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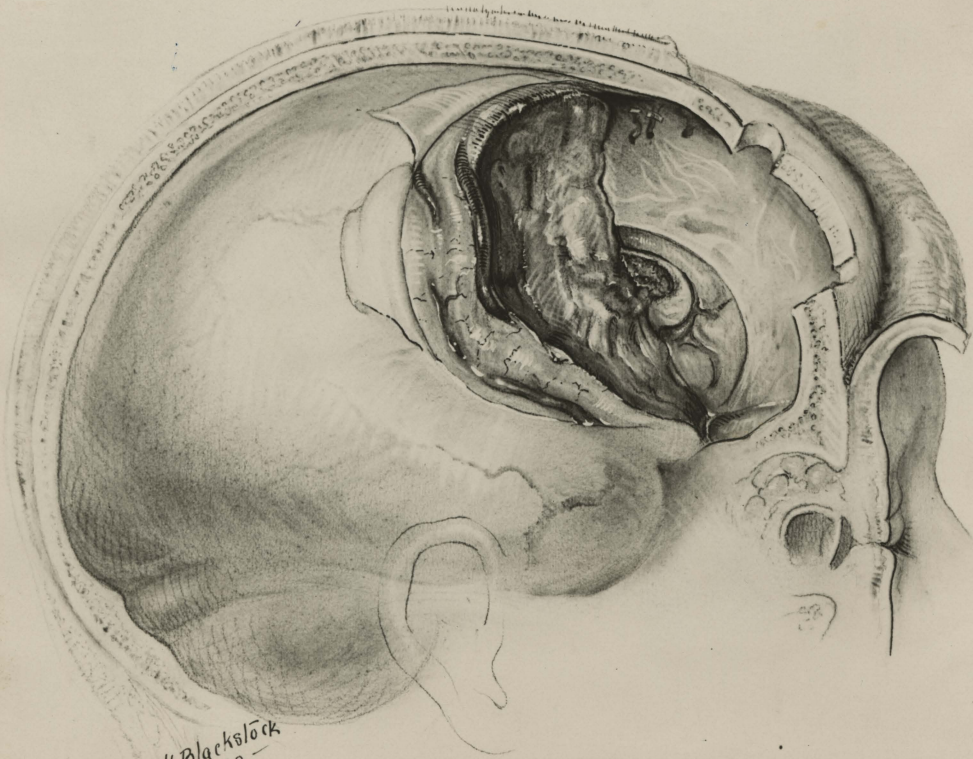


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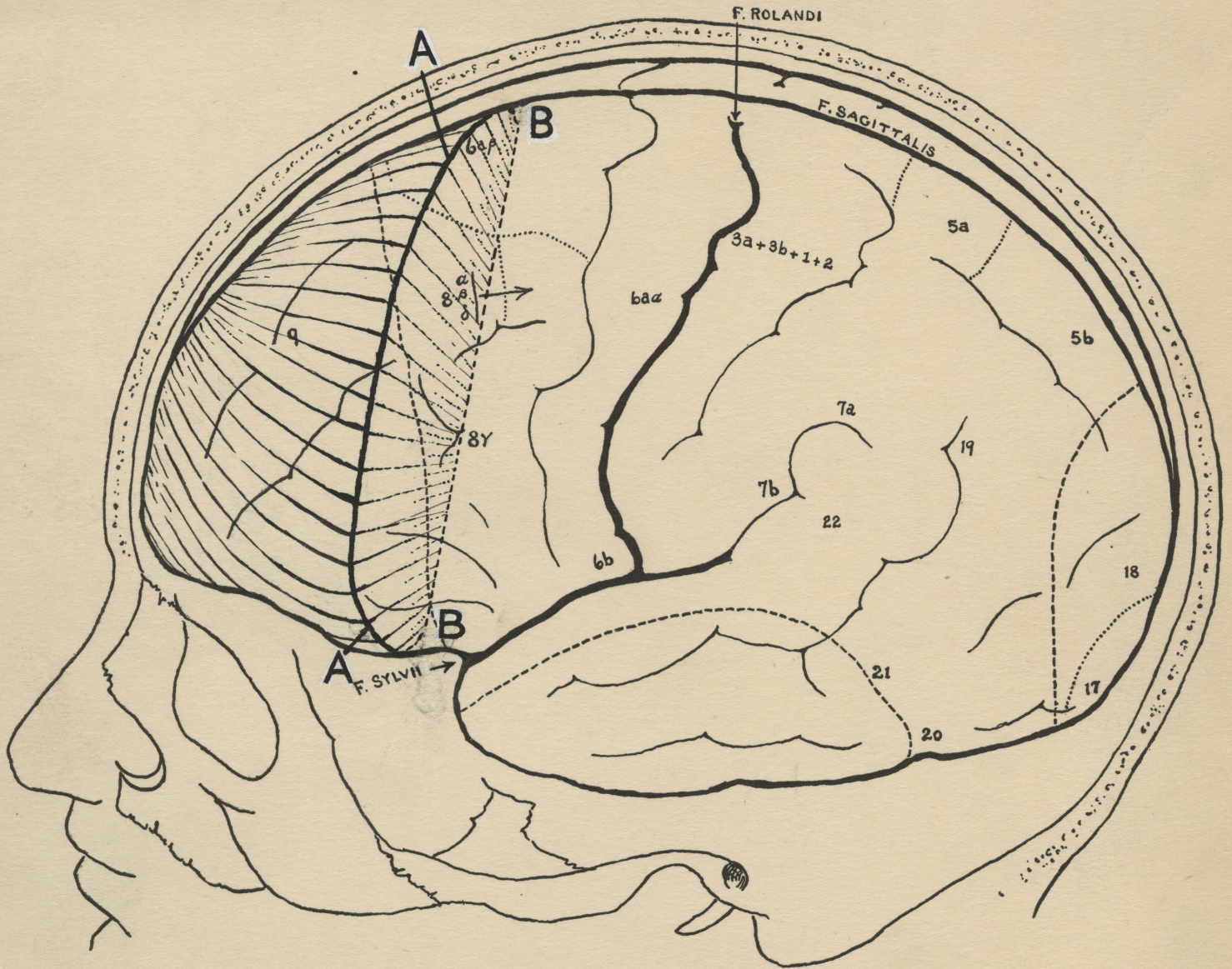
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Fig. 1



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[The Montreal Neurological Institute, Montreal. Reprint No. 45.]

