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Cerebral Localization—What Is Known, What  
Surmised, and What Is Its Surgical Value?

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*presented by the author*

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CEREBRAL LOCALIZATION—WHAT IS  
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THE physiology of the nervous system and the functional differentiation of its component parts has been but recently investigated, and is now in many particulars so well established that it seems proper before entering the domain of neurologic pathology to briefly recapitulate, not only that which has been scientifically proven, but the many speculations of eminent investigators that are as yet mere hypotheses. Without going into a detailed history of the evolution of cerebral physiology, I will refer to the great advance made by the anatomists of the seventeenth century. Before that time anatomy and physiology were necessarily theoretical, for as a basis they rested on speculation and tradition, not on the dissection of the human body. But the opinions held regarding the nervous system were even more crude than those that prevailed regarding other portions of the body, for the philosophers, led by Aristotle and Herophilus, had outlined a physiology based on their psychologic theories, and twenty centuries had served but to confound the already existing confusion.

Willis accomplished for the nervous what his contemporary, Harvey, did for the circulatory system. He not only delineated and named the cranial and spinal nerves, but recognized the important fact that the brain is not only divided into gray and white matter, and correctly explained the functions of each, but also showed that the gray matter was convoluted simply as a wise provision for inclosing the greatest surface in the smallest space, realizing that there was a direct ratio between intelligence and the volume of gray matter, and further suggesting the possibility of its function being still more differentiated.



The next great advance in the differentiation of the nervous system was Sir Charles Bell's discovery that the spinal nerves subserved the twofold purpose of sensation and motion, the one entering through the posterior root bearing sensation from the periphery, the other solely motor, making its exit by the anterior root. This he proved by experiments on living animals; and his results, published in 1811, were elaborated with so much detail that our own text-books do not contain any amplification of the theory there propounded. When, in 1870, Fritsch and Hitzig announced the result of their experiments on dogs and monkeys, they were but confirmatory of views already advanced by Hughlings Jackson, whose investigations, both clinical and post-mortem, had suggested the existence on either side the fissure of Rolando, of special centers which presided over the movements of the leg and arm. But even earlier than this, Dax had pointed out the close relationship existing between aphasia, right-sided hemiplegia and injury of the frontal convolutions; though it was Broca who definitely located the speech center at the base of the third frontal convolution of the left hemisphere.

The original experiments performed by Fritsch and Hitzig consisted in the removal of a portion of the skull of dogs and monkeys, exposing the brain and irritating the cortex. Before this it had been believed that irritation of the cortex resulted only in convulsions, but when electricity was selected as a stimulus and very weak currents used, it was found that irritation of certain convolutions produced definite motions, and so localized were these areas that it was possible for the experimenters to foretell the motion that would follow the application of the electrodes to a given area. This conclusively proved that there was some definite relation existing between these localities and movements of various members of the body.

Ferrier and Horsley in England and Munk in Germany, modifying the methods of Fritsch and Hitzig, have so extended and varied these experi-

ments as to eliminate all possible errors; the areas have been so incised as to separate them from other cells of the cortex, and portions of the cortex containing these areas have been removed and the resulting paralyzes noted. Thus have the old theories been revolutionized and most plausible arguments advanced to support the assertion that not only the special senses but that motion and sensation are located in well-defined and accurately differentiated regions of the cerebral cortex.

So brilliant and so essentially scientific were these experiments that the deductions made from them as to cerebral localization have been accepted not only by the majority of physicians, whose judgment can not be based on personal investigation, but especially by many leading neurologists. But this acceptance is not universal, and it may be said that neurologists are ranged into three schools.

The very weighty names of Brown-Séquard and Goltz appear among those who altogether repudiate localization in the sense that one portion of the cortex intrinsically so differs from another as to possess a different function. They believe that each half of the cerebrum acts as a whole, but that certain portions may be educated and probably do preside over the special senses, motion and sensation.

The second school, represented by Exner, Obersteiner, and other conservative neurologists, teach "that certain regions of the cortex are to a greater extent than the rest associated with certain functions." Obersteiner defines his position as follows: "Individual centers and cortex fields are not to be considered as sharply outlined and definitely marked off from neighboring regions; the so-called centers are rather the spots of maximal relation to functions which fade away into neighboring areas. Hence it follows that the cortex fields to a certain extent overlap one another. We shall speak of the centers in this sense as comprehending the spots of maximal physiologic relation."

