there was free purgation, and in one there was "some slight muco-fæcal discharge." From these, Wood concluded that while section of the cervical pneumogastrics, in the great majority of instances, arrests gastro-intestinal secretion and prevents the action of purgatives upon the intestinal canal, a few exceptional cases occur in which these effects are not observed.

It would be interesting to determine whether the pneumogastrics influence the intestinal secretions through their own fibres or through filaments received from the sympathetic system; but there are no experimental facts sufficiently definite to admit of a positive answer to this question. If the action take place through the sympathetic system, as in the case of the stomach, the filaments of communication join the pneumogastrics high up in the neck.

The cranial nerves that have been considered in this chapter are the third, fourth, fifth, sixth, seventh, tenth, eleventh and twelfth. The anatomical and physiological history of the olfactory (first), optic (second), auditory (eighth), gustatory (branch of the seventh and a part of the ninth) and of the general sensory nerves, as far as they are concerned in the sense of touch, belongs properly to the chapters on the special senses.

CHAPTER XVIII.

THE SPINAL CORD.

General arrangement of the cerebro-spinal axis—Membranes of the encephalon and spinal cord—Cephalo-rachidian fluid—Physiological anatomy of the spinal cord—Columns of the Cord—Direction of the nerve-fibres in the cord—General properties of the spinal cord—Motor paths in the cord—Sensory paths in the cord—Relations of the posterior white columns of the cord to muscular co-ordination—Nerve-centres in the spinal cord—Reflex action of the spinal cord—Exaggeration of reflex excitability by decapitation, poisoning with strychnine etc.—Reflex phenomena observed in the human subject.

THE nervous matter contained in the cavity of the cranium and in the spinal canal, exclusive of the roots of the cranial and spinal nerves, is known as the cerebro-spinal axis. This portion of the nervous system is composed of white and gray matter. The fibres of the white matter act solely as conductors. The gray matter constitutes a chain of ganglia, which act as nerve-centres, receiving impressions and generating the so-called nerve-force. Certain parts of the gray matter also serve as conductors.

The cerebro-spinal axis is enveloped in membranes, which are for its protection and for the support of its nutrient vessels. It is surrounded to a certain extent with liquid, and it presents cavities, as the ventricles of the brain and the central canal of the cord, which contain liquid. The gray matter is distinct from the white, even to the naked eye. In the spinal cord the white substance is external and the gray is internal. The surface of the brain presents an external layer of gray matter, the white substance being

internal. In the white substance of the brain, also, are collections of gray matter. The white matter of the cerebro-spinal axis is composed largely of fibres. The gray substance is composed chiefly of cells.

The encephalon is contained in the cranial cavity and consists of the cerebrum, cerebellum, pons Varolii and medulla oblongata. In the human subject and in many of the higher animals, its surface is marked by convolutions, by which the extent of its gray substance is much increased. The cerebrum, the cerebellum and most of the encephalic ganglia are connected with the white substance of the encephalon and with the spinal cord. All of the cerebro-spinal nerves are connected with the encephalon and the cord. The cerebro-spinal axis acts as a conductor, and its different collections of gray matter, or ganglia, receive impressions conveyed by the sensory conducting fibres, and generate motor impulses which are transmitted to the proper organs by the motor fibres.

Membranes of the Encephalon and Spinal Cord.—The membranes of the brain and spinal cord are the dura mater, the arachnoid and the pia mater.

The dura mater of the encephalon is a dense membrane, in two layers, composed chiefly of ordinary fibrous tissue, which lines the cranial cavity and is adherent to the bones. In certain situations its two layers are separated and form what are known as the venous sinuses. The dura mater also sends off folds or processes of its internal layer. One of these passes into the longitudinal fissure and is called the falx cerebri; another lies between the cerebrum and the cerebellum and is called the tentorium; another is situated between the lateral halves of the cerebellum and is called the falx cerebelli. The dura mater is closely attached to the bone at the border of the foramen magnum. From this point it passes into the spinal canal and forms a loose covering for the cord. In the spinal canal, this membrane is not adherent to the bones, which have, like most other bones in the body, a special periosteum. At the foramina of exit of the cranial and the spinal nerves, the dura mater sends out processes which envelop the nerves, with the fibrous sheaths of which they soon become continuous.