## THE FRONTAL LOBE IN MAN: A CLINICAL STUDY OF MAXIMUM REMOVALS.<sup>1</sup>

BY WILDER PENFIELD AND JOSEPH EVANS,

Montreal.

REMOVAL of very large areas of the human brain in neurosurgical practice offers an opportunity for detailed neurological study, especially in the occasional case which fortuitously presents many of the conditions which would be demanded of a physiological experiment. Three cases of radical removal of large portions of one frontal lobe have been selected for this communication because of unusual opportunity for study before and after operation and because the excised portions of the brain could be accurately examined.

Advance in knowledge of the functions of the frontal lobes is difficult to secure because of the fact that substitution of one cerebral region for another is no doubt possible, and there may well be bilateral representation of many cerebral processes which take place in this *terra incognita*. Furthermore, animal experimentation can contribute little, as all animals, even the anthropoids, possess but rudimentary prefrontal development and it is impossible to explore the finer thought processes of speechless animals.

Extirpation of a tumour, however radically carried out, does not provide a perfectly satisfactory subject for study, as tumours often displace cerebral tissue to a great extent without destroying the tissue or its function. The only tumour cases which are acceptable for investigation are those in which an infiltrating neoplasm has made it advisable to resect a large block including brain and tumour. The cases, however, which are most useful for our present purpose are those of patients suffering from chronic epilepsy due to a focal lesion of such a type and situation that lobe amputation offers the only hope of relief from the seizures.

Case 1.—R. I., R.V.H. Right frontal extirpation; calcified oligodendroglioma.

This case offers an unusual opportunity in that the patient was observed closely from childhood onward and the removal was radical. The patient was

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43 years of age. Occasional "splitting" headaches began at the age of 14. At the age of 20 there was a Jacksonian seizure. This was followed by a series of such seizures at 28 years of age and another at 33, at 34 and at 40 years. From 40 to 43 years of age, when operation was carried out, there were occasional small Jacksonian attacks.

Dr. Colin Russel, who examined her for us on her arrival in Montreal in November, 1928, found bilateral papilloedema, left plantar extension, comparative weakness of the left arm and leg, and he made the observation that she was "mentally not up to her own standard in looking after household arrangements."

A right frontal osteoplastic craniotomy was carried out by one of us (W. P.)

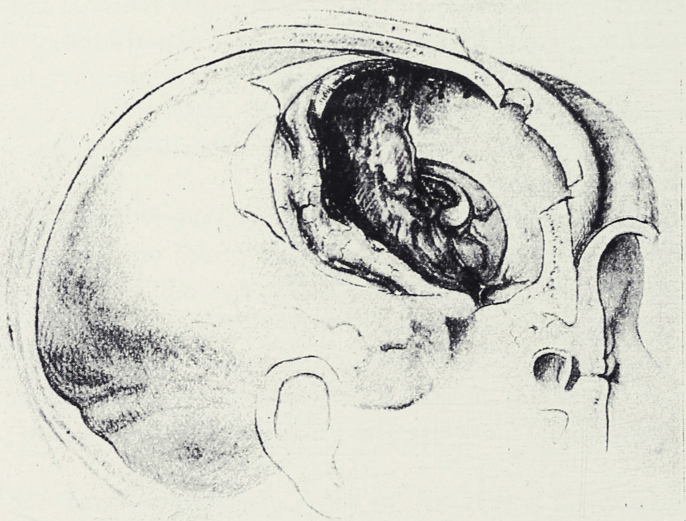


FIG. 1.—Operative sketch showing the extent of the removal in Case 1. This is the unprompted conception of the artist who was present at the operation.

and a large, partially calcified oligodendroglioma was exposed. It infiltrated the frontal lobe but did not involve the anterior pole. Tumour and lobe, except for precentral gyrus, were resected *en bloc*. Fig. 1 indicates the extent of removal as it appeared to the artist who was present at operation.

It is always difficult when dealing with an expanding lesion to know how much the cerebral tissue has been rarefied and displaced without being rendered functionless. Therefore we have indicated in fig. 2 our conception of the site of removal by the continuous line to which the arrows point. An infiltrating tumour does not displace brain to the same extent that a slowly growing encapsulated one does, but it does displace it somewhat so that the line of crosses in the same figure gives an estimate of the cerebral tissue actually destroyed which is safely conservative.

The operation was carried out under local anæsthesia. She may have lost



consciousness for a short time when there was a sharp hæmorrhage, but she was otherwise alert during the procedure, spoke to the operator frequently and talked intelligently about her children, her chief preoccupation. At the end of six hours of this operative ordeal she apologized for having made so much trouble!

That night she slept at long intervals. Twice during convalescence she was catheterized, but otherwise recovery was entirely uneventful and she was out of bed in two weeks. Neurological examination on discharge was entirely negative although she was not subjected to so searching a sensory examination as the next case. Two months after operation she had returned to her own family and during the year which followed lived a happy and essentially normal life as will be described in the discussion to follow.

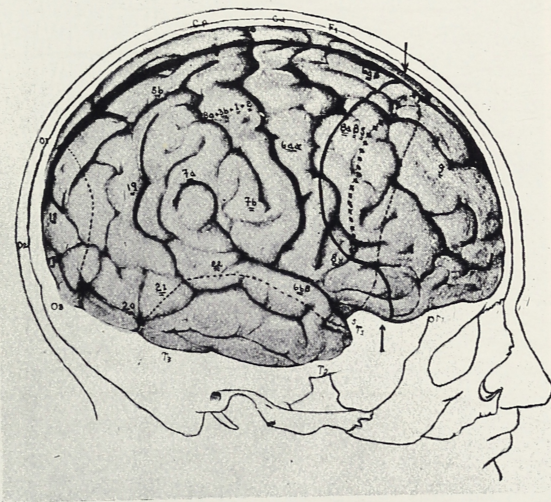


FIG. 2.—Case 1. The solid line indicates the line of removal; the crosses indicate a more conservative estimate of the cerebral tissue actually removed if the displacement which the tumour may have produced be considered.