The third, known as the English school of local-

izers, is led by Ferrier, Horsley, and Beevor. These teach the absolute segregation of centers in the cortex; that they intrinsically differ the one from the other, and that consequently their functions differ,



and that there are not only regions presiding over the special senses, sensation and motion, but divide the last into finger, hand, arm, mouth, etc., centers; and further contend that these areas are sharply defined, are easily located, and, when exsected, produce a permanent paralysis in that member of the body over which they preside.

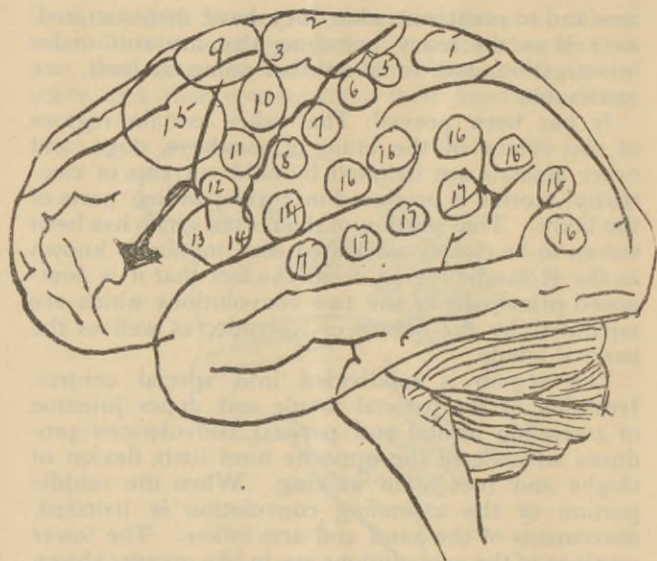
It is this last which has brought this subject into such prominence. Granting that either the first or the second school be right, it is only a step forward in the study of cerebral physiology; but if the teachings of the abrupt localizers be correct, a vast field of practical importance has been opened and cerebral surgery will at least receive a scientific recognition, rather than occupy the invidious position it even yet holds among conservative surgeons. For this reason it seems well to review the work of these investiga-

tors and to point out what they have demonstrated, as well as the many questions that are still under investigation, and to show that some, at least, are unsolvable.

It has been proved: That when certain regions of the cortex of the brain of monkeys, dogs, and other animals are irritated by mild currents of electricity, motion is produced in corresponding parts of the body. That portion of the cortex which has been shown to be closely associated with motion is known as the Rolandic region, from the fact that it is composed principally of the two convolutions which are separated by the fissure of Rolando, as well as the parietal lobule.

This region is subdivided into special centers. Irritation of the parietal lobule and upper junction of ascending frontal and parietal convolutions produces advance of the opposite hind limb, flexion of thighs and toes as in walking. When the middle portion of the ascending convolution is irritated, movements of the hand and arm follow. The lower portions of the convolutions are in like manner shown to preside over, or at least to be closely associated with, movements of the mouth, tongue and nose. Posteriorly, near the angular gyrus, irritation results in movement of the eyes and eyelids, and still farther downward on the superior temporo-sphenoidal convolution there is pricking of the opposite ear, head and eyes turn to the opposite side, and the pupils widely dilate. Other regions, though irritable, are not connected with coördinated movements, while much of the cortex is insensitive. Thus is it shown that motor activity, though present to the greatest extent in the so-called motor area, is not confined to it. These experiments have also demonstrated the fact that while each hemisphere is closely associated with the opposite half of the body, to a subordinate degree it also presides over the same side.

It is surmised: that the brain of the monkey and other animals resembles the brain of man to such a degree that what is true of the one holds equally true



of the other; that both in man and animals the brain is so differentiated that certain areas preside over allotted functions, and that they are capable of being subdivided. Especially is this true of motion. To a lesser extent it is true of the special senses, and the brain has been mapped out into centers of sensation, hearing, sight, smell, taste, and speech, and these have been located as follows:—

*Motion.*—The ascending frontal and parietal convolutions, their superior junction and the paracentral lobule, known as the Rolandic or motor region, have been subdivided into finger, hand, arm, mouth, etc., centers, every muscle or group of muscles being represented by a definite area in the brain cortex, and any given action or series of coördinated movements can be obtained by irritating the proper area of the denuded cortex. These conclusions are the result partly of comparison with animals and partly of pathologic research, and may be thus summarized:—



Superior parietal lobule (1), advance of hind limb. Upper portion ascending parietal (2, 3, 4), complex movements of leg, arm, and trunk as in swimming. Ascending parietal (5, 6, 7, 8), individual and combined movements of fingers and wrist of hand; prehensile movements. Posterior extremity of superior frontal convolution (9), extension forward of hand and arm. Ascending frontal (10), supination and flexion of forearm. Lower third of ascending frontal and junction of ascending frontal and ascending parietal (11, 12, 13, 14), movements of mouth and nose. Superior and middle frontal (15) and supra-marginal lobule and angular gyrus (16). Movements of mouth, eye deviates, pupils change and head turns (sight). First temporal (17), pricking ear (in animals), head turns and pupil dilates (as in hearing).

