Cambridge University Press
978-1-107-00749-9 - Techniques in Epilepsy Surgery: The MNI Approach
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Chapter 1

History of epilepsy surgery

Introduction

The purpose of this chapter is not to present an exhaustive review of the history of surgery of epilepsy from the beginning until today but rather to present a gallery of portraits of individual neurosurgeons who have contributed significantly in developing the field. The period covered extends from the late nineteenth century to the advent of magnetic resonance imaging (MRI) around 1984. This single event was to cause a revolution in the field and led to the creation of numerous comprehensive epilepsy centers as well as the advent of important international conferences such as the historical Palm Desert symposium organized by P. Engel in 1986. From that time onward, numerous workers from all branches of neurosciences have contributed to the development of this subspecialty that has had no equivalent in other fields of neurosurgery over the last 30 years. The reader will also note and forgive the strong emphasis on the role played by the Montreal Neurological Institute (MNI) in the development of epilepsy surgery and the creation of a diaspora that has had a widespread and continuous effect over the years.

Paul Broca (1824–1880)

Broca (Figure 1.1) was born in 1824 in the southwest of France and undertook his medical training in Paris at the Bicêtre and Hôtel-Dieu Hospital. Although neurosurgery was not known as such in nineteenth-century France, Broca was a surgeon with a special interest in the brain. His contributions to science in general were immense. He founded the French Société d'Anthropologie, and described the Cro-Magnon man and the ancient trephined skulls discovered in France and Peru. He contributed significantly to our knowledge of the limbic system (diagonal band of Broca). He studied the gyral topography of the brain, identified constant gyral relationships, and described the gyral continuum with emphasis on the anastomotic bridges between gyri which he called "plis de passage" (1). This concept of the gyral continuum will often be referred to within this book and amply justifies the inclusion of Broca as one of the great innovators in brain anatomy. When he presented his famous patient Leborgne in 1861 with aphémie, later called aphasia secondary to a left frontal lobe lesion, he initiated a revolution in neurology. Broca formed his opinions carefully and presented them convincingly so the localization of language function was soon accepted as fact. Broca can rightly be called the father of cerebral localization. In 1876, he was the first surgeon to operate guided by neurological signs when he correctly localized an intracranial abscess over the frontal speech area and drained it through a craniotomy.

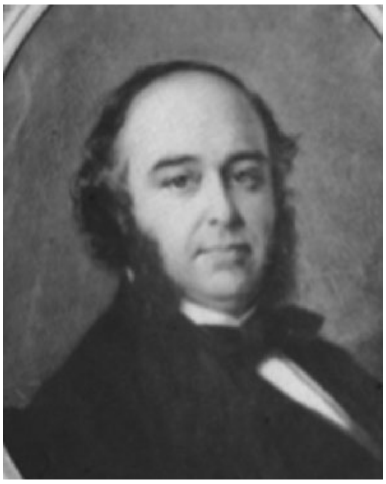

Figure 1.1 Broca was a French surgeon and anthropologist with a special interest in the topographic and functional anatomy of the brain. He is considered the father of cerebral localization.

William Macewen (1848–1924)

Macewen completed his medical studies in Glasgow where he was Lister's student. This experience was a major influence on Macewen as he advocated early on the use of antiseptic surgical techniques. He accomplished many firsts in surgery and is rightly considered a founder of the specialty of neurosurgery. He

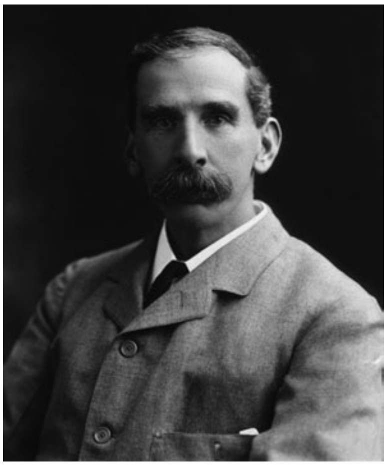

Figure 1.2 Horsley was the surgeon to the National Hospital for the Paralysed and Epileptic, Queen Square. He is considered the first true neurosurgeon.

had operated on the brain for tumors and other lesions in Glasgow a full year prior to Bennett and Godlee's more publicized craniotomy for tumor in London. He was the first surgeon to use the new tools of cerebral localization to successfully operate on a patient suffering from epilepsy. In 1888, he published a remarkable series of 12 patients operated for cerebral lesions, most prior to 1884 (2). Based on a surprising knowledge of cortical localization, lesions in diverse brain regions were accurately identified at surgery. Macewen's view on sensory localization was apparent in his approach to a child with recurrent fits heralded by a sensation in the great toe. He correctly exposed the upper central area and excised a tuberculoma from the postcentral gyrus, arresting the seizures. Five years before Horsley described the process of localizing cortical lesions by "the march of fits" (3), Macewen advocated close observation of the seizure pattern because of its value in diagnosis. He went on to say, "the record of the first indications of the impending convulsions and the parts affected by them is of great use as a guide to localisation" (4).

