right Half of the Spinal Cord Anterior to the Exit of the 4th and 8th Nerves, and (b) in the 4th and the 8th Right Spinal Ganglia

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Level of 4th Nerve (Connected with Limb)</th>
<th>Level of 8th Nerve (Not Connected with Limb)</th>
<th>Ratios</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) Normal</td>
<td>1750</td>
<td>930</td>
<td>1.881</td>
</tr>
<tr>
<td>(2) 7, 8 and 9th spinal segments substituted for the 3, 4 and 5th..</td>
<td>1300</td>
<td>824</td>
<td>1.577</td>
</tr>
<tr>
<td>(3) Limb excised (spinal cord intact)</td>
<td>1580</td>
<td>890</td>
<td>1.775</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>4th Right Spinal Ganglion</th>
<th>8th Right Spinal Ganglion</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) Normal</td>
<td>1430</td>
<td>685</td>
</tr>
<tr>
<td>(2) As in A2</td>
<td>1860</td>
<td>945</td>
</tr>
<tr>
<td>(3) As in A3</td>
<td>685</td>
<td>720</td>
</tr>
</tbody>
</table>
sembled blotting paper models of the component parts of both fourth and eighth nerves, the former of which is in connection with the limb. Both motor and sensory roots of the fourth nerve (transplanted eighth) have undergone striking enlargement under the conditions which normally produce the increased proliferation of those centres in the limb region.

The hyperplastic development of the sensory centres, secondarily brought into connection with a transplanted limb, has been shown in recent experiments, although no over-production of motor cells could be found. Under the conditions of the present experiments the nerve cells in the transplanted portion of the cord, which has been subjected to the factors normally producing the brachial enlargement, have undergone a degree of development, as indicated by a cell count, which almost equals that of the normal (table 3A, 1 and 2). The hyperplasia of the motor cells, however, under these conditions is evidently not the result of the functional activity of the limb with which the nerve is connected, for in the absence of the limb the production of cells in the limb level of the spinal cord is almost as great as under normal conditions (table 3A, 1 and 3).

The possibility that the ingrowth of the axones of a given number of peripheral afferent neurones might determine the extent to which the motor centres will develop, is negated by the facts obtained from previous limb experiments, which show that a certain degree of both hypoplastic and hyperplastic development of the sensory neurones in a given reflex pathway can be induced experimentally without effecting a corresponding measure of development on the motor side.

The evidence thus far obtained indicates, therefore, that the factor which is involved in the over-production of the motor cells is the stimulus afforded by the connection with the central neurones (bulbo-spinal fibers), a large number of which very likely run only as far as the limb level where they discharge into the appendicular motor centres.

This preliminary report will be followed by a detailed account of the experiments, as well as a discussion of the results bearing more particularly upon the factors involved in the growth phase of nervous development.

1 Detwiler, S. R., (a) These Proceedings, 5, 1919 (324–331); (b) Ibid., 6, 1920 (96–101); (c) J. Exp. Zool., 31, 1920 (117–169).
2 See 1 (c) pp. 142–147, series AS5 and AS6.
3 An account of healing and regeneration of the spinal cord in frog embryos is given, by Hooker, D., in the following papers: (a) J. Comp. Neur., 25, 1915 (469–495); (b) 27, 1917 (421–449).
5 See 1 (b).
6 See 1 (b), pp. 96–98.