*Visual Center.*—In Ferrier's original experiments this center was located in the angular gyrus (16), as blindness resulted when this was destroyed. But other operators claim that sight is centered in the occipital lobe (16), and showed that when the gyrus only was destroyed and the life of the animal was prolonged beyond a few days, sight returned. On destroying the occipital lobe with the angular gyrus the resulting blindness was more prolonged. Ferrier says: "After extensive destruction of the occipito-angular region in one hemisphere, the temporary amblyopia of the opposite eye leaves a more enduring homonymous lateral hemiopia to the opposite side, yet unless the destruction of the cortex is absolutely complete (and in none of the recorded experiments was this the case), restoration occurs, to such an extent, at least, that the defect ceases to be perceptible by any tests applicable to the lower animals." In other words, provided this be the center, some other portion of the brain assumes the function and is able to successfully receive and transmit visual impressions. It is further claimed that the simultaneous destruction of occipital regions in both hemispheres may produce permanent blindness, and Ferrier even goes the length of claiming that these

regions are the central expansions of the optic tracts and consequently structurally differ from other centers, and that in his experiments atrophy of the nerves and tracts has followed destruction of these zones. But localizers are by no means agreed among themselves as to many of the minor facts, though the occipital lobe is the accepted center.

*Auditory Center.*—Experiments made on the lower animals as to the center of hearing are, from the very nature of the facts to be elicited, extremely unsatisfactory. It has been found impossible to eliminate the complications incident to the difficulty of intelligently interpreting the phenomena following the various lesions. Experiments seem to point to the superior temporal convolutions, and it is claimed that post-mortem researches bear out this location.

*Olfactory Center.*—This has been selected from purely anatomical considerations. The roots of the olfactory nerve have been traced to the hippocampal region and the sense of smell has been assigned to the tip of the temporo-sphenoidal lobe. Comparative anatomy teaches us, however, that the olfactory bulb itself is a portion of the brain, and it would seem that if any portion of the brain were selected for special functions, this would alone preside over the olfactory sense.

*Tactile Center.*—There is no question in cerebral localization more undermined and apparently more undeterminable than is this. It is well known that the sensory fibers when they pass through the internal capsule are differentiated from the motor tract, but the region to the cortex to which they are distributed has not been determined. Ferrier and his school locate this center in the hippocampal region, but the majority of neurologists agree with Flechsig, who believes that the cortical fields of motion and sensation overlap each other, both occupying the Rolandic region.

*Center of Speech.*—By motor aphasia is meant an inability to articulate, not to properly understand and appreciate what is heard. This center, situated at the base of the third frontal convolution of the left hemi-

sphere, known as Broca's convolution, has received much attention at the hands of pathologists, and medical literature teems with post-mortem facts that prove the close relationship this region bears to articulate speech. It has been further claimed that only in right-handed persons is this center on the left side, while in the left-handed it occupies a corresponding position in the right hemisphere. There is no fact in cerebral localization more generally recognized by the profession than is this speech center, and it may be a matter of surprise that it is not included among those questions of cerebral physiology which have been proven. Nevertheless, that this center presides solely over speech, and that its functions can not be assumed by other portions of the cortex, has by no means been demonstrated. It is not possible to here enter into a discussion of this point, but it can be stated positively that while many facts point to a connection between this center and articulate speech, it has been conclusively shown that tumors involving this region have not produced aphasia. One such well-authenticated case is sufficient to overcome any number of facts which are adduced in support of the theory of a well-defined speech center. Not only have tumors been found which interfered with the Broca convolution, but embolisms have been recorded in which this whole area was softened and disintegrated without causing a loss of speech. Leading authorities, notably Bateman in his recent work on aphasia, take the middle ground. While they recognize the close relationship between the destruction of the Broca center and aphasia, they deny absolutely that it is in the strict sense of the term a *center*. They believe that it, as well as other regions of the brain, bear some as yet undetermined relation to the faculty of speech. With all the light before us the most that can be said is that when the Broca center is involved in some destructive process, there is often right-sided hemiplegia with motor aphasia.

From the above summary it will be seen that very little has been irrefutably demonstrated. The great

majority of questions that are of practical importance are by no means settled. The one fact that coördinated movements may follow electrical irritation of the motor area is regarded by some neurologists as simply one of the curiosities of physiology, and they by no means accept the deductions which the localizers have drawn from such experiments.