Victor Horsley (1857–1916)

By the time he began his surgical career, Horsley was already an accomplished neurophysiologist (Figure 1.2). In collaboration with Schäfer and Beevor, he had produced detailed maps of the motor responses to bipolar stimulation of the internal capsule and cortex in primates (5–7). In 1886, Horsley was appointed surgeon to the National Hospital for the Paralysed and Epileptic, Queen Square. By the end of 1886, he had used knowledge from his physiological investigations to perform ten operations on the brain (3). Most of the cases were for the removal of a scar or tumor causing epilepsy localized in the central area by the sensorimotor manifestations. The fifth craniotomy was a patient with epilepsy starting in the face, but without a visible lesion on the cortical surface. In this patient, Horsley became the first surgeon to stimulate at craniotomy to plan the resection, "Trephining over "facial center," and removal of cortex composing that center as determined by faradism at the time" (3). Horsley performed his surgery under general anesthesia using morphine and chloroform. Although he suggested the use of local anesthesia, the fear of infection from the unproved sterility of a cocaine skin injection made him argue against it (8).

Horsley devised the subpial technique of gyral resection to prevent injury to neighboring gyri. He developed bone wax and, with Clark, a stereotaxic headframe used in animal experiments. Horsley dedicated most of his surgical career to neurological problems and he is considered the first true neurosurgeon. He also successfully treated many patients with epilepsy. Focal motor and sensory seizure onset was localized to the central area and those centers were removed. This treatment was successful in arresting the seizures, and in a time when there was no other effective therapy, the resulting paresis was an acceptable deficit.

Fedor Krause (1857–1937)

Krause was a pioneering German surgeon who early in his career concentrated on surgery of the brain and spinal cord (Figure 1.3). He was educated in Berlin and completed his surgical training under Volkmann in Halle. In 1900, he returned to Berlin where he began a close collaboration with the neurologist Oppenheim. His contributions included a subtemporal extradural approach to remove the gasserian ganglion for trigeminal neuralgia, section of the VIIIth nerve for tinnitus, and new approaches to reach posterior fossa structures.

In 1910, Krause reported the results of focal cortical excisions for "Jacksonian epilepsy" in 29 patients (9). Eight were considered markedly improved and four cured. These patients had focal sensory or motor seizure onset, and Krause described his best results in surgery for this type of epilepsy. He advocated

Figure 1.3 Krause worked in Berlin as a surgeon. He advocated stimulation to localize function in the central area and to reproduce the seizure onset.

stimulation to localize function in the central area and to reproduce the seizure onset. Identification and excision of the "primary spasmic center" was Krause's stated goal to realize the greatest impact on the seizure tendency (10). He reported stimulating the central area to map function and identify the seizure focus as early as 1893 (11). Ultimately, Krause produced one of the first detailed motor maps of the human cortex (Figure 1.4).

Harvey Cushing (1869–1939)

Among Cushing's many contributions to the field of neurosurgery, he first demonstrated the sensory function of the postcentral gyrus (12). The motor function in the central area was well known from stimulation experiments in animals since the nineteenth century as well as from neurosurgery with cortical stimulation in anesthetized patients by Krause, Frazier and Cushing himself among others. However, the function of the gyral strip posterior to the central sulcus was unproven prior to Cushing's contribution. In his 1909 publication (12) he described two patients with epilepsy and sensory auras arising from the hand. The patients underwent anesthesia induced with chloroform and morphine and were allowed to awaken after completion of the craniotomy. In both cases, Cushing used unipolar faradic stimulation and observed clear sensory responses isolated to the gyrus just posterior to the central sulcus.

Cushing identified a clear distinction in responses obtained from precentral and postcentral stimulation. The precentral stimulation responses were described as a forced change of position not unlike the experience accompanying movement associated with stimulation of a peripheral nerve, whereas postcentral stimulation was experienced as definite sensory impressions.

