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ATLAS OF CONSECUTIVE STAGES IN THE RECONSTRUCTION OF THE NERVOUS SYSTEM

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BANNERSTONE HOUSE

301-327 East Lawrence Avenue, Springfield, Illinois, U.S.A.

Published simultaneously in The British Commonwealth of Nations by

BLACKWELL SCIENTIFIC PUBLICATIONS, LTD.,
OXFORD, ENGLAND

Published simultaneously in Canada by

THE RYERSON PRESS, TORONTO

First Edition, First Printing, 1953
First Edition, Second Printing, 1956
First Edition, Third Printing, 1957

Printed in the United States of America

INTRODUCTION

The illustrations represent consecutive stages in the reconstruction of the nervous system based on the method described by Meyer (1), Meyer and Hausman (2, 3), and Hausman (4). As the model was built, photographs were taken of the various stages and then converted into pen and ink drawings by Miss Zelda Oser. The reconstruction was made from the serial sections contained in the Atlases of the Spinal Cord and Brainstem and the Forebrain (4). It is four times the natural size of the brain.

The illustrations are so arranged that in a ventral view the right side of the nervous system is on the left side of the page. Each illustration emphasizes a new part which has been added to the preceding figure. As each system appears for the first time, its color scheme is indicated in the legend so that it can be colored accordingly and thus further stressed. Most of the illustrations are model size; a few are reduced as noted in the legends.

THE PRINCIPLE AND ARCHITECTURAL PLAN OF THE RECONSTRUCTION. The reconstruction follows a logical architectural scheme, one based on the precise plan of development which the evolution and embryology of the nervous system reveal. Without the phylogenetic and embryological studies the structure and functions of the nervous system cannot be easily understood.

The study of comparative neuroanatomy discloses the fundamental principle that the nervous system as it expands in ascending forms is put down in layers which reflect the phylogenetic development of the animal. As the nervous system unfolds in each succeeding phylum (from the invertebrates to the vertebrates) new layers appear and are added to the older ones of the preceding type. This arrangement, in a general way, resembles the concentric rings in the trunk of a tree as seen on cross-section; the oldest ring lies in the center, the most recent at the periphery, the intervening ones representing the corresponding stages of development.

Likewise, in the nervous system, the oldest layers lie in the center around the lumen of the neural tube; in the spinal cord, around the spinal canal; in the brainstem, around the ventricle and aqueduct. Those layers which are more recently acquired lie nearer the surface; the most recent, like the pallium, forming the bark or cortex right on the surface of the brain.

The study of the embryology of the nervous system in man is very rewarding for it provides a succinct recapitulation of its phylogenetic development. The unfolding of the nervous system in terms of layers is clearly reflected in the maturation of its various parts. As the human embryo develops, the old neural structures are differentiated earlier than the new ones. For that reason, the different systems can be logically studied and conveniently reconstructed in the sequence of their development. This brings into focus the physiological significance of the various systems in the order of their appearance and thus leads to a better understanding of the functions of the nervous system as a whole.

In discussing and reconstructing the nervous system, consideration is therefore given at the outset to the oldest layer. The latter appears in the center and forms the core of the nervous system in all forms. It is the foundation on which the whole nervous system is erected. In the reconstruction, therefore, it is the first part to be built. It comprises those structures which develop early phylogenetically and embryologically, namely, the efferent peripheral cerebrospinal nerves and their nuclei of origin.

The efferent cranial nuclei lie in the motor plate or reticular substance of the brainstem (Fig. 3). The efferent spinal nuclei lie in the motor plate formed by the ventral and lateral horns of the spinal cord. This motor plate constitutes the central core of the nervous system. It extends throughout the length of the spinal cord and brainstem. It lies immediately adjacent to the lumen of the cord (spinal canal) and that of the brainstem (4th ventricle and aqueduct).

The afferent equivalent of the motor plate is the receptor plate made up of the cerebrospinal ganglia, which rise to the peripheral afferent spinal and cranial nerves.

The peripheral efferent and afferent cerebrospinal nerves and their cells of origin in the motor and receptor plates, respectively, constitute the neural foundation and form the segmental nervous system. This system directly connects each segment of the nervous system with a corresponding segment of the body.

After these old parts have been studied and reconstructed, the newer structures, i.e., the suprasegmental, are then considered and added to the model in the order of their development: first, the cerebellum with its different stages (Figs. 19-28), then the colliculi, (Figs. 29, 30), and finally, the various stages of the forebrain, (Figs. 31-71). These suprasegmental organs are connected with each segment of the nervous system by means of the fibers which form the afferent and efferent suprasegmental systems.