My instinctive reaction (W.P.) was to withhold this case from publication. The patient was my only sister. But the close bond of sympathy that had existed between us for many years makes it possible for me to evaluate the effect of the loss of the frontal lobe upon her personality and her mental capacity. My opinion at all events must be interpreted in the light of this personal relationship and if she were alive I am sure she would approve of such an analysis in the hope that it might help others.

After this case had been presented before the Association for Research in Nervous and Mental Disease the following letter was received from Professor Russel, which is now printed in full as it expresses his opinion of the case.

"Because of my great interest in her I would have liked to contribute to the discussion of the condition of your sister following lobectomy. You will



remember that I sat and talked to her during the operation and left her only at about 5 o'clock when you were cleaning up. You showed me how much of the anterior lobe had been removed, and one could see in the midline the falx perfectly clean.

"I dropped in to see her between 8 and 8.30 that evening and although she was somewhat nauseated and had been vomiting, probably the result of the local anæsthetic, she expressed her appreciation of what she considered my kindness in giving up my time, so perfectly and with so much courtesy that it was really very impressive. She said that she had felt so afraid of causing you distress by making an exhibition of herself and that I had helped her.

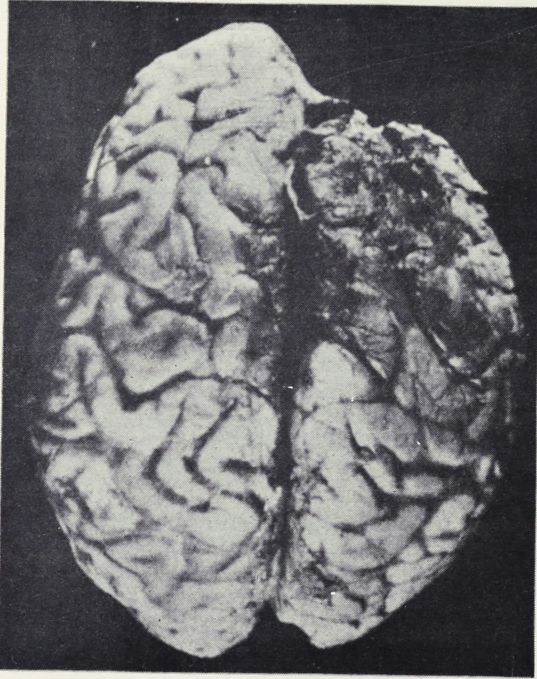


FIG. 3.—The brain of Case 1 as seen at autopsy, two years and five months after the operation of figs. 1 and 2, The anterior portion of the amputated pole is recurrent neoplasm.

When I remarked that the only exhibition I had seen was one of the best exhibitions of courage that it had been my fortune to witness, she expressed her gratitude so nicely that one could not help wondering how much the frontal lobe had to do with the higher association processes. Of course, as you have already said, it is not so much the frontal lobe as a slow growing tumour that involved the frontal lobe, and probably the function of that lobe had been gradually taken on by other parts of the brain.

"During her convalescence I so often would get her to discuss books that she had read, and her memory was so good, and she showed such good judgment in her criticisms that I cannot help but feel that her feeling of



inadequacy explained in her letter to you when she asked for some means of sharpening up her intelligence might very well be explained by the fact that she had been a very conscientious mother of several children who had neglected her social contacts on account of her domestic duties, and was feeling the lack of facility in social intercourse. It is not an uncommon experience under such circumstances."

Her condition following operation will be taken up in detail in the discussion to follow.



FIG. 4.—The same brain as fig. 3, seen from below.

Twenty-two months later, following a rather sudden reappearance of symptoms, she was re-operated upon at our request by Dr. Harvey Cushing who found a recurrence of the tumour and removed it again without any further amputation of cerebral tissue. She continued to feel well but six months later died from hæmorrhage into the tumour and autopsy again showed neoplastic recurrence. Thanks to the kindness of Dr. Carl Rand of Los Angeles, who performed an autopsy, we can show a photograph of her brain (figs. 3 and 4). It will be seen in fig. 3 that there is sufficient regrowth of the tumour to make the hemisphere appear about 3 to 5 cm. longer than it really was. Re-growth of such a tumour not infrequently simulates brain in form.



Complete examination of the brain showed that there was no neoplasm nor abnormality elsewhere. The case will be taken up again under the heading of general discussion.

*Case 2.*—W. B., R.V.H. Left frontal lobectomy. Post-traumatic epilepsy, cerebral cicatrix.

At 16 years of age he fell from a scaffolding and received a depressed fracture of the right frontal region. He was unconscious for two and one-half weeks. He left the hospital in two months and felt "all right" except that his memory did not seem as good as formerly. He did not work for a year, at the end of which time he took a position as caretaker of a skating rink, a position he continued to hold until recently. At the age of 22, epileptiform seizures of the frontal lobe type made their appearance as described elsewhere.<sup>1</sup>

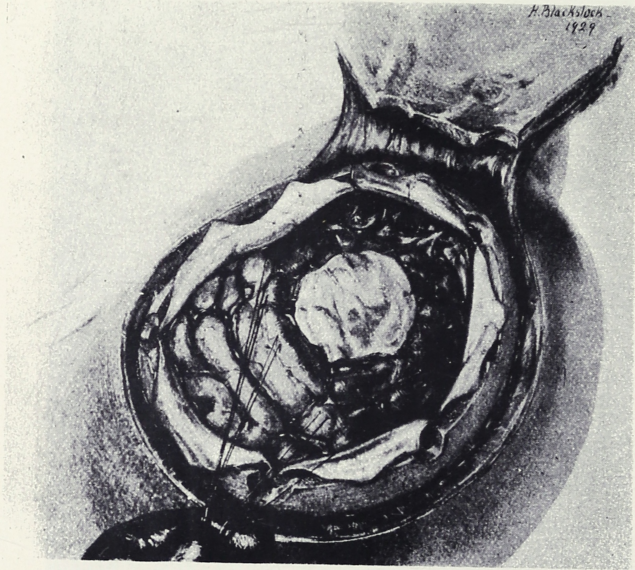


FIG. 5.—Sketch of the lesion exposed at operation in Case 2, showing the sclerosed and atrophic frontal pole and the meningeal adhesions.