The arachnoid is a delicate membrane, resembling the serous membranes, with the exception that it presents but one layer. Its inner surface is covered with a layer of tesselated endothelium. There is a considerable quantity of liquid between the arachnoid and the pia mater, surrounding the cerebro-spinal axis, in what is called the subarachnoid space. This is called the cerebro-spinal, or cephalo-rachidian fluid. The arachnoid does not follow the convolutions and fissures of the encephalon or the fissures of the cord, but it simply covers their surfaces. Magendie described a longitudinal, incomplete, cribriform, fibrous septum in the cord, passing from the inner layer of the arachnoid to the pia mater. A similar arrangement is found in certain situations at the base of the skull.

The pia mater of the encephalon is a delicate, fibrous structure, very vascular, seeming to present, indeed, only a skeleton net-work of fibres for the support of the vessels going to the nervous substance. This membrane covers the surface of the encephalon immediately, follows the sulci and fissures, and is prolonged into the ventricles, where it forms the choroid plexus and the velum interpositum. From its internal surface small vessels are given off which pass into the nervous substance.

The pia mater of the encephalon is continuous with the corresponding membrane of the cord; but in the spinal canal the membrane is thicker, stronger, more closely adherent to the subjacent parts, and its blood-vessels are not so abundant. In this situation many of the fibres are arranged in longitudinal bands. This membrane lines the anterior fissure and a portion of the posterior fissure of the cord. At the foramina of exit of the cranial and the spinal nerves, the fibrous structure of the pia mater becomes continuous with the nerve-sheaths.

Between the anterior and posterior roots of the spinal nerves, on either side of the cord, is a narrow, ligamentous band, the ligamentum denticulatum, which assists in holding the cord in place. This extends from the foramen magnum to the terminal filament of the cord, and is attached, internally, to the pia mater, and externally, to the dura mater.

It is not necessary to enter into a detailed description of the arrangement of the blood-vessels, nerves and lymphatics of the membranes of the brain and spinal cord, or of the vascular arrangement in the substance of the cerebro-spinal axis, as these points are chiefly of anatomical interest. The circulation in these parts presents certain peculiarities. In the first place, the encephalon being contained in an air-tight case of invariable capacity, it has been a question whether or not the vessels be capable of contraction and dilatation, or whether the quantity of blood in the brain be subject to modifications in health or disease. These questions may certainly be answered in the affirmative. In infancy and in the adult, when an opening has been made in the skull, the volume of the encephalon is evidently increased during expiration and is diminished in inspiration. Under normal conditions, in the adult, it is probable that the quantity of blood is increased in expiration and diminished in inspiration; but it is not probable that the cerebro-spinal axis undergoes any considerable movements. The important peculiarities in the cerebral circulation have already been fully considered in connection with the physiology of the circulation. It has been shown that the encephalic capillaries are surrounded or nearly surrounded by canals (perivascular canal-system), which are connected with lymphatic trunks or reservoirs situated under the pia mater. The system of canals may, by variations in its contents, serve to equalize the quantity of liquid in the brain, as the blood-vessels are distended or contracted.

Cephalo-Rachidian Fluid.—The greatest part of the fluid in the cranium and in the spinal canal is contained in the subarachnoid space. The ventricles of the encephalon are in communication with the central canal of the cord, and are also connected with the general subarachnoid space, by a narrow, triangular orifice situated at the inferior angle of the fourth ventricle. By this arrangement the liquid in the ventricles of the encephalon and in the central canal of the cord communicates with the liquid surrounding the cerebro-spinal axis, and the pressure upon these parts is equalized.

