*The*

# PYRAMIDAL TRACT

*Its Status in Medicine*

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# Introduction

MOVEMENT, or the ability to propel through space, is characteristic of the biological world. There are some authorities who are convinced that the central nervous system has evolved primarily to produce motion. Although the pyramidal tract is universally regarded as being concerned with innervating voluntary muscles, all chordates below mammals (pisces, amphibia, reptilia and aves) are able to make adjustments to their respective environments without it. The motor behavior in sub-mammalian species varies but evolves from simple undulating swimming actions to hopping, to walking, climbing and running, and finally to flying. The problems for those interested in broad research on the pyramidal tract would be probably to find what its true anatomical, physiological, pathological and clinical role may be in mammals. It is the purpose of this monograph to collect and correlate the known facts on the pyramidal bundle in an attempt to ascertain its true status in medicine.

There are about a half-dozen pathways in the central nervous system about which much is known and can be written. The pyramidal belongs to this group. The reasons for this are inherent in the tract itself. It was one of the first fasciculi to be observed in man and to excite general curiosity. It was assigned a major function and the results of a continuous series of investigations over a period of many years did not materially alter the original conceptions of it. Further, no other group of fibers in the central nervous system resembles it in respect to its length, its varying position from the surface, its square area, its fiber constituents, its splitting into bundles, its crossing characteristics

and its blood supply. It has been regarded as the most vulnerable division in the brain and spinal cord on the basis of the frequency with which voluntary motor paralysis, a debilitating symptom, is encountered clinically. Therefore, the pyramidal tract should have considerable applied significance.

This pathway has apparently been of investigative interest principally to medical men. Most of the fundamental facts regarding its status in man were contributed before 1900. The majority of publications have emanated from the countries of Britain, the U. S., Germany, France and Italy. These five nations have published about 95% of all the articles listed under the heading of "pyramidal tract" in the Medical Index as far back as can be traced. Very few investigators have devoted their full time and energies to investigating it so that the studies, on the whole, have been scattered, heterogeneous and little correlated.

Every neurological investigative approach has been utilized in studying the origin, course and termination of pyramidal neurons. The following is an outline of the methods employed:

*A. Anatomical.*

I. Gross dissection.

II. Embryological—the myelinogenetic method.

III. Histological—including biometrical studies.

*B. Physiological.*

I. Electrical and strychnine stimulation.

II. Effect of lesions—experimental, diseased processes and surgical.

*C. Pathological.*

I. Studies of secondary degeneration—experimental and pathological. Involves the use of such stains as silver, myelin sheath, cellular and Marchi.

II. Retrograde degeneration.

*D. Clinical*—studies of signs and symptoms in man.

All the general methods were applied, in one form or another,

before the year 1909. Of the categories listed above, the physiological has been apparently the most popular. The gross dissection and myelinogenetic approaches have enjoyed but a short vogue. Probably the biggest gap in our over-all knowledge of the pyramidal tract in man exists in the neuropathological field because few exact scientific studies have been made since the original pertinent investigation of Bouchard in 1866. Great reliance and confidence have been placed on certain specific methods of investigation. For example, the results of retrograde degeneration have to be regarded as important since they were initially judged to prove unequivocably that the pyramidal fibers arise from Betz cells. In more recent years, the application of silver stains in studying degeneration in the fibers and their end bulbs as well as oscillographic recordings following stimulation of the tract fibers have been added to the array of research procedures.

On checking and comparisons, it is noticeable that there are hardly any two investigations on the pyramidal tract, using identical technics, which harmonize in all essential facts. Every neurological method seems to have some inherent weakness. There is no one stain, for instance, which acts on all the component parts of a pyramidal neuron. All the approaches utilized for studying function are crude by comparison with what goes on normally in the brain and cord. Besides, there is a human factor which depends upon the background, skill and interpretative ability of the contributing investigators.