Two years later encephalography demonstrated enlargement of the anterior horn of the left lateral ventricle, a cyst in the left frontal lobe and migration of the third ventricle toward that side. Osteoplastic craniotomy was carried out (November, 1929). It revealed abnormal, leathery frontal convolutions and dense dural adhesions (fig. 5). Amputation was carried out through normal tissue as indicated by the cutting threads in fig. 5 (see also fig. 6). Incision was made directly inward to the wall of the ventricle. The plane of excision was then sloped somewhat forward so that at the falx the removal was about as far anterior as the end of the ventricle. The line of removal as seen on the surface is indicated in fig. 7.

<sup>1</sup> Penfield, W., and Gage, L. "Cerebral Localization of Epileptic Manifestations." *Arch. Neurol. and Psychiat.*, **30**, 709, 1933.



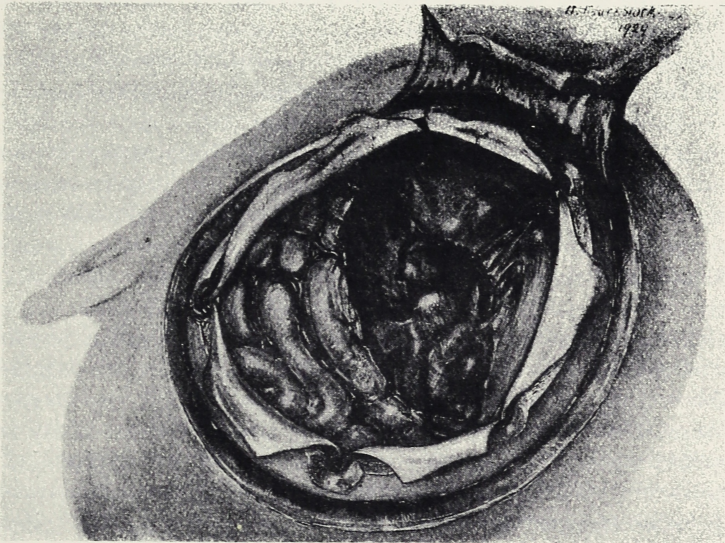


FIG. 6.—The artist's conception of the extent of the lobe amputation in Case 2.

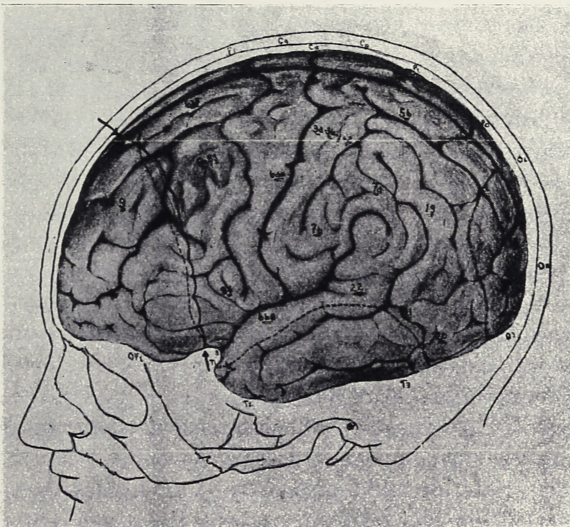


FIG. 7.—Surface projection of the amputation done in Case 2. The traction of the huge scar probably pulled the whole hemisphere forward so that the line of removal should be placed farther posterior.



During the operation, which was done under local analgesia, the patient was able to talk with us intelligently. Following it, at midnight, he was mentally clear but did not remember about the operation nor did he seem to recall recent events. In the first week after operation he became disorientated and somewhat confused mentally and developed a hemiparesis. He had difficulty in finding words.

One week after operation he had become well orientated for place and partially for time. Memory, however, was still deficient as far as recent events were concerned. The hemiparesis was improving. Two weeks after operation he was much clearer; he seemed slow but remembered recent and past events fairly well and could do simple arithmetical sums but not difficult ones, and the hemiparesis had disappeared.

Six months after operation the patient's physical examination showed him to be normal and he had returned to his former occupation. He reported that he was able to think better, act more quickly and that he was less irritable and quarrelsome than before operation. This should not be taken to mean that we consider frontal lobectomy would benefit a normal individual. The improvement over his former condition which continues up to the present time (five years later) is, of course, due to the complete arrest of his epileptiform seizures.

It is not wise to compare the man too closely with himself as he was before operation, because of the disappearance of the epilepsy. We can only study him objectively and in the light of the promise which he gave at the age of 16 before the accident.

*Psychological examinations.*—Dr. David Slight has examined the patient on several occasions and we here quote from his notes.

February 6, 1929 (two and a half months after operation): "General manner and appearance normal. When seen before leaving the Hospital the patient gave the impression of what can only be described as being 'blank' or 'out of touch.' Orientation good for time, place and person. On leaving Hospital he was distinctly hazy about time, but he has had no lapses in the past month.

"*Stream of thought*: Rate normal, flow coherent and logical. Denies any periods of confusion or dreaminess.

"*Emotional status*: Bright and consistently so. For a time after leaving the Hospital he was distinctly irritable, being upset over minor things, but he is now controlled and balanced. Denies any periods of depression or other fluctuations in emotional state.