As far as is known, the office of the cephalo-rachidian fluid is simply mechanical, and its properties and composition have no very definite physiological significance. Its quantity was estimated by Magendie, in the human subject, at about two fluidounces (60 c. c.); but this was the smallest quantity obtained by placing the subject upright, making an opening in the lumbar region and a counter-opening in the head to admit the pressure of the atmosphere. The exact quantity in the living subject could hardly be estimated in this way; and it is difficult, indeed, to see how any thing more than a roughly approximate idea could be obtained. The quantity obtained by Magendie probably does not represent all the liquid contained in the ventricles and in the subarachnoid space, but it is the most definite estimate that has been given.

The general properties and composition of the cephalo-rachidian fluid are in brief the following: It is transparent and colorless, free from viscidity, of a distinctly saline taste, an alkaline reaction, and it resists putrefaction for a long time. It is not affected by heat or acids. It contains a large proportion of water (981 to 985 parts per thousand), a considerable quantity of sodium chloride, a trace of potassium chloride, sulphates, carbonates and alkaline and earthy phosphates. In addition it contains traces of urea, glucose, sodium lactate, fatty matter, cholesterine and albumen.

As a summary of the office of the cephalo-rachidian fluid, it may be stated in general terms that it serves to protect the cerebro-spinal axis, chiefly by equalization of the pressure in the varying condition of the blood-vessels, filling the space between the centres and the bony cavities in which they are contained. That the blood-vessels of the cerebro-spinal axis are subject to variations in tension, is readily shown by introducing a canula into the subarachnoid space, when the jet of fluid discharged will be increased with every violent muscular effort. The pressure of the fluid, in this instance, could be affected only through the blood-vessels.

Physiological Anatomy of the Spinal Cord.

The spinal cord, with its membranes, the roots of the spinal nerves and the surrounding liquid, occupies the spinal canal and is continuous with the encephalon. Its length is fifteen to eighteen inches (38·1 to 45·7 centimetres) and its weight is about an ounce and a half (42·5 grammes). Its general form is cylindrical, but it is slightly flattened in certain portions. It extends from the foramen magnum to the lower border of the body of the first lumbar vertebra. It presents, at the origin of the brachial nerves, an elongated ovoid enlargement flattened antero posteriorly, and a corresponding enlargement at the origin of the nerves which supply the lower extremities. It terminates below in a slender, gray filament, called the filum terminale. The sacral and coccygeal nerves, after their origin from the lower portion of the cord, pass downward to emerge by the sacral foramina, and they form what is known as the cauda equina. The substance of the cord is composed of white and gray matter, the white matter being external. The inferior, pointed termination of the cord consists entirely of gray matter.

The cord is marked by an anterior and a posterior median fissure, and by imperfect and somewhat indistinct anterior and posterior lateral grooves,