Although the foundational studies were made on man, the pyramidal tract has been investigated broadly. Some animals have been observed more than others. Certain species, because of their restricted and remote geographical location from the important neurological laboratories, have not been analyzed from the standpoint of their motor systems; in this category can be placed such groups as edentates (ant-eaters), insectivores (moles), cetacea (whales) and chiroptera (bats). Ease of ob-

tainance has undoubtedly been a factor in the selection of such animals as the rat, cat, dog and monkey. Such investigations as have been made show that the pyramidal tract is a relatively late phylogenetic addition to the central nervous system, that it is not cast on any standard mold and that there is a gap in our knowledge of its anatomy and physiology in marine and air mammals.

From the medical point of view, research on the pyramidal tract of sub-human mammals would be probably classified as basic. The question arises as to what practical value results from studies on lower ranking mammals. The great concept of cerebral motor localization began with a crude, electrical experiment on the cortex of the dog (Fritsch and Hitzig, 1870) and this approach has been popular and influential ever since; the phylogenetic age of the pyramidal tract is thought by some clinicians to be of significance in its susceptibility to diseased processes and actual physical and chemical differences have been prognosticated for it on this basis (Brouwer, 1920). Observations on sub-humans have also been taken into consideration by clinicians in respect to the type, character and permanency of the paralysis produced by pure lesions in the pyramidal tract.

From the phylogenetic aspect, pyramidal neurons have been investigated in some mammals in respect to their origin, course and termination. Attention has been paid to the lower extent of the bundle, the position it may occupy in the funiculi of the spinal cord and whether it subdivides into component parts. Since it has been found that the constant feature of the pyramidal tract is its passing, in relative isolation, through the anterior pyramids of the medulla oblongata, this region has been chosen as a site to make biometrical measurements. Its square area, the determination of the size of the individual fibers and the total number of axons as well as its degrees of myelinization have been studied in the pyramids.

There have been a few attempts to correlate the physio-

logical results obtained on motor studies in lower mammals with the anatomy of the tract. Most of the functional work has been done by means of either electrical stimulation, ablations of the motor cortex or section of the pyramids. The last two named methods have been the most influential and in late years the results obtained in apes have been instrumental in raising questions regarding spastic or flaccid phenomena. Both morphological and physiological results indicate that the tract assumes more importance in its evolution from lowest to highest mammals.

Although the pyramidal tract offers an opportunity for studies in experimental pathology, only several investigations have been made. These have been concerned with determining the sensitivity and reaction of the large, intermediate and small-sized neurons in response to trauma of their cells of origin.

The advantage of the experimental method in sub-human mammals lies in the fact that accurate circumscribed lesions can be made in some portions of the pyramidal tract and their effects studied. The disadvantages from the clinical viewpoint are the following: Comparatively speaking, lower mammals do not have a well-developed pyramidal tract, their postures are not erect and their voluntary movements are less skilled. Investigations restricted to man alone have the handicap that they must concern themselves largely with the experiment of disease, the lesions of which may not be accurately localized. It may be, however, that the key to the understanding of the pyramidal tract in man lies in ascertaining the meaning of its varied morphological and physiological characteristics throughout the phylogenetic scale. By continued research, the question may be solved as to whether it basically changes its function as the mammalian phylogenetic scale is ascended.

There exists a tremendous volume of literature revolving around the pyramidal tract in man. Some of this is off the

beaten highways and is to be found objectively in general articles or isolated case reports. There is an extensive bibliography on the sign of Babinski alone. A review shows that human paralysis has been known and speculated upon for thousands of years; the anatomy, physiology and pathology of the pyramidal tract has been studied for about a century. The view which developed quickly in the mid-nineteenth century and became firmly crystallized in the minds of medical men is that the pyramidal tract is the great motor fasciculus and that when involved by pathological lesions there develops a definite syndrome. This involves interference with movement, tone, and reflexes. The classical symptomatology usually given is the following: paralysis of voluntary motion, the presence of spasticity, the absence of atrophy in the muscles, the ability to respond actively to electrical stimulation of peripheral nerves in spite of paralysis and finally a host of abnormal reflexes among which the Babinski is regarded as the most important. Not all the muscles are said to be affected equally by pyramidal lesions, some being more vulnerable. It is only in recent decades that some of these traditional concepts have been questioned.