Pioneering work in the nineteenth century by Ferrier, Horsley, Sherrington and others to elucidate the somatotopic organization of motor function in the central area was a significant advancement for the field of neurosurgery. Prior to imaging, the only reliable means of cerebral localization for brain pathology was in the patient that presented with a focal motor seizure or localizable neurological deficit. Cushing's observations enabled cerebral localization in patients with sensory phenomena, and established our current knowledge of central area physiology, that the postcentral area is related to afferent sensory phenomena and the precentral area has an efferent motor function (Figure 1.5).

Otfrid Foerster (1873–1941)

Foerster was born in Breslau, Germany (Figure 1.6). He studied neurology with many of the famous clinicians in Europe and especially in Paris before returning to Breslau to join Wernicke's neurological practice. Eventually, Foerster established an Institute of Neurology with the support of the Rockefeller Foundation in 1934, the same year as the founding of the Montreal Neurological Institute (MNI). Foerster made many contributions to neurology including a meticulous description of the dermatomal distribution of the posterior spinal roots. He established a number of neurosurgical treatments such as posterior

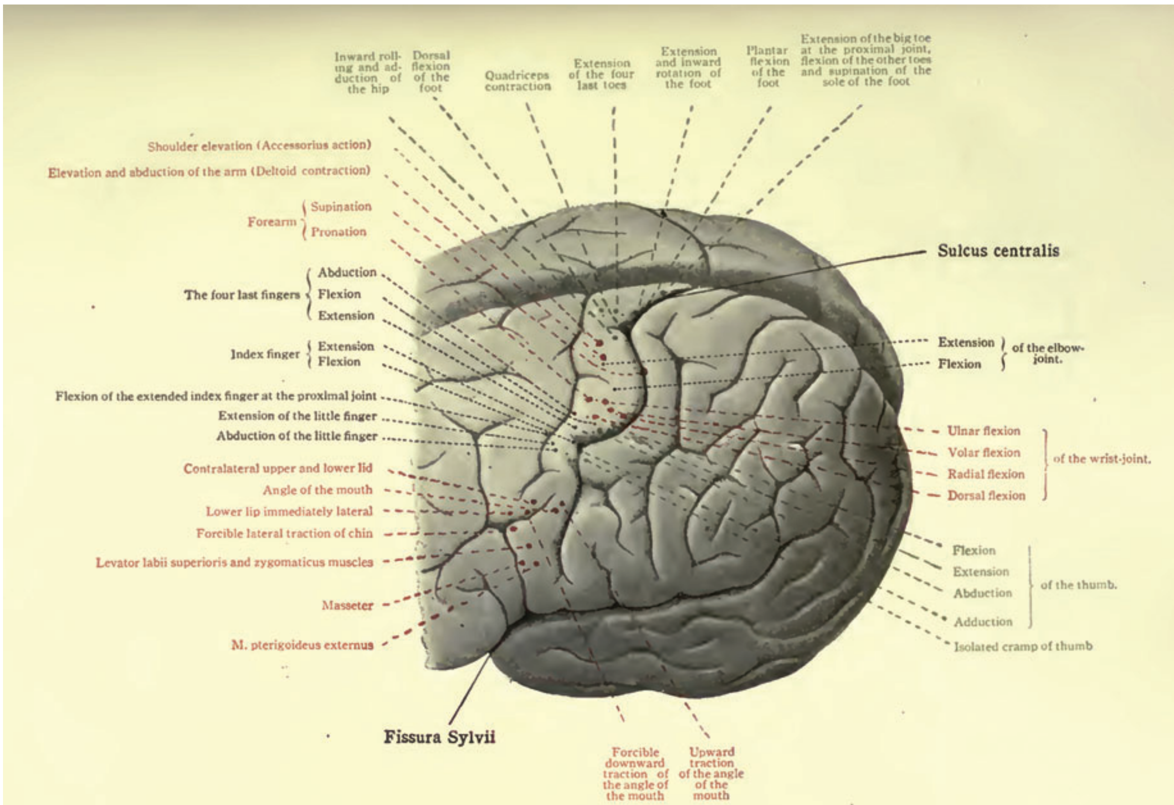

Figure 1.4 Somatotopical organization as determined by Krause. One of the first detailed maps of the human motor cortex. Note emphasis on central sulcus. Reprinted from: Krause F. *Chirurgie des Gehirns und Rückenmarks*. Berlin: Urban & Schwarzenberg, 1911.