The afferent suprasegmental fibers arise in the suprasegmental cells of the association plate in each neural segment. In the cord the association plate is formed by the dorsal horn; in the brainstem by the lateral part of the reticular substance. These suprasegmental cells in the cord give rise to fibers which transmit impulses to the cerebellum, the colliculi and the forebrain as the spinocerebellar, spinocollicular and spinothalamic fibers, respectively. Similar fibers arise from the association plate of the brainstem. All of these fibers form the afferent suprasegmental nervous system. They transmit to the suprasegmental organs the impulses coming into each neural segment from the receptor end-organs of the corresponding body segment.

The suprasegmental organs which receive these afferent suprasegmental systems give rise in turn to the efferent suprasegmental systems. The latter influence the segmental motor mechanisms of each segment and ultimately the effector end-organs of the corresponding body segment. The forebrain gives rise to the corticobulbar and the corticospinal fibers of the pyramidal system; the colliculi to the colliculobulbar and the colliculospinal fibers and the cerebellum indirectly to the vestibulospinal, the rubrospinal and the rubroreticulospinal fibers, as well as others. The efferent suprasegmental fibers of the colliculi and cerebellum constitute the extrapyramidal system which also includes similar efferent fibers from the forebrain, not belonging to the pyramidal system.

TEACHING METHOD. This method of building the brain in three dimensions has been used as the basis for teaching clinical neuroanatomy and neurophysiology to undergraduate and postgraduate students. Each student is required to build a model, in connection with which he studies the anatomy and functions of the various parts of the nervous system as they are reconstructed. One advantage of this approach is that it enables the student to visualize more readily the relations of the different structures to each other. In addition, a definite color scheme is used. It serves to emphasize the physiological significance as well as the anatomical connections of the various parts of the nervous system. Those structures which have the same function and work closely together are represented in the same color. For example, the cerebellar mechanisms are represented in both yellow and brown, the former to indicate the afferent, the latter the efferent systems of the cerebellum. Thus, whenever these colors appear on the model, they indicate cerebellar connections and functions. The color scheme which is followed was outlined in the atlas of serial sections (4).

This method of reconstructing the nervous system and the principles underlying it have been incorporated in a course which extends over a period of twelve weeks. It consists of two lectures and one laboratory period each week.

At the two weekly lectures preceding each laboratory period, the structure and functions of the part to be built are considered and the pertinent symptoms and syndromes discussed. The clinical application is stressed at once; throughout this approach emphasis is placed not only on the anatomical and physiological aspects of the nervous system but also on the clinical. The connections of the body segments with the nervous system are therefore always kept in mind. Just as the cells of the motor and receptor plates form neural segments, so the receptor and effector end-organs of the body are grouped into body segments.

The arrangement is such that each body segment is connected by the peripheral nerves of the segmental nervous system with the corresponding neural segment. It is important to recognize that the suprasegmental nervous system is also connected with the segmental foundation of each neural segment; the afferent suprasegmental systems with the receptor plate and the efferent with the motor plate. Since the motor and receptor plate of each neural segment are connected through their peripheral afferent and efferent nerves directly with the end-organs of the corresponding body segment, it becomes significantly evident that the end-organs of the body serve as the indicators of activity for both the segmental and the suprasegmental divisions of the nervous system. It is these end-organs which are used at the bedside to examine the nervous system of each individual. Their arrangement into body segments provides a convenient and useful tool for examining the segmental and suprasegmental divisions of the nervous system in each individual.

Accordingly, the nervous system is taken up segment by segment. The foundation of each segment is discussed in terms of the corresponding body segment. Then the segmental, intrasegmental, intersegmental, and suprasegmental provisions of each neural segment are taken up in that order, the sequence following the phylogenetic and embryological development of the nervous system.

Each segment of the nervous system is therefore analyzed in terms of the following parts and in the following sequence:

A. The segmental or older parts which form the foundation of the segment:

1) Efferent segmental system

2) Afferent segmental system

3) Intra- and intersegmental connections

B. The suprasegmental systems or newer parts connected with each neural segment:

1) Afferent cerebellar systems

2) Efferent cerebellar systems

3) Afferent and efferent systems of the inferior colliculi

4) Afferent and efferent systems of the superior colliculi

5) Afferent systems of the forebrain

6) Efferent systems of the forebrain

In studying the cerebellum it is considered in terms of its different stages of development, old and new. Likewise, the forebrain is discussed in terms of first, the older part, the diencephalon with its hypothalamus and thalamus (old and new), then the cerebral hemisphere in terms of the corpus striatum (old and new), and finally, the cortex (old and new).

As these different systems are taken up, one by one, the various levels of integration within the nervous system are brought into focus and the significance of each in terms of the whole evaluated.

The sequence outlined above is followed in the lectures, the reconstruction, the illustrations, and the study of the sections. A part of each lecture is also devoted to the showing of lantern slides of microscopic Pal-Weigert sections of the brain pertinent to the reconstruction of the subsequent laboratory period. Slides of that particular stage of the reconstruction are likewise shown.