"*Mental content*: No delusions, hallucinations or other abnormal phenomena. Memory is good, both for immediate and past events with the exception of a period of amnesia extending over much of the time in Hospital. For example, he can relate what he had for supper last night and also incidents at a theatrical show he attended a week ago. He can repeat six digits forward and five backwards. (One might claim that this is slightly below par since the average adult is expected to repeat six digits backwards, and the fourteen



year old level to repeat seven digits forward.) Intellect is good and he tests up to the fourteen year old level according to the Binet-Simon scale. Judgment and insight appear good.

*Conduct*: No abnormalities so far as can be gathered. He apparently occupies himself in a normal fashion, reads the paper, goes out, and as already stated, attended a show last week. Writing and speech are normal.

"To sum up: It would appear that the patient shows no demonstrable mental change at the present time, and to judge from his previous occupation and other information it would seem that there is no mental loss. This is said with the reservation that any tests or judgments relate to what may be called a static condition, and do not entitle one to pass judgment on the patient in what may be called the dynamic situation."

Following a later examination (December 22nd, 1932, four years after operation) Dr. Slight again reported: "The patient was co-operative during the examination and gave a good account of himself. He is apparently free from any subjective sensations and has no complaints to make regarding his ability to live and behave in a normal way. Clinical examination of his mental state does not show any apparent indications of abnormality, and if one were not aware of the previous surgical procedures one would probably pass him without particular comment. On further questioning he does acknowledge one difficulty, and that is in regard to processes of mental arithmetic such as are involved in playing cards, and he particularly mentions a game called 'Five Hundred.' He is apparently unable to add figures together mentally and finds it necessary to use paper.

"Although his memory span tests up to the average adult level, a Binet-Simon examination made through the courtesy of Dr. W. T. B. Mitchell shows that on the Stanford revision of the Binet-Simon he has a mental age of 12 years and 4 months, with an intelligence quotient of 82. During this examination it was noted that he showed an apparent fatiguability and that there was a 'scatter' in the test. On the Healey completion test No. 2 he had a score of 73; 66 being regarded as the average level. The Healey completion 'B' test was completed in 45 seconds and 14 moves, which gives him a performance level of seventeen years.

"One point interesting and worthy of note is his spontaneous statement that emotionally he feels much more controlled now than in the past. He states that previously he was very antagonistic toward people and toward religious topics and such like, whereas now he finds himself more controlled in approaching and discussing such matters."

*Vestibular reactions*: Before operation the following examination was recorded in the Outpatient Clinic of the Department of Otolaryngology:

"February 7, 1928: Hearing losses of middle ear variety. Cold caloric test of both ears reveals normal response from each ear with 4 c.c. of ice-cold water. Both internal ears would seem to be normal but there is a hearing loss from the healed middle ear disease."

Six months after operation he was examined by Dr. W. J. McNally, who



made the following note (May 10, 1929): "Cold caloric test: Right ear: Four c.c. ice-cold water elicits a response of nystagmus from the horizontal canal—no response from the vertical canal, i.e. when head is erect; no dizziness. Ten c.c. of water at 120° F. elicits a few nystagmoid movements from the right horizontal canal. No response from the vertical canal, or very weak response.

"Left ear: Four c.c. ice-cold water—no response from either vertical or horizontal canal. Ten c.c. water at 120° F. elicits a definite nystagmus from the horizontal canal sharper than from the other ear; no response from the vertical canal. Ten c.c. of ice-cold water in the right and left ear produces a response from both the horizontal and vertical canals, but it is definitely diminished. This may be due to thickening of the drums from previous middle ear disease. There is no dizziness from any irrigation.

"Impression: Suggestion of diminished irritability of both internal ears, more marked in the vertical canals. There is a weakly positive de Kleijn sign from the left cerebral hemisphere. There is a long history of previous middle ear disease which has interfered with hearing."

Four years after operation Dr. McNally made a second note (December 7, 1932): "The right ear drum is thickened, milky white, intact. The left drum is thickened, milky white and shows scar in the postero-superior quadrant. No spontaneous eye nystagmus. While standing the patient is not disturbed by placing the head in any position nor is he disturbed or over-balanced by any sudden passive movement of the head or shoulders.

"Two and one half c.c. of ice-cold water in the left ear elicits a prompt nystagmus normal in character from the vertical and horizontal semicircular canals of that side. The duration of the nystagmus is quite short, about one minute. There is no dizziness. Two and one half c.c. of ice-cold water in right ear elicits the same normal response as above except that it is slightly less marked. In both cases the response from horizontal canals was more marked than from vertical canals. Ten c.c. at 120° F. in the right ear elicits prompt nystagmus from the horizontal and vertical canals, but definitely less marked when compared with the opposite side."

Dr. McNally summed up the vestibular examinations: "In other words there is no evidence that the quick phase of nystagmus shows any exaggeration toward the side of the lesion (de Kleijn's sign of a cerebral hemisphere lesion). If anything, this patient shows more response when the quick phase of nystagmus is to the opposite side of the lesion. When one considers the thickness of the drum one must conclude that both labyrinths are responding normally to stimulation.

"In the wheel chair with head erect (horizontal canals) normal response after ten turns to either side; no dizziness. It is worthy of note that after the caloric stimulation and rotation tests there was never at any time the slightest dizziness or past-pointing in spite of the fact that the other objective signs of labyrinthine stimulation were quite normal. I do not know quite what the significance of this fact may be."



*Special sensory examination.* November 28, 1932.

(A) *Spontaneous sensation.*—He has had no pain, numbness or tingling in the extremities, nor is there any lack of recognition of the position of the limbs. No paraesthesia of any nature.

(B) *Objective study.*

*Light touch.*—Recognition of cotton wool entirely normal, over the ulnar and radial sides of the forearms and over the lower limbs. Tactile acuity as tested with the von Frey hair is normal over the ulnar and radial borders of the arms, over the lower legs and also over the dorsi of the feet.

*Pressure touch.*—Not tested.

*Localization.*—Errors in centimetres. Ten trials.