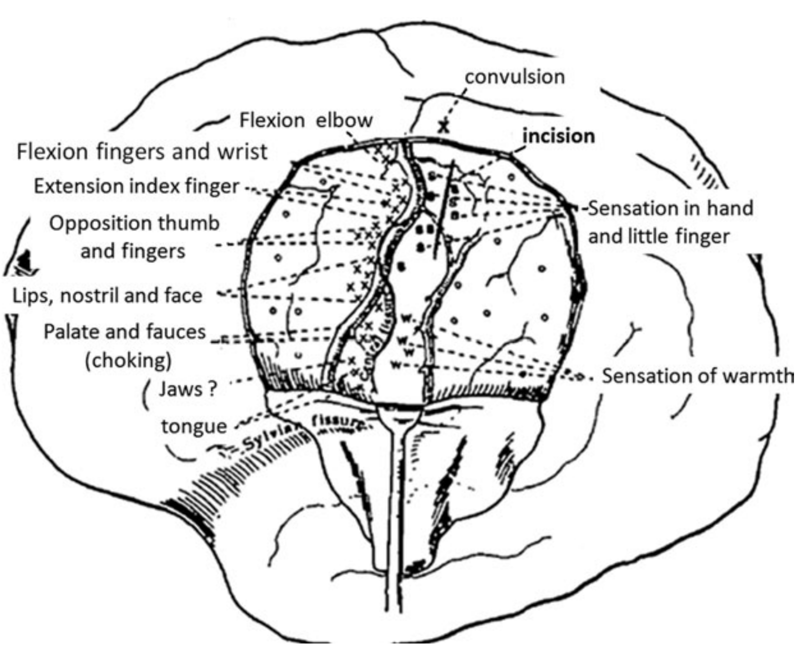

Figure 1.5 Cushing was able to awaken patients during cortical stimulation, to record the localization of sensory impressions. Reprinted from Cushing H. A note upon the faradic stimulation of the postcentral gyrus in conscious patients. *Brain* **32**: 44–53, 1909.

Figure 1.6 Photograph of O. Foerster dedicated to Wilder Penfield. Foerster trained as a neurologist. He became a surgeon during the First World War and developed an interest in epilepsy.

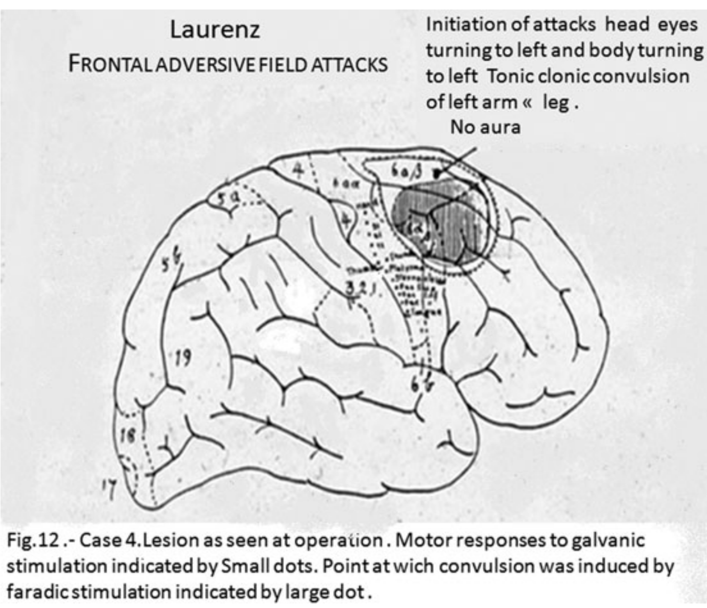

Figure 1.7 Operative brain map by Foerster with detailed mapping of lesion, extent of resection and results of cortical stimulation. Reprinted from: Foerster O, Penfield W. The structural basis of traumatic epilepsy and results of radical operation. Brain 53: 99–119, 1930.

rhizotomy to treat spasticity and anterolateral cordotomy for intractable pain. His expertise across a range of neurological topics was evident in an encyclopedic text of neurology he co-edited with Bumke (13).