Each laboratory period is devoted to the work outlined in the two preceding lectures. The part of the nervous system which has been discussed in these lectures is studied in microscopic sections and gross dissections of the brain, and reconstructed. The so-called blue-prints for the reconstruction are provided by the illustrations of the model herewith presented, and the atlases of serial sections of the spinal cord, brainstem and forebrain (4). Like the sections, the scale of the reconstruction is four times the natural size of the brain and cord. As each part is built, it is traced in the sections of the atlas and colored in keeping with the color scheme of the model. It is also followed in the illustrations of the model which are similarly colored. At the end of the course each student has a reconstruction of the brain, an atlas of sections and an atlas of illustrations of the model.

The construction of the model, the study of the gross brain, and the study of the slides and atlas sections are mutually helpful in the orientation of one another. In a sense, the atlas sections are "reconstructed" like the model, from the inside out, beginning with the oldest layer (motor plate which forms the core in the center and proceeding progressively towards the outside of the nervous system, layer by layer, until the final layer, the cerebral cortex, is reached at the surface of the brain. Each part is colored in the order of its appearance. For example, when the first structure, the motor plate is studied and built, it is identified and colored in the corresponding sections. Then, when the cerebellum is built, its various systems are likewise studied and colored in these sections; and so with the systems pertaining to the colliculi and the forebrain. Eventually, all the systems in each section are colored, one by one. The student is thus provided with a systematic, logical analysis. As to the illustrations of the model, each system is colored only when it appears for the first time. This serves to emphasize that structure in the illustration.

It should be emphasized again that as each part is built, its function is given and the pertinent syndromes discussed. As a result, the student acquires a three-dimensional working knowledge of the nervous system which he can apply more readily to clinical problems at the bedside.

THE RECONSTRUCTION. The reconstruction includes the brain and the first two cervical segments of the spinal cord. As the model is built, the clinical application is constantly kept in mind. For that reason the effector and receptor end-organs of a given segment of the body are represented on the paper symbol which is mounted on the base of the stand. Its purpose is to stress the fact that these end-organs are the indicators of neural activity, both segmental and suprasegmental.

Since the reconstruction arbitrarily provides for the left side of the body, the end-organs and the corresponding peripheral nerves on the left side are represented. Likewise, the left cerebellar hemisphere and the right cerebral hemisphere are built, since those parts control the left side of the body. As to the cord and brainstem, both sides are reconstructed since some of the pathways (cellebellar) are represented on the left side, others (cerebral) on the right side. The reconstruction is to scale (x4 natural size) and, as previously noted, is made from the architectural blue-prints furnished by the atlas of serial sections of the nervous system and the illustrations of the model herewith presented.

To expedite the reconstruction and to reduce technical problems to a minimum, a skeletal framework of the model is provided. It consists of the following parts: metal base, metal motor plate, wooden symbols, paper symbols and paper patterns. The metal base and the metal motor plate represent the framework of the segmental foundation of the nervous system. The wooden symbols and the corresponding paper symbols represent the framework of the suprasegmental nervous system.

The metal base serves as the foundation to which the metal motor plate is attached. On this base is mounted the paper symbol containing the end-organs of the body segment corresponding to the second cervical neural segment.

The metal motor plate forms the central core around which the model is built. It constitutes the foundation or oldest part of the nervous system and therefore is considered first. It consists of the reticular cells and the efferent nuclei which give rise to the peripheral efferent cerebrospinal nerves; the latter are connected directly with the effector end-organs of the body segments. To save time and to provide a solid foundation for the reconstruction, the motor plate was built of metal. Templets were made of the motor plate of each section of the atlas. These were then cut out of plasticine and placed in position, one upon the other, and molded together to form the entire motor plate of the upper cord and brainstem. A plaster cast was then made from which the aluminum model was poured. The lines and numbers on the motor plate mark the levels of the corresponding sections of the brainstem-cord atlas. The two projecting pins at the upper end of the motor plate are for the attachment of the wooden midline symbol.

Instead of the metal base and metal motor plate, one may use a wooden stand which consists of a wooden base and central dowel. In that case the motor plate is built around the dowel by using gray clay cut out according to the sections in the brainstem-cord atlas. The rest of the reconstruction is the same as that of the metal foundation.

The wooden suprasegmental symbols. These consist of the midline, the thalamic and the cortical symbols, which, like the rest of the model, are to the scale of four.

The midline symbol represents a mesial view of a sagittal section of the cerebral hemisphere, the colliculi, and the cerebellum on the right side. The cerebral cortex is not represented on this symbol. There are two holes at the base of the symbol into which the projecting pins of the motor plate fit.

The thalamic symbol represents a transverse section through the posterior part of the thalamus and adjoining structures on the right side of the brain. It becomes attached to the lateral side of the midline symbol.

The cortical symbol represents an oblique vertical section in the plane of the central sulcus of the right cerebral hemisphere. The upper part includes the sulcus with its anterior and posterior walls; the lower part comprises the temporal lobe and the lateral sulcus.