Points tested on the right forearm and indicated by the left index finger	1.4	1.8	0.8	0.6	1.6	2.0	1.0	1.3	2.0	1.8	Average 1.4 cm.
Left forearm indicated by right index finger.	2.0	1.5	2.0	0.6	1.6	3.0	1.0	1.0	1.5	1.0	Average 1.5 cm.
Right leg indicated with right index finger.	2.0	0.5	0.8	2.8	1.5	0.5	2.5	1.5	3.2	4.0	Average 1.9 cm.
Left leg indicated with left forefinger.	0.7	2.7	0.3	1.0	2.0	1.5	1.7	0	0.3	0	Average 1.0 cm.

*Roughness.*—Not tested with the Graham Brown esthesiometer, but three grades of sandpaper were used, No. 2, No.  $\frac{1}{2}$ , and the reverse or smooth side of either of these called 0. Recognition of these various grades of sandpaper, interchanged, was quite normal over all the fingers, except for a slight confusion in the right fifth and also in the third left. There were no gross abnormalities in the skin, because of which there might be expected abnormal sensation. In any event these changes were very slight and may well not be significant.

*Tickling and scraping.*—Normal over the palms of both hands, over the soles of the feet. Cotton wool tickling and scraping were all normal.

*Vibration.*—Tested over the nails of the first and fifth fingers and the first and fifth toes and was quite normal.

*Compass test.*—Equally accurate on thenar and hypothenar regions of the two hands.

*Pain.*—(a) Superficial pain: Pinprick recognized normally over the lower arms and over the radial and ulnar borders of the hands, also over the lower legs and dorsi of the feet. (b) Pressure pain: This was tested in the forearms, in the upper third between the radius and ulna. Pain was recognized at 7 kgm. on the right side and at  $7\frac{1}{2}$  kgm. on the left. In the legs the testing was done in the medial portion of the calf. On the right pain was recognized at 10 kgm. pressure; on the left at  $8\frac{1}{2}$  kgm.

*Temperature.*—Differences of 27 and 34 degrees and 29 and 30 degrees were recognized over the lower extremities and over the forearms. A temperature difference of 29 and  $29\frac{1}{2}$  degrees could not be differentiated.

*Position.*—Imitation of the position of one extremity by the other was prompt and accurate.



*Passive movement.*—Three to five degrees of movement were recognized in the fingers and in the toes accurately and without hesitation. No falling away of the unsupported upper limbs when the eyes were closed; lower extremities not tested.

*Active movement.*—(See above)

*Weight.*—Right hand supported able to differentiate between 100 and 105 gm. of weight and the left hand able to do the same. The right hand unsupported differentiated between 105 and 120 gm., 110 and 120 gm., and on one occasion between 100 and 105 gm., though on a second trial 100 to 105 gm. were called about the same. Left hand unsupported not able to differentiate between 100 and 105 gm., nor between 110 and 120 gm., but the difference between 105 and 120 gm. was recognized.

*Size.*—This was tested in the hands by the use of test tubes of the following diameters: 1.1, 1.6, 1.7 and 2 cm. The two middle tubes were confused rather readily but this was within normal limits.

*Shape.*—Triangle recognized in both hands promptly.

*Form.*—Calipers, two-point compass and throat sticks were all recognized readily.

*Texture.*—Cotton wool, paper and a rough towel all correctly named.

*Consistency.*—Hard rubber tip recognized as such. Thermometer bulb recognized as hard and cotton recognized as soft.

*Figure writing.*—

Left palm:—											
Written ..	..	7	4	3	2	1	6	8	9	0	5
Called ..	..	2	4	3	?	1	6	8	9	8	5
Also left palm:—											
Written ..	..	5	7	2	3	6	1	9	0	8	
Called ..	..	5	7	2	3	6	1	9	0	8	
Right palm:— (four trials)											
Written ..	..	5	7	2	3	6	1	9	0	8	
Called ..	..	5	7	2	3	5	5	5	0	8	
		5	7	2	3	6	5	9	9	8	
		5	7	2	3	8	1	9	0	8	
		2	7	2	3	6	1	9	8	8	

#### SUMMARY OF FINDINGS ON SENSORY EXAMINATION.

(1) Suggestive error in spot finding on the right leg as indicated with the right index finger.

(2) Slight unexplained error in recognition of grades of sandpaper fifth finger right and third finger left.

(3) Left hand unsupported recognized the differences in weight less readily than the right.

(4) There seems to be definitely diminished acuity in recognition of figure writing in the right palm. This is irrespective of radial or ulnar border.



## SUMMARY OF OBJECTIVE EXAMINATION.

The defects which we were able to detect in this case were as follows:—

(a) Small errors in sensory examination which are probably negligible, i.e., in spot-finding in right leg, in figure writing with the right hand and in weight differentiation with the left hand.

(b) Unexplained absence of dizziness and past-pointing after caloric and rotation stimulation although both labyrinths respond normally to stimulation. De Kleijn's sign of a cerebral hemisphere lesion was absent.

(c) Subjective decrease in capacity for mental arithmetic and bridge playing. Mental age of 12 years and 4 months with an intelligence quotient of 82 by Stanford revision of Binet-Simon test. Completion level of seventeen years in Healey completion test.

(d) Some lack of initiative. See discussion to follow.

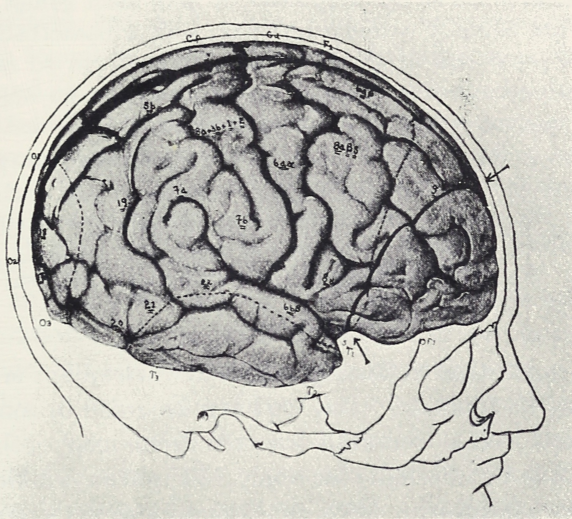


FIG. 8.—Surface projection of the removal carried out in Case 3. There was much traction here also as in Case 2.