Foerster was a neurologist up to World War I when with large numbers of wounded soldiers to treat for neurological problems, he decided he could best care for them as a surgeon, and from that point he was a neurosurgeon. He operated for diseases of the peripheral nerves, spinal cord, and brain with good results. However, for this discussion, his greatest contribution arose from his interest in the surgical treatment of epilepsy. After the war, veterans presented to him with cerebral injuries now causing seizures. He diagnosed and localized the cicatrix by a careful analysis of the seizure pattern, the neurological exam, and pneumoencephalography imaging. He performed surgery under local anesthesia with cortical stimulation, and he advocated as complete a resection of the scar as possible to achieve the best results in reducing the seizure frequency. He performed the first electrocorticography with Altenburger (14). In the tradition of Krause, Foerster produced a detailed brain map of his stimulation results. However, Foerster's map was more extensive including sensory as well as responses outside the central area (Figure 1.7). With cortical stimulation, he obtained responses we now associate with the supplementary motor area in man (13).

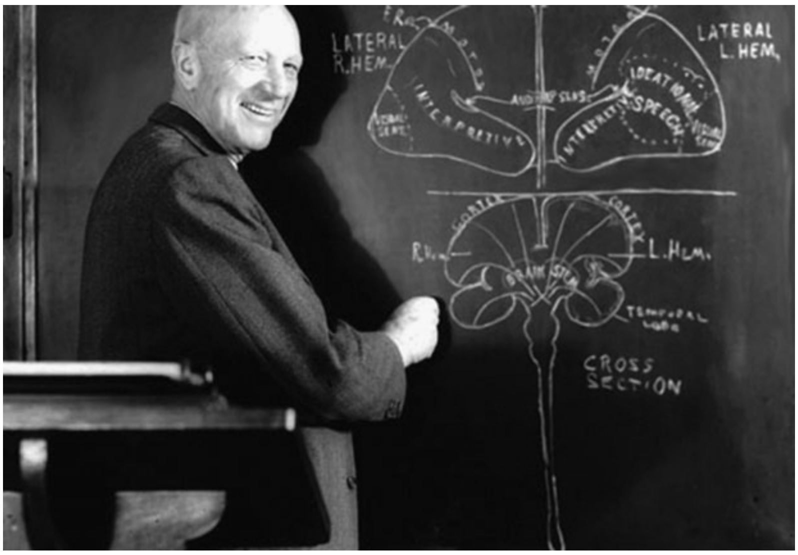

Figure 1.8 Penfield (1891–1976) founded the MNI. He brought to Montreal Foerster's approach to the surgery of epilepsy.

Foerster attracted students like John Fulton, Percival Bailey, Paul Bucy and Wilder Penfield. Penfield was particularly influenced by Foerster and eventually established the MNI modeled after Foerster's center in Breslau.

Montreal Neurological Institute

Wilder Penfield (Figure 1.8) and William Cone moved to Montreal to establish a neurosurgical unit at McGill University and Royal Victoria Hospital in 1928. They were recruited to Montreal by Edward Archibald, for some time the only neurological surgeon in Canada. Archibald had made significant contributions to neurosurgery. In 1908 he authored one of the earliest comprehensive texts of neurosurgery that demonstrated his advanced knowledge of cerebral localization (15). Although Archibald was increasingly interested in chest surgery, he saw the importance of a well-developed neurosurgical clinic.

Penfield was a neurosurgeon at the Presbyterian Hospital in New York. He had worked with Cajal and Hortega in Madrid to learn neurocytology and the silver staining technique. Prior to arriving in Montreal, Penfield spent 6 months with Foerster in Breslau. Together, they published important papers on surgery for traumatic epilepsy (16), Penfield expanded on Foerster's description of secondary motor and sensory areas (17), and it was Foerster's approach to epilepsy surgery that Penfield brought to Montreal. By 1934, with a Rockefeller Foundation grant and funding from Canadian sources, construction was begun on the Montreal Neurological Institute, a free-standing institute of neurology, neurosurgery, and neuroscience research (Figure 1.9). Penfield and Cone's work in neuropathology attracted fellows like Dorothy Russell to Montreal. Penfield had edited an important book on the subject (18).