The paper suprasegmental symbols. There are four sets of paper symbols: 1) cerebellar, 2) forebrain and collicular, 3) thalamic, and 4) cortical. Each set contains two sides of the corresponding wooden symbol. These paper symbols are cut out and pasted on the corresponding wooden symbols.

The paper patterns. To aid in the reconstruction of the various parts of the nervous system, to save time, and to circumvent the need for any special technical skill, paper patterns are provided. By means of them, various parts of the nervous system can be cut out to scale in keeping with the size and shape required. For example, the corpus striatum, which is a large mass, is built of wire mesh according to the corresponding paper patterns; on the latter are outlined the component parts: the globus pallidus, the caudate and the putamen. Likewise, there are paper patterns for the reconstruction of the efferent and afferent cranial nerves which are represented schematically by means of red and blue wires, respectively. Similar patterns are provided for many other parts of the nervous system.

The materials. Colored clay, wire mesh, and colored wire are used to represent the gray masses and nerve fibers of the nervous system. When clay is used to represent fibers, it is striped, otherwise it represents nuclei. In some instances wire mesh is used and painted the proper color to take the place of the clay; this saves weight and permits a certain degree of transparency.

The materials for the reconstruction are put together in a brain reconstruction kit which contains the framework of the reconstruction, the clay, the wire, and other accessories. It can be obtained through Dr. Louis Hausman, 140 East 54 Street, New York 22, New York.

I am greatly indebted to Dr. Ellsworth C. Alvord, Jr. for the patterns of the cranial nerves and receptor plate mesh used in connection with the brainstem.

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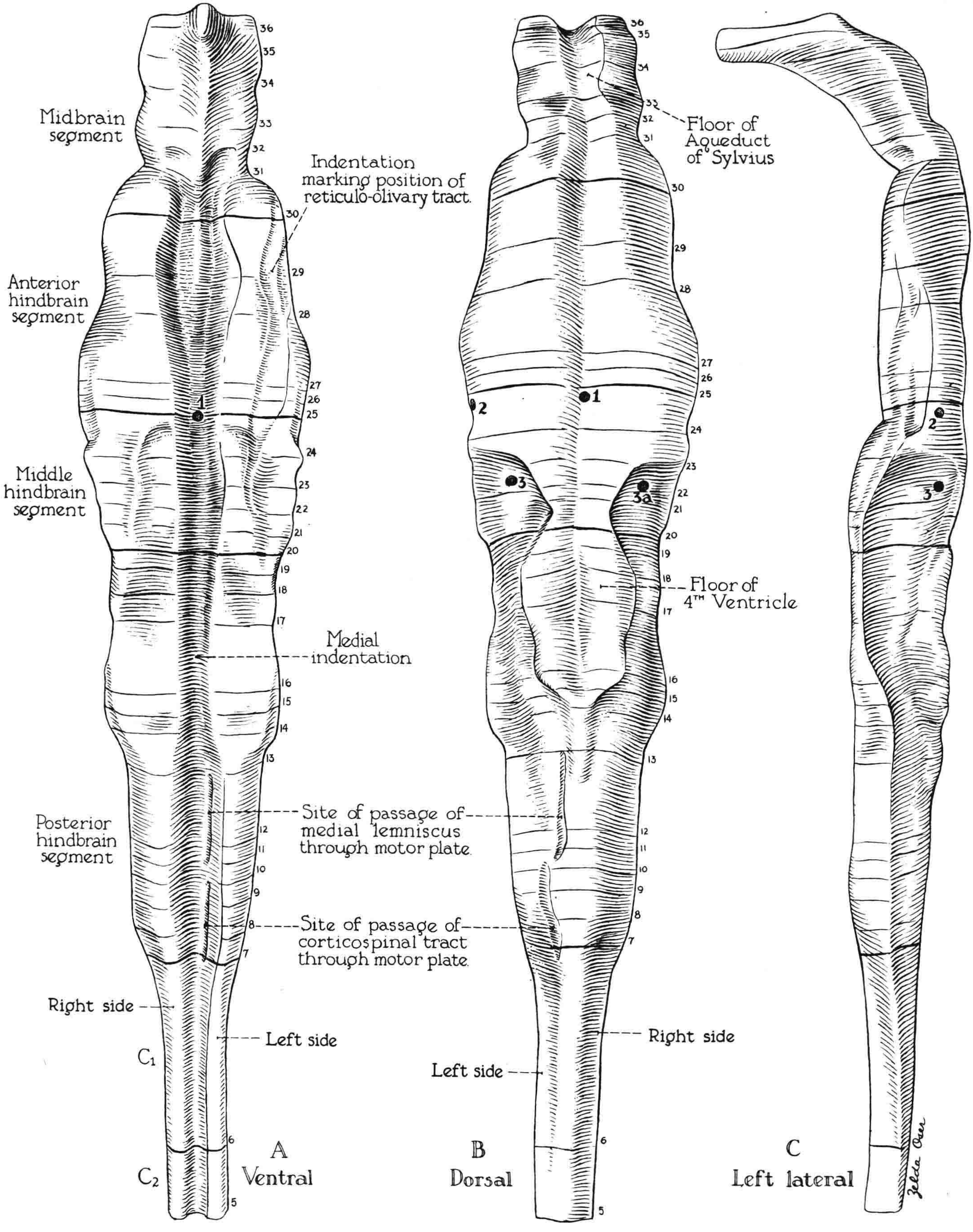


