The Contribution of the Precentral Gyrus to the Pyramidal Tract of Man

JOHN A. JANE,* DAVID YASHON, WILLIAM DEMYER, AND PAUL C. BUCY
Illinois Neuropsychiatric Institute, Indiana University, and Northwestern Medical School, Chicago, Illinois

The origin of the pyramidal tract of man is not known. For carnivores, monkeys, and man, virtually all fibers arise from the neocortex, but the exact contribution of each cortical area is known only for the cat and macaque. In man this noteworthy lack of information results from the improbability that ordinary brain lesions will be restricted to specific cortical areas. The lesions of natural disease, trauma, and, except in rare instances, congenital malformations are much too diffuse to approximate the precision of experimental cortical ablations. Since the usual clinical material is of little help in locating the areas of origin of the pyramidal tract, any case which approximates the experimental ideal gains in importance. In the case reported here, the cortical arm, trunk, and leg area of a patient was surgically removed under unique circumstances comparable to experimental conditions. The clinical features, some of which have been reported before, are important in evaluating the resulting degeneration in the pyramidal tract.

Case Report

The patient's birth and early infancy were uneventful. At the age of 2-½ years, she was found to have purposeless, involuntary movements of her left arm and left leg. These movements continued and, at the time of her first hospital admission at the age of 25, were described as an arrhythmic torsion spasm occurring at a rate of about one per second in the left arm including the shoulder, elbow, and wrist. There was little evidence of spasm in the left hip or knee, but the ankle showed internal rotation and plantar flexion. There was some weakness of the left hand; the left lower abdominal reflex was not obtained, but there was no Babinski sign. At that time the left anterior column was cut at C-2 by Dr. Eric Oldberg. This was accomplished by rotating the cord and attempting to crush the anterior column with a hemostat; it resulted in temporary relief from the involuntary movements.

At the age of 27, a right frontoparietal craniotomy was performed. All parts of the exposed area were systematically stimulated with a 60-cycle sinusoidal current; only the precentral gyrus was found excitable. All of the precentral gyrus which produced movement of either the left arm or leg was excised. This included the paracentral lobule on the medial surface of the hemisphere and the anterior wall of the Rolandic fissure.

An inexitable area between the representation of the fingers and eyelids was not removed initially. At the age of 31, when involuntary movements returned in the left hand, this remaining cortex was removed.

The patient made an excellent recovery with marked diminution in the involuntary movements. She continued to show a moderately-severe left hemiparesis; the arm was worse than the leg. She could not make purposeful movements of individual fingers. She also showed loss of position sense, two-point discrimination, and perception of figure writing on the left side. She died when she was 51 years old, 7 days after a primary hemorrhage into the left cerebral hemisphere and 20 years after the last cortical extirpation.

Methods and Results

The gross extent of the two excisions is shown in Fig. 1. To determine whether structures giving rise to or conveying the pyramidal tract were damaged before the cortical excisions, we examined the brain by semi-serial section. Multiple sections were taken and stained with Luxol fast blue. The cortex anterior and posterior to the ablation did not have the cytoarchitectonic features

Received for publication April 22, 1966.
Revision received August 19, 1966.
* Present address: Western Reserve University School of Medicine, Division of Neurosurgery, University Hospitals, Cleveland, Ohio.
FIG. 1. Excision of the right precentral gyrus in man. A. Lateral view of right hemisphere. B. Semi-lateral view of right hemisphere showing medial extent of the lesion. C. Superior view of right hemisphere.
FIG. 2. Photomicrograph of brain stem showing the small pyramid and medial lemniscus on the right.

of Area 4. No other areas of cortex were damaged, and the boundary of the lesion was sharp. The right thalamus had multiple cavitations and was severely shrunken. There were no gross or microscopic cavitations in the caudate nucleus or internal capsule. The right medial lemniscus was one third of its normal size. We assumed that the cavitations in the thalamus were partly due to the original pathology and partly to retrograde degeneration secondary to the cortical lesion. At the time of autopsy, the cord and brain were separated at the C-2 level so that the original Oldberg lesion in the cord could not be confirmed.

Frozen sections of the pyramids were silver-impregnated for axon counting. The left pyramid had a cross-sectional area of 8.8 mm² and contained 1,300,000 axons; these figures were considered within normal limits. The right pyramid measured 5.45 mm² and contained 522,000 axons, or 40% of the number in the left. The larger axons were preferentially lost (Fig. 2). Although some axons were fragmented due to the intracerebral hemorrhage, they were included in the census and did not significantly affect the estimate of the total number of fibers.