A few early North American neurosurgeons such as William Keen had demonstrated an interest in surgical treatments for epilepsy, but by the time Penfield arrived in Montreal, there was little enthusiasm for this approach. From the beginning, the MNI became an important center for treatment and study of epilepsy. In 1936, Penfield discussed the importance of localizing the epileptic focus to plan a resection (19). The seizure pattern, neurologic signs, imaging findings, and responses to direct stimulation were the stated keys to discovering an epileptic focus. A number of articles concerning aspects of localization and surgery for tumor, scar, and congenital lesions followed with collaboration from Erickson, Tarlov, Humphreys, and others (20–22). Cortical stimulation was an important part of surgery for epilepsy, and like the neurological surgeons before him (Horsley, Keen, Cushing, Krause, and Foerster), Penfield made detailed maps of the sensorimotor area (23) (Figure 1.10). However, he and Rasmussen went further in identifying a variety of complex and higher cognitive responses including speech, secondary sensory and motor areas, autonomic function, as well as dreams and memories (24). Penfield and Roberts expanded on the

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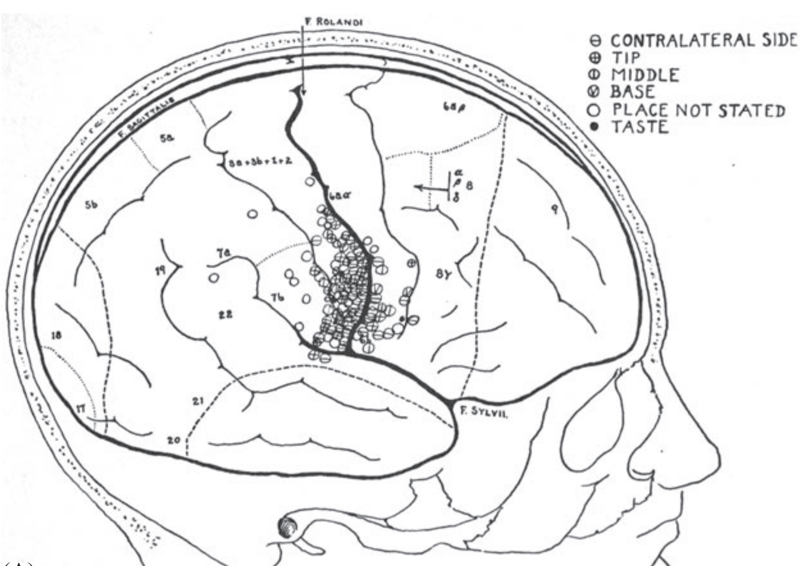
Figure 1.9 The MNI around 1934, shortly after its construction. The bridge across University Street joins it to the Royal Victoria Hospital. From the Neuromedia Archive, MNI.

localization of speech, memory, and higher cognitive functions (25).

Most of the early surgery for epilepsy at the MNI was extratemporal. However, the correlation of EEG, seizure pattern, and cortical stimulation demonstrated the typical manifestations of temporal lobe epilepsy, that Penfield called psychical seizures (26), ultimately leading to more temporal lobe resections. The technique evolved from restricted resections to the so-called anterior temporal lobectomies with or without the mesial temporal structures. In 1950, Penfield and Flanigin reported results of surgical resection for temporal lobe epilepsy in 51 patients operated over the previous 10 years (27). The importance of recognizing the typical semiology of temporal lobe attacks and lateralizing the focus with imaging and EEG was underscored. In only two cases was the hippocampus excised, and 53% became seizure free or had only a rare seizure. In these patients electrocorticography (ECOG) was interpreted by Jasper and found to be important in guiding the resection (28). Additionally, Jasper, in contrast to the Boston group of Gibbs, Gibbs, and Lennox, put emphasis on the anatomic localization of the abnormal spiking activity rather than EEG morphology. Penfield and Baldwin, in 1952, described in detail the surgical technique of anterior temporal lobectomy and introduced the term "incisural sclerosis" to describe the hippocampal sclerosis often encountered in cases of temporal lobe epilepsy. They proposed the etiology to be birth trauma and herniation of the mesial temporal lobe over the tentorial



(A)

Figure 1.10A Early MNI brain map by Penfield, from the MNI archives.