Fig. 1. (3/4 model size)

THE MOTOR PLATE

The reconstruction of the metal motor plate includes the ventral horns of the upper cervical cord and the corresponding reticular substance of the brainstem. The heavy lines mark off the neural segments of these parts as labelled. The lines numbered 5-36 refer to the corresponding levels of sections of the cord-brainstem atlas (4). The holes numbered 1, 2, 3 and 3a are for the insertion of the support wires as follows: 1 for the pons wire, 2 for the receptor plate wire, 3 and 3a for the fourth ventricle wire.

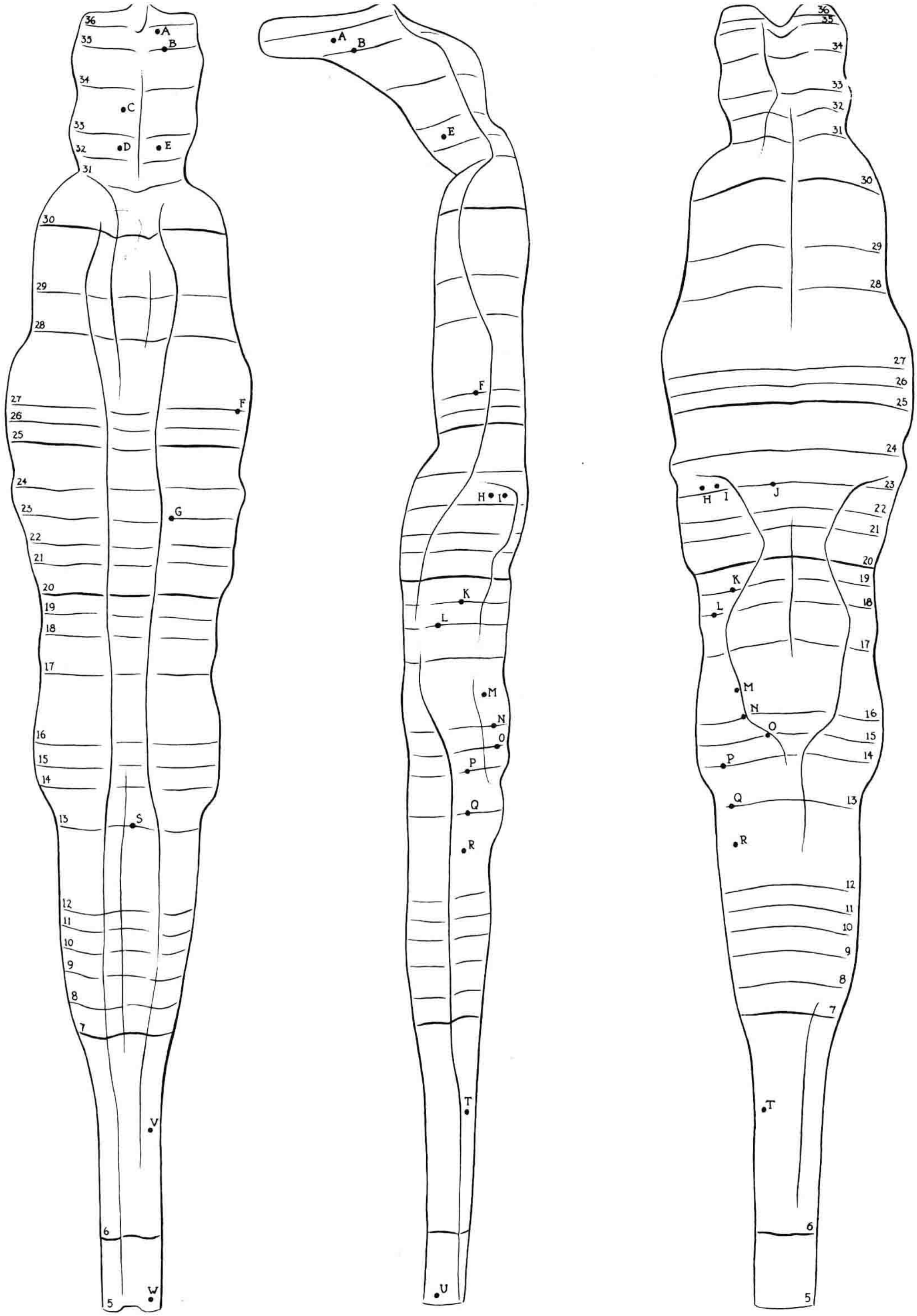


Fig. 2. (2/3 model size)

IDENTIFICATION OF HOLES IN MOTOR PLATE FOR THE ORIGIN OF THE EFFERENT CRANIAL AND UPPER CERVICAL NERVES.