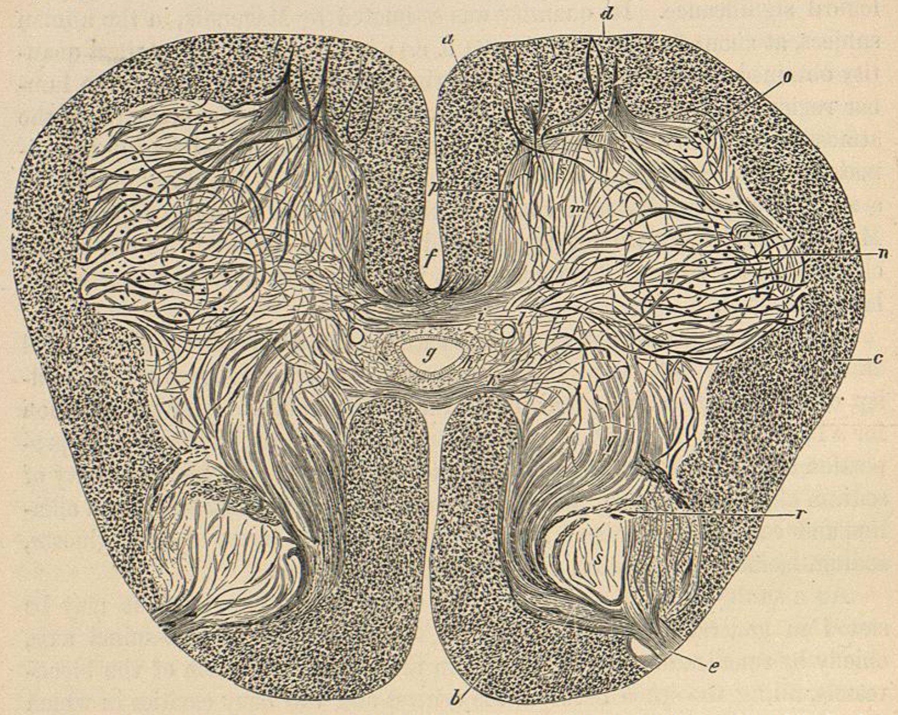

FIG. 216.—*Transverse section of the spinal cord of a child six months old, at the middle of the lumbar enlargement, treated with potassium-auric chloride and uranium nitrate; magnified 20 diameters. By means of these reagents, the direction of the fibres in the gray substance is rendered unusually distinct* (Gerlach).

a, anterior columns; *b*, posterior columns; *c*, lateral columns: *d*, anterior roots; *e*, posterior roots; *f*, anterior white commissure, in communication with the fasciculi of the anterior cornua and the anterior columns; *g*, central canal with its epithelium; *h*, surrounding connective substance of the central canal; *i*, transverse fasciculi of the gray commissure in front of the central canal; *k*, transverse fasciculi of the gray commissure behind the central canal; *l*, transverse section of the two central veins; *m*, anterior cornua; *n*, great, lateral cellular layer of the anterior cornua; *o*, lesser, anterior cellular layer; *p*, smallest, median cellular layer; *q*, posterior cornua; *r*, ascending fasciculi in the posterior cornua; *s*, substantia gelatinosa.

from which latter arise the anterior and the posterior roots of the spinal nerves. The posterior lateral groove is tolerably well marked, but there is no distinct line at the origin of the anterior roots. The anterior median fissure is perfectly distinct. It penetrates the anterior portion of the cord, in the median line, for about one-third of its thickness and receives a highly vascular fold of the pia mater. It extends to the anterior white commissure. The posterior fissure is not so distinct as the anterior, and it is not lined throughout by a fold of the pia mater, but is filled with connective tissue and blood-vessels, which form a septum posteriorly, between the lateral halves of the cord. The posterior median fissure extends nearly to the centre of the cord, as far as the posterior gray commissure.

The arrangement of the white and the gray matter in the cord is seen in a transverse section. The gray substance is in the form of a letter H, presenting two anterior and two posterior cornua connected by what is called the gray commissure. The anterior cornua are short and broad, and they do not

reach to the surface of the cord. The posterior cornua are larger and narrower, and they extend nearly to the surface, at the point of origin of the posterior roots of the spinal nerves. In the centre of the gray commissure, is a narrow canal, lined by cells of ciliated epithelium, called the central canal. This is in communication above with the fourth ventricle, and it extends below to the filum terminale. That portion of the gray commissure situated in front of this canal is sometimes called the anterior gray commissure, the posterior portion being known as the posterior gray commissure. The central canal is immediately surrounded by connective tissue. In front of the gray commissure, is the anterior white commissure.

The proportion of the white to the gray substance is variable in different portions of the cord. In the cervical region, the white substance is most abundant, and in fact it progressively increases in quantity from below upward throughout the whole extent of the cord. In the dorsal region, the gray matter is least abundant, and it exists in greatest quantity in the lumbar enlargement.

The white substance of the cord is composed of nerve-fibres, connective-tissue elements (neuroglia) and blood-vessels, the latter arranged in a very wide and delicate plexus. The nerve-fibres are variable in size and are composed of the axis-cylinder and the medullary substance, without the tubular membrane.