Ferrier explains these phenomena by supposing that cells in certain areas—not necessarily disassociated because a sulcus happens to intervene—possess an essentially motor function, and that when irritated this irritation passes directly to the white fibers which spring from these cells, and that these fibers are collected into differentiated bundles, pass out through the internal capsule, become the anterior and lateral pyramidal tracts, and convey impressions through the anterior cornua into the anterior root. In other words, he teaches that the motor area is the cortical expansion of the motor tract, and that consequently the cells from which the fibers spring are functionally differentiated from other cortical cells. Those who are not localizers find much to criticize even here. No one familiar with Ferrier's work doubts the experiments recorded. What they are not willing to accept is the legitimacy of his conclusions. Granting that the brain of the monkey differs from that of man merely in number and complexity of convolutions, rather than any intrinsic quality, and that the cells of the cortex are irritable, they still maintain that each cell is so closely connected not only with adjacent cells and those in neighboring areas, as well as widely separated regions even of the opposite hemisphere, that no irritant could be applied which would not equally irritate all the ramifications and connections of these cells. But even the irritability of the cortex is denied. It is well known that nerve fibers can be irritated by many agents, both chemical and physical, but it has not yet been proved that the cerebral cortex is susceptible to other than electrical irritation, and this electrical irritation can be attributed to its quality of diffusion. It has

been shown that when the exposed sciatic nerve of a frog or the still more delicate galvanometer was connected with the brain, the application of even light currents at a distance resulted in movements of the leg or deflection of the needle, thus showing that there was extrapolar conduction. Therefore, it is claimed that the electricity does not necessarily irritate the cells of the cortex, but many penetrate to the white fibers as they pass through the internal capsule. It is conceded that in this location the fibers are differentiated, and that they are susceptible of irritation. The so-called motor region is therefore "motor" only because it happens to be contiguous to the internal capsule, and Dupuy, of Paris, points out the further fact that this region is unusually rich in deeply penetrating blood vessels: "The pia mater over the Rolandic convolutions is almost a complete network of vasomotor fibers and cells, and blood-vessels which penetrate into the convolutions. One system of blood-vessels only ramifies and ends in the cortex proper; the other enters the white substance by means of larger vessels accompanied by nerves and ganglion cells. It follows from this arrangement that the cortex proper is much more vascular and the white substance or fibers a great deal less so, and moreover that while the vessels irritating the cortex are spread well over, those going into the white substance are isolated from one another. Now I have shown that those points which when 'excited' by electricity give rise to a motor action, coincide with spots where arteries with nerves penetrate into the white matter or strands of fibers. The best method to demonstrate this fact consists in injecting one carotid artery after having marked with ink the position of the motor centers ascertained beforehand by means of electricity."

Ferrier and his school, while not denying the diffusibility of electricity, claim that in their experiments its action can not be thus explained. Ferrier says:—

"Irritation of the ventricular aspect of the corpus

striatum causes general contraction of the muscles of the opposite side of the body; and it is impossible by applying the electrodes to the surface of this ganglion to produce differentiated contraction in any one muscle of a muscular group." "We know therefore by direct experiment what irritation of the basal ganglia should produce; but the phenomena of irritation of the cortex are of a very different order." And again: "The great and significant feature of the reactions produced by electrical excitation of the cortex is that they are definite and predictable and vary with the position of the electrodes." But there is no fact more strongly urged by the localizers than that of the differentiation of white fibers in the corona radiata and the internal capsule, and Ferrier would be the last to deny that could these fibers after differentiation be separately irritated, corresponding movements would ensue. In fact, this is far better established than is cortical differentiation. Dupuy claims that the electricity following the penetrating blood-vessels and being so circumspectly applied to the strands is capable of producing coördinated movements—and at least in his recent writings does not say that this irritation necessarily takes place in the basic ganglia.

Another point that has given rise to controversy is the interpretation of the results that follow destruction of the cortex. Having measured the strength of the minimum current that will produce motion, the cortex is sliced off and left *in situ*. It is found that on reapplying the electrodes a stronger current is required to produce the same movement. The localizers claim that in the one case the electricity acted physiologically, in the other physically, and point to the increased strength of the current as proof. Their opponents explain the necessity of the increased currents because of the two new surfaces which have been created and the coagulation that necessarily takes place in the cut vessels, and they moreover urge that no better proof can be adduced that the electricity acts by diffusion of current than

the fact that motion will follow the application of electricity to the cortex, even after it has been mechanically separated from the brain and lies merely in apposition. Another fact that is claimed will substantiate this same view is that when the cortex is frozen it is still susceptible of electrical irritation, a statement which Ferrier denies but other and later authorities consider well established.