Throughout the years, numerous scientific terms have been selected to describe pyramidal lesions producing paralysis of voluntary motor muscles such as hemiplegia, paraplegia, diplegia, monoplegia, tetraplegia, brachioplegia, acroplegia and others. These are based on the location of the parts exhibiting motor deficits and imply maximal paralysis. No scientific terminology has been formulated regarding variations in the degree of musclar deficiencies outside of the term paresis which means a milder form of paralysis. Few case reports need to be studied to learn that it is possible to have pathological involvement of the central nervous system so that the symptoms vary from simple or maximal deficits. For example, the Babinski sign may be the only evidence of disturbance present, or altered ten-

don reflexes, or interference with tone, or any possible degree of paralysis or, finally, any combination of these.

One of the controversial issues revolving around the pyramidal tract syndrome is its relation to muscular tonicity both under normal and pathological conditions. Whether spasticity or flaccidity occurs in man following degeneration in its fibers is a problem that is being explored in both experimental and clinical fields of research.

The status of reflex activity has been extensively studied for many years in patients exhibiting voluntary motor paralysis. Alterations have been noted in skin reflexes affecting the big toe and in the abdominal and cremaster muscles. The most important sign in neurology is regarded by some as the Babinski reflex. Other pathological signs of a somewhat similar nature are manifold and include such well-known ones as the Oppenheim, Schaefer, Allen and Cleckley, Chaddock, Gonda, Weinberg and the resistant reflexes.

The question arises as to whether any correlation has been made between any or a combination of these motor abnormalities with observed involvement of the pyramidal tract. The syndrome is only as good as the pathology or experimental evidence which supports it. External signs and symptoms are much easier to study than their causes within the brain and cord. The pyramidal syndrome appears to be a phenomenon occurring largely in man in the phylogenetic scale and it is known to follow such pathological entities as neoplastic, vascular, traumatic, inflammatory, toxic, sclerotic and congential processes in the central nervous system. Just how each of these conditions affect the pyramidal neurons is an unexplored field.

Surgery has been performed in the past few years to alleviate the presence of tremors by sectioning of pyramidal fibers. The theoretic basis for this procedure is that the tract, in these cases, is thought to conduct abnormal impulses of a release nature. So far, the surgical lesions in man have been made in ap-

proachable sites, the spinal cord below and the motor regions above.

There has been a minority group of theorists and investigators during the past hundred years who have refused to consider the pyramidal tract as a self-sufficient, autonomous unit. They have taken the afferent system into account in attempts to explain what initiates, directs, modifies and dominates the pyramidal impulses leaving the cerebral cortex. Their conclusions are presented in the text in the belief that the sensory aspects of motor behavior have been neglected and underrated in the considerations of the mechanism behind efferent physiology.

It is the belief of the author that the pyramidal tract, from the broad viewpoint, is such that it constitutes an enigmatic and challenging pathway. Since 1850, medical men have regarded it as the most important in the central nervous system. In the past two decades, there has been a revival of scientific interest in certain aspects of its anatomy, physiology, pathology and clinical significance. These recent results and interpretations are such that some traditional views have been questioned. Some attempt is here made to cover the major facts in its evolutionary history and to present the story of the pyramidal tract with emphasis on man.

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# Events Leading to the Discovery of the Pyramidal Decussation- 460 B.C.-1710 A.D.

MEDICAL men have long been interested in the manner and frequency in which the voluntary muscles of man can be affected by disease of the brain and spinal cord. In the earliest times, paralysis was the only symptom known for involvement of the central nervous system. Hippocrates (460-377 B.C.) knew that disease of one side of the brain produces motor deficits on the contralateral half of the body. As far as is known, this was the first step in cerebral localization. However, he thought that paralysis was caused by phlegm blocking the channels which transmitted the pneuma.