The anterior cornua of gray matter contain blood-vessels, connective-tissue elements (neuroglia), very fine nerve-fibres, and large multipolar nerve-cells, which are sometimes called motor cells. The posterior cornua are composed of the same elements, the cells being much smaller, and the fibres exceedingly small, presenting very fine plexuses. The cells in this situation are sometimes called sensory cells. Near the posterior portion of each posterior cornu, is an enlargement, of a gelatiniform appearance, containing small cells and fibres, called the substantia gelatinosa. The connections between the nerve-cells and the nerve-fibres have already been described in connection with the general structure of the nervous system. The multipolar nerve-cells are supposed to present certain prolongations which do not branch and are directly connected with the medullated nerve-fibres. These are called axis-cylinder prolongations. In addition, fine, branching poles are described under the name of protoplasmic prolongations. In both the white and the gray substance of the cord, is a ground-work of delicate connective-tissue fibres and cells, called neuroglia. This supports the nerve-cells, nerve-fibres, vessels etc. The neuroglia is particularly abundant in that part of the posterior cornua of gray matter, called the substantia gelatinosa.

The division of the spinal cord into columns has a physiological as well as an anatomical basis. Anatomists usually recognize, on either side of the cord, an anterior column, bounded by the anterior median fissure and the line of origin of the anterior roots of the spinal nerves, a lateral column, bounded by the lines of origin of the anterior and of the posterior roots of the nerves, and a posterior column, bounded by the line of the posterior roots of the spinal nerves and the posterior median fissure. As the anterior or posterior columns include either the white or the gray matter, they are called respectively the anterior or posterior white and gray columns. Physiological and pathological researches, however, have shown that the cord may properly be farther divided as follows:

1. *Columns of Türck.*—By the sides of the anterior median fissure, are two narrow columns of white matter, one on either side, extending to the white commissure (A, in Fig. 217), called the columns of Türck, the direct, or the uncrossed pyramidal tracts. The fibres of these columns descend, probably decussate in the cervical region of the cord, and the columns are lost in the lower dorsal region. Destruction of certain motor parts in the brain is followed by descending secondary degeneration of the fibres of these columns.

2. *Crossed Pyramidal Tracts.*—These are situated, one on either side, in the posterior portion of the lateral columns (G, G, in Fig. 217), and are bounded internally by the posterior cornua of gray matter and externally by a narrow band called the direct cerebellar tract. In following the columns upward, it is found that they pass forward in the upper part of the cervical region and decussate in the lower portion of the anterior pyramids of the medulla oblongata. These are descending tracts, and their fibres undergo descending secondary degeneration as the result of destruction of certain motor parts in the brain.

3. *Anterior Fundamental Fasciculi.*—These fasciculi (B, in Fig. 217), are bounded internally by the columns of Türck and externally by the anterior cornua of gray matter and the anterior roots of the spinal nerves. Their fibres are supposed to connect the gray matter of the anterior cornua of the cord with the gray matter of the medulla oblongata.

4. *Anterior Radicular Zones.*—These columns (E, E, in Fig. 217) are in the anterior portion of the lateral columns. Their fibres are supposed to connect the gray matter of the cord with the gray matter of the medulla oblongata.

5. *Mixed Lateral Columns.*—These columns (F, F, in Fig. 217) are in the lateral columns of the cord, next the gray matter. With the anterior fundamental fasciculi and the anterior radicular zones, they probably connect the gray matter of the cord with the gray matter of the medulla oblongata.

The fibres of the anterior fundamental fasciculi, the anterior radicular zones and the mixed lateral columns do not degenerate in either direction as the result of section of the cord. Their fibres seem to connect nerve-cells with each other, and their trophic cells exist at both extremities, which accounts for the absence of degeneration, just mentioned.

6. *Direct Cerebellar Fasciculi.*—These fasciculi (H, H, in Fig. 217) are situated at the outer and posterior portion of the lateral columns. Their fibres pass to the funiculi graciles, or posterior pyramids of the medulla oblongata, and thence to the cerebellum, by the inferior peduncles. They connect the cells of the posterior cornua of gray matter with the cerebellum. These columns make their appearance first in the lumbar region of the cord, and they increase in size from below upward. After section of the spinal

cord, the fibres of the direct cerebellar fasciculi show ascending secondary degeneration. Their trophic centres probably are the cells of the posterior cornua of gray matter of the cord.