*Case 3.*—G. G., R.V.H. Right frontal lobectomy. Post-traumatic epilepsy, cerebral cicatrix.

This boy of 19 years received a severe head injury at the age of 8 and was referred by Dr. Colin Russel. Epileptiform seizures of right frontal lobe type had been present for one year. In November, 1931, a right frontal osteoplastic craniotomy was performed. Three cysts were found in the frontal pole and radical excision was carried out as indicated in fig. 8, cutting across the anterior end of the ventricle. The excised tissue, after evacuation of the cysts, weighed 34 grm.

There was a post-operative hæmorrhage which necessitated re-operation on the second day. Otherwise the recovery was uneventful, neurological



examination was negative on discharge and he has had no recurrence of the epileptic seizures up to the present, three years later.

One year after operation, in December, 1932, he was examined with the following results:—

(1) Special sensory tests similar to those in Case 2 above were entirely negative.

(2) Audiographic and vestibular tests by Dr. Scott-Moncrieff were entirely normal.

(3) Psychometric examinations by Dr. David Slight may be summarized as follows:—

“He shows no apparent psychiatric difficulty. He appears to have adjusted well to work and has on several occasions been able to give public demonstrations of his firm's products in a large store.

“Since being at home he has continued to play such games as cards and tennis, and he has actually continued playing with a basketball team. It is said that there is no loss of ability in these games. In so far as reading, writing and arithmetic processes are concerned there is no apparent loss of function. His memory span is 8 digits forward and 6 backward. He appears to be interested in his work and has ambitions to make progress, hoping and planning to take up studies to further his work.”

In summary the excision in this case was smaller than in the two former cases. The portion of brain removed was doubtless partially incapacitated before removal. Physical and psychological examinations reveal no defects.

#### DISCUSSION.

It may be urged that to destroy a delicate instrument is not the best way of studying its function. But we have recorded in some detail the results of three frontal removals selected from many other available cases because of their suitability for study. It is always difficult to assess the value of the information from clinical cases as we are not carrying out experiments on normal patients, but, rather, desperate operations upon patients in the brain of each of whom there was abnormality to begin with. With these criticisms in mind the cases presented still seem to offer an opportunity of making deductions of value with regard to the frontal lobe, deductions both positive and negative.

It is evident that removal of large portions of the brain may be carried out without even temporary loss of consciousness. The vestibular reactions were normal in the two cases carefully examined. But in the large left frontal removal (Case 2) there was unexplained absence of dizziness and past-pointing after caloric and rotary stimulation. This defect was not present in the smaller removal (Case 3) and was not tested for in Case 1.

The removal of left frontal lobe in Case 2 had been carried out in



this case back to within one or two centimetres anterior to the precentral gyrus. In its lower extent the line of removal crossed Broca's convolution not far from the anterior end of the fissure of Sylvius. At the base of the hemisphere the removal skirted closely the posterior edge of the orbital plate and lesser wing of the sphenoid. Mesially the plane of removal was more anterior than laterally.

Aphasia in this man did not develop immediately and disappeared within three weeks, leaving behind no difficulty in speech whatever. The disturbance of speech was therefore attributable to transient neighbourhood change in cerebral structures which had not been removed. Special psychological tests record a normal level for a man of his limited education. He showed at no time reflex forced grasping.

What defects has he? He, himself, is conscious of only one unfavourable sequel to operation, that is difficulty in performing mental arithmetic and in playing bridge (a game which calls, no doubt, for a certain limited type of memorization and computation!). If he can write the figures down and see them he says he can do his arithmetic. But even after five years he cannot summon the figures and add or subtract them in his head as easily as formerly. That ability seems to have been partially removed with the amputation.

Is there anything else lacking in this man, perhaps lacking since the original laceration of his frontal lobe? His mother praises him as being docile at home, but admits that he may have shown too little initiative ever since his injury. His father is head groundsman for McGill University, the son having worked under him for two years before operation and for more than a year afterwards, was laid off only along with others at the time of a general "cut." The father states that as a workman he never had a better helper, "but," he added, "he never had a job that I didn't get for him." He should have added "since the accident," for it may be recalled that this patient had had enough initiative at the age of 16 to find his way to England, and had secured himself a job there.

To sum up: this patient is a likeable fellow, a good workman and a useful citizen. It is quite certain he will never be a revolutionist. He has lost something that psychometric examination does not evaluate. He has lost initiative; not all of it, but much of it.

The extirpation of the right frontal lobe in Case 1 was the largest of the three removals, and may be discussed at greater length. To recall the details, this was the case of a woman of 43 whose lobe contained a calcified oligodendroglioma and whose amputation was carried back to



within a centimetre of the motor gyrus all the way down to the lowest frontal gyrus. From this line it passed across cleanly to the mid-line so that the septum pellucidum and the anterior two or three centimetres of the sectioned corpus callosum were visible after the removal (fig. 1).

To judge what this patient had lost by being deprived of nearly all of her right frontal lobe demands that an estimate be made of what she would have been had she had a normal right frontal lobe at that age. Because one of us (W. P.) had known her intimately from childhood we believe it is possible to evaluate the mental and personal changes. This we have undertaken at all events.

The history was long. For twenty-three years before operation there were Jacksonian seizures at very long intervals, which indicates that the oligodendroglioma was probably present for that length of time, an increase in the rate of growth doubtless occurring towards the end. The removal was of lobe and tumour, not of tumour alone. This was borne out by the post-mortem examination, which also showed that other areas of the brain were normal.

The rapid recovery and relief from the symptoms of compression do not concern us. The fact of the compression renders a comparison of her state immediately before operation with that afterward of no value. Such comparison would, of course, show only improvement. The analysis must go back to a much earlier period.