Discussion

The axon count made it clear that the maximum number of fibers that could have arisen in the excised cortical tissue was 60% of the total number of pyramidal tract fibers originally passing through the right pyramid. Although we can state this maximum with confidence, we cannot state the minimum number that may have arisen in the excised cortex because some axons may have been previously destroyed by an unidentified lesion, causing symptoms when the patient was 2-½ years old. Nevertheless, the data suggest that a high proportion of man's pyramidal fibers originate from the precentral gyrus.

This inference is supported by the evolutionary history of the pyramidal system as judged from examination of a marsupial, an insectivore, and various primates. It should
be emphasized that the relationships between these groups and the actual antecedents of man is only an approximation. For instance, the marsupials might best be considered as arising independently from the therapsid reptiles rather than bearing any special relation to the eutherian mammals; moreover, the proper systematic position of the tree shrews is by no means settled.  

However, if we compare the neocortical origin and spinal termination of this tract in an opossum (Didelphis virginiana), a Malayan tree shrew (Tupaia glis), a prosimian primate, the slow loris (Nycticebus coucang), and an old-world monkey (Macaca mulatta) with that in our human case, the change may be described as a convergence of pyramidal cells into a progressively more restricted cortical location. In the opossum, for instance, a wide area of cortex is electrically excitable, but motor and sensory areas cannot be differentiated. Indeed, the motor and sensory figures are completely congruent. Moreover, this single sensorimotor area shows a representation of body parts (back caudally and limbs rostrally) that is typical of the sensory and not the motor representation in all other mammals studied.

From this observation we surmise that the motor cortex is the more recent phylogenetic acquisition arising rostrally from the combined sensorimotor area and becoming progressively devoted to motor behavior. This development may be noted in two aspects of the organization of the motor cortex: first, a relatively smaller area gives rise to the tract, and second, a greater concentration of fibers arises from the precentral gyrus. Thus, in the slow loris, a prosimian primate, fibers arise from the tip of the frontal and well back into the parietal lobes. In the shrew, a preprimate, they also arise from a wide area, although apparently not from the extreme frontal tip.

In the macaque, however, few if any fibers originate in the frontal lobe anterior to Area 6, while 31% of the pyramidal tract originates from the precentral gyrus. This second characteristic in the evolution of the cortical origin of the pyramidal tract is emphasized by the fact that in our human case 60% of the fibers arose in the precentral gyrus. Furthermore, in a recent study on man, a complete absence of the pyramidal tract was noted in association with a congenital cleft in the Rolandic region. Because of this progressive restriction of the area of origin of the pyramidal tract during primate evolution and because in man 60% of the fibers arise from the precentral gyrus, it seems likely that virtually all of the fibers of the pyramidal tract of man arise in the region of the Rolandic fissure.

As motor cortex differentiates from primitive sensorimotor cortex, the spinal course of the pyramidal tract undergoes an analogous transition. In the opossum and tree shrew, the fibers in this tract are located in the dorsal columns beneath the phylogenetically more recent pathway to the thalamus and end, not on the motor cells of the ventral horn, but on the sensory or internuncial of the intermediate grey columns. However, in the loris, monkey, chimpanzee, and man, the tract is lateral, terminating upon ventral horn cells thus giving the neocortex direct control over motor function by virtue of a discrete motor area, motor pathway, and termination upon motor cells. Alternatively, one might assume that the position of the tract is an independent acquisition in each order. A choice between these interpretations is difficult to make because the actual ancestors are not available for study.

There are many aspects of the development of the pyramidal system that are similar to the transitions seen in the sensory systems. For instance, the way in which the motor cortex is derived from a combined sensorimotor area is reminiscent of a postulated development of the dorsal thalamus, where specific nuclei for somesthesia and audition may have developed from a multimodal sensory area. Also, the long motor tract by-passes dorsal and intermediate zone cells in the spinal grey matter and ends on the ventral horn cells, as noted in the sensory pathways by Bishop. Herrick has described the development of the nervous system in similar terms, namely, that the specific long pathways may have developed and assumed specific functions after differentiating from a diffuse multi-functional neuropile.

In contradistinction to many phylogenetic speculations, our hypothesis that there is an increasingly restricted origin for the pyramidal tract has the advantage that it can be
operationally tested. When the surface area of the neocortex and the quantitative contribution of each specific cytoarchitectural area to the pyramidal tract is known for a wide series of animals, the problem can be resolved. These determinations are well within the capability of current techniques.

Summary

The precentral gyrus of man has been found to contribute a maximum of 60% of the fibers of the medullary pyramid. This figure was determined by counting the fibers remaining in the pyramid following surgical removal of the precentral gyrus. Because of this finding and because the evolutionary history of the pyramidal tract indicates a progressive tendency toward a restricted neocortical site of origin, and finally because a congenital cleft in the Rolandic region has been found to be associated with absence of the pyramidal tract, it seems probable to us that in man virtually all of the pyramidal tract arises from the region of the Rolandic fissure.

References