7. *Columns of Burdach.*—These columns (D, in Fig. 217) are in the posterior columns of the cord, between the columns of Goll and the posterior cornua of gray matter. Their fibres connect some of the cells of the gray matter of the posterior cornua with the cerebellum; or at least the fibres pass upward and are connected with the restiform bodies, going to the cerebellum through the inferior peduncles. The fibres also connect nerve-cells of different portions of the cord with each other. No secondary degenerations have been noted in these columns.

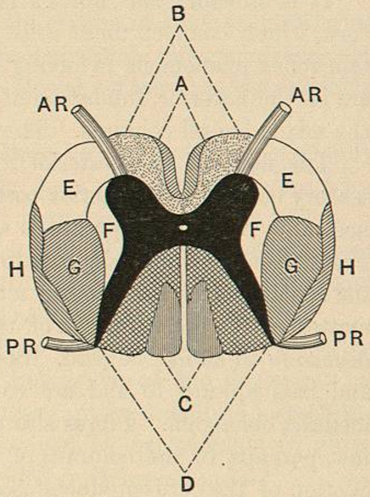

Fig. 217.—*Diagram of the columns and conducting paths in the spinal cord in the upper dorsal region* (enlarged and modified from Landois).

AR, AR, anterior roots of the spinal nerves; PR, PR, posterior roots; A, columns of Türck; B, anterior fundamental fasciculi; C, columns of Goll; D, columns of Burdach; E. E, anterior radicular zones; F, F, mixed lateral columns; G, G, crossed pyramidal tracts; H, H, direct cerebellar fasciculi. The gray matter of the cord is in black. The figure also shows the anterior and posterior median fissures, the white and gray commissures and the central canal.

8. *Columns of Goll.*—These delicate columns (C, in Fig. 217) are situated on either side of the posterior median fissure. They are lost in the lower dorsal or upper lumbar region. Their fibres pass upward and are lost in the funiculi graciles of the medulla oblongata. After section of the cord, ascending secondary degeneration is observed in the fibres of these columns.

Directions of Nerve-Fibres in the Cord.—Many of the points in the description of the course and connections of the fibres in the cord are given as probable. Anatomical observations have been somewhat contradictory, but these have been corrected or verified by following the paths of degeneration. What is called secondary degeneration is the anatomical change in the nerve-fibres which follows separation of the fibres from the cells which act as their trophic centres, or the centres presiding over their nutrition, these changes being secondary to the destruction or degeneration of the centres.

The fibres of the anterior roots of the spinal nerves, following these fibres inward and upward, pass directly to the large, multipolar motor cells of the anterior cornua of gray matter and have no direct connection with the white columns. Their direction through the white columns of the cord is oblique and slightly upward. They are continuous with the axis-cylinder prolongations of the cells. From the nerve-cells, prolongations are given off, by branching processes, in two bundles, median and lateral. The fibres of the median bundle pass to the anterior white commissure, in which they decussate. They then go each one to the column of Türck on the opposite side and pass upward in the so-called direct pyramidal tracts. The fibres of the lateral bundle go to the crossed pyramidal tract in the lateral column of the same side and pass upward to decussate at the medulla oblongata.

The fibres of the columns of Türck and the crossed pyramidal tracts are the only fibres of the cord which are known to convey motor impulses from the brain. Destruction of certain parts of the brain produces descending secondary degeneration of these fibres.

It is probable that fibres arise from the cells of the gray matter of the cord, which connect these cells with each other and are concerned in certain reflex phenomena involving the action of the cord alone. These fibres are in the anterior fundamental fasciculi, the anterior radicular zones and the mixed lateral columns. They present no secondary degeneration.