The holes correspond to the following nerves: A. Oculomotor nerve arising from the Edinger-Westphal nucleus; B. Oculomotor nerve arising from the lateral oculomotor nucleus of the same side; C. Oculomotor nerve arising from the lateral oculomotor nucleus of the opposite side; D. Trochlear nerve; E. Trochlear nerve; F. Motor root of the trigeminal nerve; G. Abducens nerve; H. Great superficial petrosal nerve arising from the lachrymal nucleus; I. Nervus intermedius arising from the superior salivary nucleus; J. Facial nerve; K. Glossopharyngeal nerve arising from the inferior salivary nucleus; L. Glossopharyngeal nerve for the stylopharyngeus muscle arising from the ambiguus nucleus; M. Vagus nerve to the heart arising from the dorsal vagus nucleus; N. Vagus nerve to the lungs arising from the dorsal vagus nucleus; O. Vagus nerve to the gastrointestinal system arising from the dorsal vagus nucleus; P. Vagus nerve to the larynx arising from the ambiguus nucleus; Q. Vagus nerve to the pharynx arising from the ambiguus nucleus; R. Vagus nerve to the soft palate arising from the ambiguus nucleus; S. Hypoglossal nerve; T. Spinal accessory nerve; U. Spinal accessory nerve; V. First cervical nerve; W. Second cervical nerve.