It took twenty-two centuries after the time of Hippocrates before the observations of pioneering investigators on the human brain-stem suggested an explanation for the presence of paralysis opposite to the side of the lesion. Much of this tardiness in progress can be explained on the basis of the universal restrictions placed on human dissections. During this scientifically retarded era, only a few publications were made on this subject. The first of these was by Galen (131-201 A.D.) regarded as the founder of experimental physiology. Although he was considered to be the most skillful practitioner of his time and must have observed many cases of human paralysis during his wanderings from capital to capital, he is best known for his investigations on animals. He may have

been the first to produce experimental injuries in the central nervous system, using apes and swine. Some of his contributions to motor neurology are the following: a complete transection of the spinal cord produces a total paralysis whereas a hemisection affects the same side; by contrast, a longitudinal incision is not followed by a loss of movement. Galen apparently did not mention the crossed effects of brain lesions. As an anatomist, he left many excellent descriptions of the motor system. Much of the work, however, was faulty and inaccurate in its application to man.

The first theoretical explanation of an anatomical nature for the crossed paralysis occurring in head injuries appears to have originated from Aretaeus of Cappadocia, who is thought by some to have lived in Alexandria, Egypt, about the second half of the first century A.D.; by others he is placed in the early second century. This physician is acclaimed by Mettler (1947) as the greatest after Hippocrates. He believed that a decussation of each of the peripheral nerves from its point of origin in the central nervous system to the opposite side could best account for crossed paralysis. In modern terms, this would mean a lower motor neuron crossing in the spinal cord and brain-stem instead of a decussation of the upper or pyramidal. In spite of his being wrong in the light of our present knowledge, the idea of Aretaeus was an enlightened one for his time and is based on sound theoretical reasoning.

Other early ideas as to the etiology of voluntary motor paralysis were that it is due to the clogging of the motor nerves by thick, viscid humors (Aetius of Amida, Fl. 380 A.D.) or that the responsible phenomenon is a stoppage of the flow of animal spirits caudally (Caelius Aurelianus, Fl. 400 A.D.).

Although apoplexy was known as a clinical syndrome for many centuries, it wasn't until 1658 that Wepfer defined it as being due specifically to vascular insult, thus placing its pathology for the first time on a hemorrhagic basis. In his

treatise, which has been regarded as historically important, he stated that the opposite muscles are mostly affected but felt that some lesions produce unilateral effects.

Some, but not all, historians credit Domenico Mistichelli (1709), professor of medicine at the University of Pisa, as being the one who discovered and first described the decussation of the human pyramids. The latter was done in a treatise on apoplexy which has become a rare work. In it, he explains the contralateral paralysis by a new concept. He stated that the "medulla is on the outside interwoven with fibers, which by their criss-cross superposition, resemble a woman's braid, whence it comes that many nerves which branch out on one side, have their roots on the other." He believed that the cranial and spinal nerves arose from the pia mater instead of the nerve tissue underneath. It would seem that Mistichelli had very little understanding of even the most primitive neurologic concepts involved in the phenomenon of crossed motor conduction. However, he must have searched for an explanation of contralateral paralysis and dissected the human medulla oblongata. Having noticed the pyramidal decussation, he inferred that it was the answer to the question which had puzzled medical men for centuries. Thomas (1910), in his historical inquiry into the decussation of the pyramids, says it is remarkable that Mistichelli is spoken of as the discoverer of this part of the nervous system.

Just one year later, the much less equivocal results of the investigation of Petit were published in a pamphlet entitled *Lettres d'un Medicine, etc.* Namur, (1710). Two hundred copies were made, none of which have been found in America. In his study of the pyramidal decussation, he used three approaches combining the clinical, experimental and anatomical methods. This was unique considering the scientific atmosphere of the early eighteenth century.

Petit observed on patients that brain injury, usually abscess,