The fibres of the posterior roots of the spinal nerves pass to the small, sensory cells of the posterior cornua of gray matter of the cord and are connected by branching processes with branching prolongations of these cells. Processes from these cells pass to the gray commissure and decussate around the central canal, conducting sensory impressions to the brain, in the gray matter of the opposite side of the cord. The sensory conductors therefore decussate all along the cord. Some of the fibres go to the columns of Goll and pass upward to and are continuous with the funiculi graciles of the medulla oblongata. Fibres also pass to the direct cerebellar fasciculi and a few, perhaps, to the columns of Burdach, to go upward to the cerebellum. Section of the cord produces ascending secondary degenerations in the columns of Goll and the direct cerebellar fasciculi. Fibres originating in the nerve-cells of the posterior cornua pass in and out, along the cord, and connect the cells with each other. These may properly be called longitudinal commissural fibres. They probably constitute the greater part of the columns of Burdach and they present no secondary degeneration.

General Properties of the Spinal Cord.

As regards the general properties of the cord, as shown by the effects of stimulus applied to its exterior or to its cut surface, the term excitability will be used to express a property indicated by direct muscular contraction following stimulation of the cord, and sensibility, a property which enables it to receive impressions which produce pain. In exciting different parts of the cord with electricity, it is necessary to carefully guard against an extension of the current beyond the points which it is intended to stimulate. Some physiologists regard the cord as absolutely inexcitable and insensible, both on its surface and in its deeper portions. With this view, it is supposed that parts of the cord will conduct motor impulses received from the centres situated above, but are not excited by a stimulus applied directly. In the same way, it is thought, parts of the cord will convey sensory impressions received through the nerves, but are insensible to direct irritation.

The results of the observations of Van Deen, Brown-Séquard, Schiff and others, were simply negative; but the positive results obtained by Longet, Fick, Vulpian and those who regard parts of the cord as excitable and sensible, show that certain of the columns react under direct stimulation.

In some experiments made in 1863 (Flint) upon a living dog, the cord having been exposed in the lumbar region and stimulated mechanically and with an electric current two hours after the operation, certain positive results were obtained, which led to the following conclusions:

The gray substance is probably inexcitable and insensible under direct stimulation.

The antero-lateral columns are insensible, but are excitable both on the surface and in their substance; and direct stimulation of these columns produces convulsive movements in certain muscles, which movements are not reflex and are not attended with pain. The lateral columns are less excitable than the anterior columns.

The surface, at least, of the posterior columns is very sensitive, especially near the posterior roots of the nerves. The deep portions of the posterior columns are probably insensible, except very near the origin of the nerves.

The above conclusions refer only to the general properties of different portions of the cord, as shown by direct stimulation, in the same way that the general properties of the nerves in their course are demonstrated.

Motor Paths in the Cord.—What has been said regarding the direction of the fibres in the cord and the situation and course of the degenerations following destruction of motor cerebral centres conveys a definite idea of the motor paths in the cord. This idea is sustained by experiments in which different columns of the cord have been divided in living animals.

The motor paths are in the direct pyramidal tracts (columns of Türck) and in the crossed pyramidal tracts of the lateral columns. The motor impulses are conveyed by the fibres of these tracts to the multipolar cells in the anterior cornua of gray matter and are thence transmitted to the anterior roots of certain spinal nerves. In the lower dorsal region the conduction is confined to the crossed pyramidal tracts in the lateral columns, while above, the direct pyramidal tracts participate in this action.

The motor fibres decussate in the anterior pyramids of the medulla oblongata (crossed pyramidal tracts), and in the cervical region, to a comparatively slight extent, before the direct pyramidal tracts (columns of Türck) pass to the encephalon. In the cervical region the decussation takes place probably in the anterior white commissure. The fact of this decussation of motor conductors is sustained by pathology—paralysis of motion following brain-lesions, occurring on the opposite side of the body—and by experiments in which the fibres as they cross are divided by a longitudinal median section in the medulla and in the cervical region of the cord.

Vaso-motor nerve-fibres exist in the lateral columns of the cord and probably are connected with the cells of the gray matter. They pass out in the anterior roots of the spinal nerves and go to the blood-vessels either from the branches of the spinal nerves directly or through filaments sent to the sympathetic.

Sensory Paths in the Cord.—The gray matter of the cord is the part concerned in the conduction of sensory impressions (Bellingeri, 1823). This fact has been verified by recent experiments; but it is thought that some of