After operation she resumed her duties as wife and the mother of six children with greatly increased efficiency. But she was conscious of not being quite as alert mentally as she should be. This is best expressed in her own words. In July, 1929, seven months after operation, she wrote:—

“Dr. Taylor asked me if I felt that mental activity was improving, and I said ‘Yes,’ but it seems as though each time I feel encouraged that way I do a series of very stupid things. Perhaps it is just a case of ‘pride goeth before a fall’ and is the time one needs to be wary. I am trying to be more alert, sometimes it seems to be very slow progress, but still it is progress I am sure. If you have any advice to offer as to how to learn to think, how to get something of an education when old, &c., it will be gratefully received.”

Her greatest difficulty was in household administration and she did not discipline the younger children as she had done when she herself was younger, although her general health was excellent. Nevertheless, she was still careful of her own person and orderly. Her sense of humour, memory, and insight into the thought and feelings of others was altogether unimpaired. She was capable of intelligent conversation and did not



talk either more or less than good taste demanded. Another letter from California may be quoted, written this time on the first anniversary of her operation:—

“It has been a very wonderful year with new life, new strength, new hope . . . I need firmly to convince myself that I am not really slow, nor stupid, not incapable, &c., and the rest will come.

“We will often think of you at Christmas and I am thankful I can picture you as you will be—the sunshine in the dining room and study, the cheery open fire, and the children going out to skate and coast or ski, the cars slipping and sliding, the cold crunch of the snow.”

This shows insight, vivid memory and power of expression. In her home there was little or no discord. Her husband was patient and sympathetic and her children reflected the unselfish personality of their mother. Her own home provided in some ways a better background for study than the consulting room of the psychologist. The following test, though not sanctioned by psychological usage, may illustrate her shortcomings.

One day about fifteen months after operation she had planned to get a simple supper for one guest (W. P.) and four members of her own family. She looked forward to it with pleasure and had the whole day for preparation. This was a thing she could have done with ease ten years before. When the appointed hour arrived she was in the kitchen, the food was all there, one or two things were on the stove, but the salad was not ready, the meat had not been started and she was distressed and confused by her long continued effort alone. It seemed evident that she would never be able to get everything ready at once. With help the task of preparation was quickly completed and the occasion went off successfully with the patient talking and laughing in an altogether normal way.

Although physical examination was negative and there was no change in personality or capacity for insight, nevertheless the loss of the right frontal lobe had resulted in an important defect. The defect produced was a lack of capacity for planned administration. Perhaps the element which made such administration almost impossible was the loss of power of initiative. If we express it as she did with no attempt at analysis: she could not “think well enough,” was a little “slow,” a little “incapable.”

In Case 3 the removal of the frontal pole, about half of the lobe, produced no detectable loss of function. This may be due to the fact that we could not study this boy before his accident. Or it may be due



to the fact that the anterior one half of the frontal lobe subserves only transferable function.

#### CONCLUSIONS.

Large amputations of the frontal lobe, if the precentral gyrus be left intact, produce surprisingly little disturbance of function which can be detected by ordinary methods of examination. There is no disturbance of the control of micturition, no forced grasping, no alteration of tone of the extremities or in the activity of deep or superficial reflexes.

In Case 2 the operative removal affected only the middle one-third of the left frontal lobe, as the anterior one-third had already been destroyed by the traumatic injury, if one may arbitrarily so divide the lobe. This removal of the middle one-third in a right-handed man produced a partial loss of his capacity for mental arithmetic (oral as distinguished from written). The patient also had an unexplained absence of dizziness and past-pointing after rotation and caloric tests, even though vestibular function was otherwise normal.

Detailed studies of sensation showed only changes that we presume to be within the limits of normal spontaneous variation. In Case 2 there was decreased appreciation of figures written upon the palm of the contralateral hand which may perhaps be related to the difficulty that the patient noted in the visualization of figures in "mental arithmetic."

The removal of approximately the anterior half or two-fifths of the right frontal lobe in Case 3 was not associated with any alteration, neurological or psychological, that we can detect.

The two larger removals (Cases 1 and 2), present certain important defects in common and we consider these removals to have begun at the time of the origin of the initial lesion and merely to have become complete at the time of operation. Neurologically each was normal. By the ordinary psychometric tests each would have to be judged normal although neither would rank very high. Each patient was lacking in initiative. Each was very good-natured and co-operative which may in some cases perhaps be an evidence of lack of initiation of ideas. Although it may not be of value here we may also remark in passing that we have in several other cases been told by relatives that removals of a very large area of frontal lobe with included neoplasm have resulted in marked improvement in the patient's temper.

Insight and capacity for introspection were preserved. Capacity to follow instruction was unimpaired, but initiative and capacity for



planned action were clearly defective. This was especially true of the woman of 43. She had become incapable of discerning for herself possible courses of action so that she might choose. If others presented to her the possibilities she made up her mind quite easily, and when a task lay before her there was no reluctance nor hesitation in undertaking it.

In so far as final conclusions from the first two cases are justifiable, it may be stated that maximum amputation of right or left frontal lobe has for its most important detectable sequel impairment of those mental processes which are prerequisite to planned initiative.



The first part of the report deals with the general situation of the country and the progress of the work. It is followed by a detailed account of the various expeditions and the results obtained. The second part of the report is devoted to the description of the various plants and animals discovered. The third part contains a list of the names of the various places visited and the names of the various persons who accompanied the expedition. The fourth part contains a list of the names of the various plants and animals discovered. The fifth part contains a list of the names of the various places visited and the names of the various persons who accompanied the expedition. The sixth part contains a list of the names of the various plants and animals discovered. The seventh part contains a list of the names of the various places visited and the names of the various persons who accompanied the expedition. The eighth part contains a list of the names of the various plants and animals discovered. The ninth part contains a list of the names of the various places visited and the names of the various persons who accompanied the expedition. The tenth part contains a list of the names of the various plants and animals discovered.