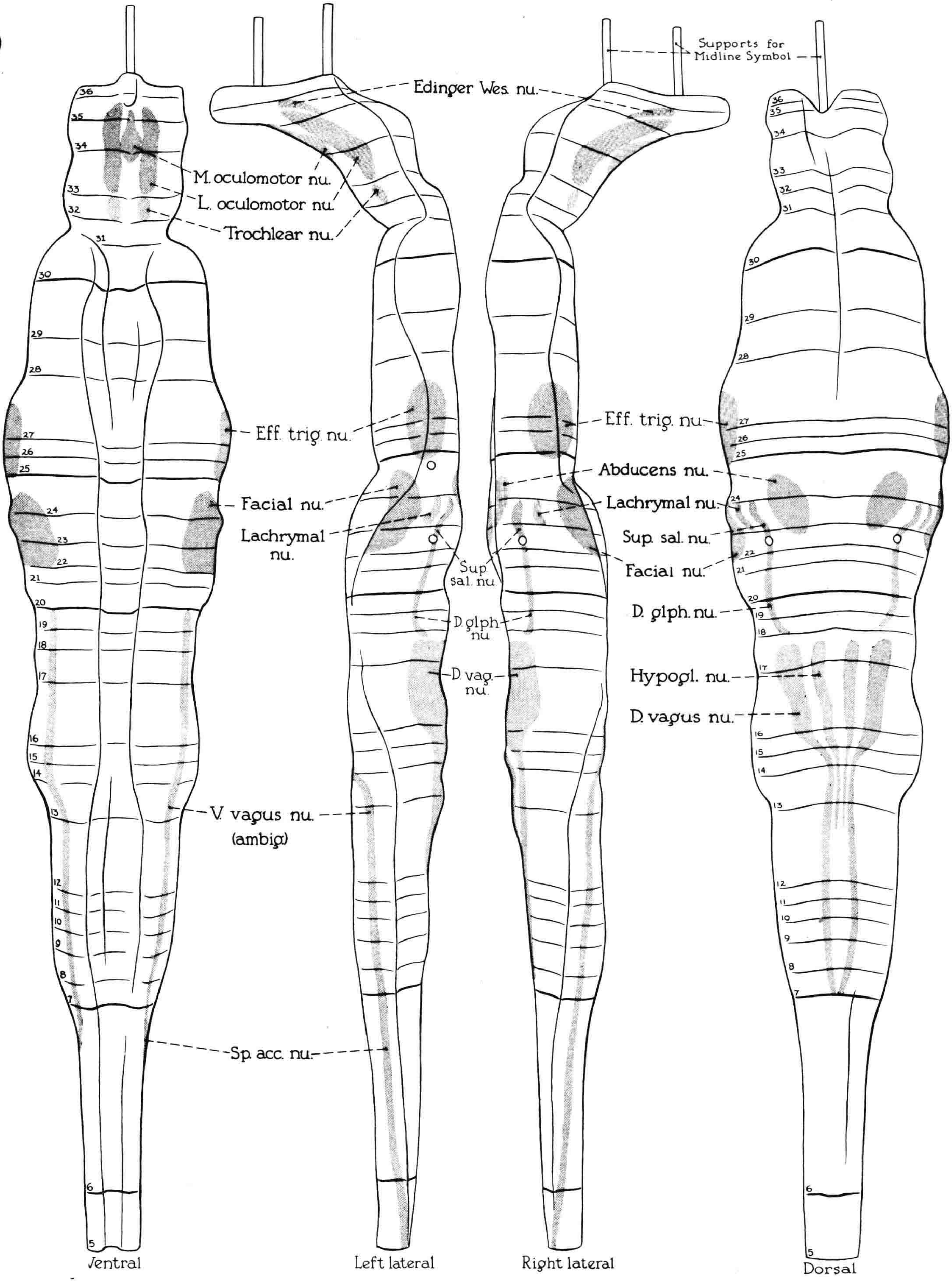


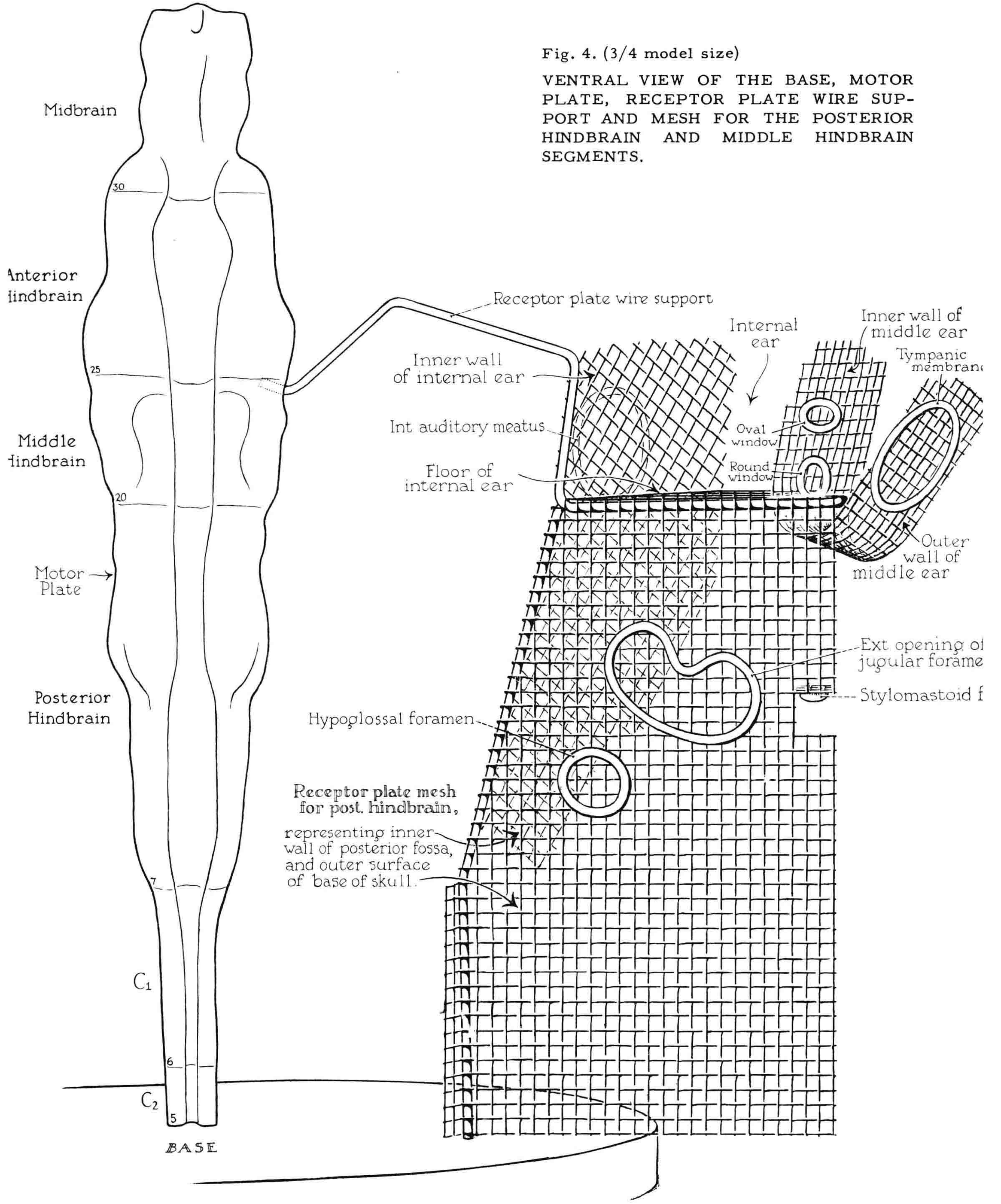
Fig. 3. (3/4 model size)

NUCLEI OF THE MOTOR PLATE OF THE BRAINSTEM AND UPPER CORD.

These efferent nuclei should be colored red on the metal motor plate. The rest of the motor plate is reticular substance.