Another experiment of Frank's consists in freezing the motor center and then irritating the hard frozen surface. It is found that whereas before the freezing the motor action in the limb was longer in duration than the current used, and was epileptic, and besides only occurred after a lapse of about six and one-half hundredths of a second, when the same current is applied during the frozen state, the time of reaction is only about four and one-half hundredths of a second and the contraction is only tonic. The claim is made from these results that the reaction time is greater (six and one-half hundredths of a second) when the cortex is not frozen, because it reacts physiologically and the time is shorter (four and one-half hundredths of a second) when the cortex is frozen because it acts physically. This I consider a very unaccountable interpretation; it is unnecessary to state that the white substance, as well as the cortex, is influenced by the freezing process and the irritability of both endangered and altered.

These cortical destructions and alterations of the motor centers are, perhaps, the most important proof the localizers have brought forward, but they are by no means agreed as to the interpretation of experiments supposed to be identical. For instance, Ferrier destroyed the angular gyrus with resulting hemianopsia, and so placed the visual center in this region, but others have shown that this blindness was temporary, and placed this center in the occipital region, where the results of destruction seemed more permanent; but no experiment yet performed seems conclusive, for the reason that complete removal of the cortex without destruction of the underlying

fibers in the higher animal is not possible, while in simple-brained animals even great destruction is well borne with but few motor or sensory symptoms. Here, however, the localizers claim that automatism comes into play and can not therefore be compared with brains markedly convoluted.

Another objection to experiments of this kind is that when the brain cortex is mutilated the animal's disposition is so entirely changed that no just deductions can be drawn by comparing it with a normal animal, with whom at best we can not intelligently communicate.

The true and only test as to the truth of this theory that has so far been applied is the observation of lesions in the human brain. Numberless cases are on record where cortical lesions have resulted in paralyzes and disturbances of the special senses. Cortical destruction of the motor region is often followed by paralysis; in the frontal lobe by mental weakness; in the occipital lobe by visual disturbances, and in the temporal by deafness. Left-sided paralyzes accompanied by aphasia are frequently found to have their origin in lesions near the base of the third frontal convolution. On the other hand, equally well-defined lesions impinging on or completely destroying these centers have not resulted in corresponding deficiencies. However, in the vast majority of lesions due either to a tumor, apoplexy or embolism, the lesions are not circumscribed, and as a rule the destruction involves so many important divisions of the brain as to materially interfere with scientific deduction.

The importance of these researches is undoubtedly great, for they have opened up a new and fertile field for the experimenter and have added vastly to our knowledge of the physiology of the brain. On the other hand, they have been a basis for the justifications of the many operations performed for the removal of localized growths or deposits in or on the brain, and as such their accuracy and diagnostic value are rightly questioned. Surgeons have interpreted



these researches in a manner that conservative investigators can not approve.

Our medical journals are filled with accounts of operations which have either justified the diagnoses, or where the results were not so bad as to completely confound and condemn both the operator and the operation. Unfortunately the many unsuccessful and otherwise disastrous operations remain unreported. As regards tumors, even were the localizers able to absolutely and definitely point the way to the surgeon, yet post-mortems teach us that at least 75 per cent of such growths could not be successfully removed; and were all the results of such operations known, characterized as many of them are by mistaken diagnoses and surgical mishaps, 95 per cent would more nearly represent the proportion of the operations which are either useless or criminal failures. Granting that 5 per cent of the operations result in improvement or cure, this small proportion does not justify the readiness with which such operations are undertaken. But surgeons have gone further than this. Not content to interfere with pathologic cerebral tissues, they have opened brains practically normal, removed the recognized centers, and noted results. This has frequently occurred in the so-called Jacksonian epilepsy, where consciousness is seldom lost and only one limb or group of muscles is involved, and the relief occasionally following such operations for all forms of epilepsy has been falsely attributed to the removal of a growth or pressure rather than to the well-known *per se* effects of operations in general. Some of our recent text-books have even gone further and advised exploratory incisions as an aid in diagnosis, as if the trephining of the brain was as simple a procedure as is the opening of the peritoneal cavity, or the results which follow healing as insignificant.

While granting the advance made by experiments on animals in elucidating the physiology of the brain, the modern cerebral surgery based on this is not jus-

tified, either by reason of the possibility of accurate diagnosis or the probability that the operation *per se* may benefit. The results of operations, even those selected for publication, are not encouraging, much less do they lead us to regard the operation as one of minor surgery.