Fig. 4. (3/4 model size)

VENTRAL VIEW OF THE BASE, MOTOR PLATE, RECEPTOR PLATE WIRE SUPPORT AND MESH FOR THE POSTERIOR HINDBRAIN AND MIDDLE HINDBRAIN SEGMENTS.



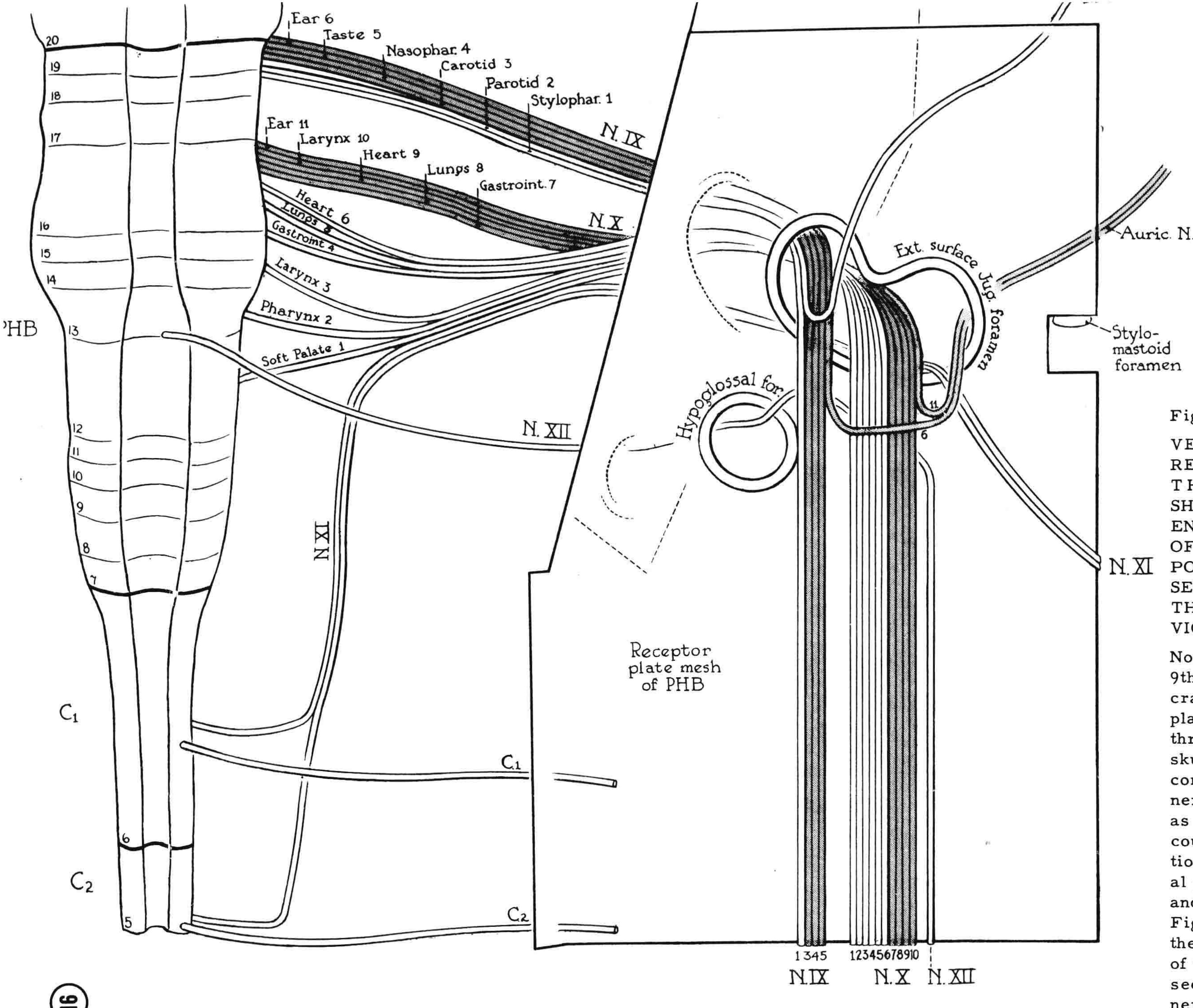


Fig. 5. (model size)

VENTRAL VIEW OF THE RECONSTRUCTION OF THE EFFERENT (UNSHADED) AND AFFERENT (SHADED) NERVES OF THE MEDULLA OR POSTERIOR HINDBRAIN SEGMENT (PHB) AND THE UPPER TWO CERVICAL SEGMENTS.

Note the relation of the 9th, 10th, 11th, and 12th cranial nerves to the motor plate and their passage through the foramina of the skull (see also Fig. 6). The component parts of the nerves are numbered so as to aid in tracing their course. For the continuation of the small superficial petrosal nerve (S.S.P.N.) and the auricular nerve, see Figs. 10, 11, 16 and 18. For the origin and termination of the afferent components, see Fig. 6. Color afferent nerves blue; efferent, red.