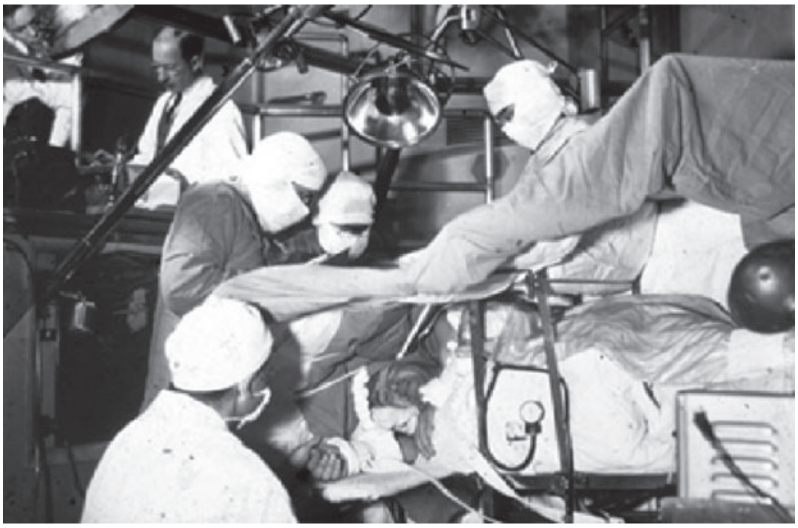

(B)

Figure 1.10B The Montreal Procedure, circa 1954. Penfield operating and Jasper reading the ECOG behind the glass wall. Operation for epilepsy performed under local anesthesia at the MNI. From Penfield W, Jasper H (eds), *Epilepsy and the Functional Anatomy of the Human Brain.* Boston, MA: Little, Brown, 1954.

Figure 1.11 Penfield and Jasper in 1954 at the time of publication of their seminal book entitled *Epilepsy and the Functional Anatomy of the Human Brain.*

incisura. In 1954, Penfield and Jasper published an important book, *Epilepsy and the Functional Anatomy of the Human Brain* that added significantly to the current knowledge of focal epilepsy (29).

Herbert Jasper (Figure 1.11) arrived at the MNI in 1938 from Brown University to establish an EEG and neurophysiology laboratory. The addition of preoperative and intraoperative EEG greatly improved the identification of the seizure focus.

Theodore Erickson, in his graduate thesis at the MNI, presented the results of his experimental studies on the role of the corpus callosum in the manifestation of cerebral seizures (30). He clearly showed the disruption of seizure spread with callosal section. In 1941, Penfield and Erickson published a monograph that encompassed the complete evaluation of the epileptic patient including localization, pathophysiologic mechanisms, imaging, types of lesions

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encountered, different treatments, and their results (31). Jasper included an excellent chapter describing the use of EEG and the value of spikes viewed in monopolar and bipolar configurations to identify an epileptic focus.

Jasper's laboratory attracted many fellows for training and collaboration. Doogleever-Fortyn, Olszewski, and Ajmone-Marsan published important atlases of the cat diencephalon and monkey thalamus (32, 33). Rayport and Morrell studied epilepsy and its effects on the brain. Morrell and Whisler at Rush Presbyterian in Chicago later developed the technique of multiple subpial transection. Pierre Gloor carried out classical studies on the diencephalon and amygdala. He succeeded Jasper as the head of EEG and neurophysiology and became very involved in the investigation of patients studied with intracranial recording. Gloor and Christian Vera studied electrical discharge from the hippocampus. Juhn Wada introduced the intracarotid amobarbital test while working at the MNI with Rasmussen and later moved to Vancouver. Charles Branch performed microelectrode studies in the cat cortex. Phanor Perot, Bryce Weir and Dan Pollen studied epileptic discharges with microelectrodes. With Penfield, Perot studied experiential responses to stimulation in humans and ultimately took up the chairman of neurosurgery position at Medical University of South Carolina and was joined by Vera. Weir became chairman of neurosurgery at University of Chicago. He succeeded Joe Evans, Theodore Rasmussen, and John Mullan, all former MNI neurosurgical fellows.

Arthur Ward completed his neurosurgical training at the MNI under Penfield. In 1947, he became chief of neurosurgery at University of Washington where he developed a neurophysiology laboratory for microelectrode recording and a surgery for epilepsy program. George Ojemann trained under Ward and succeeded him to head the surgery for epilepsy program and pursue work on speech localization. William Wilson, a fellow under Jasper, became director of the EEG laboratory at Duke University and worked with two MNI-trained neurosurgeons, Blaine Nashold and Guy Odom, to form the Duke University Epilepsy Surgery Program. After an MNI fellowship, Mark Rayport developed an epilepsy surgery program at Albert Einstein College of Medicine. Following his fellowship at the MNI, Flanigin established epilepsy for surgery programs at the University of Arkansas and later at the Medical College of Georgia. Maitland

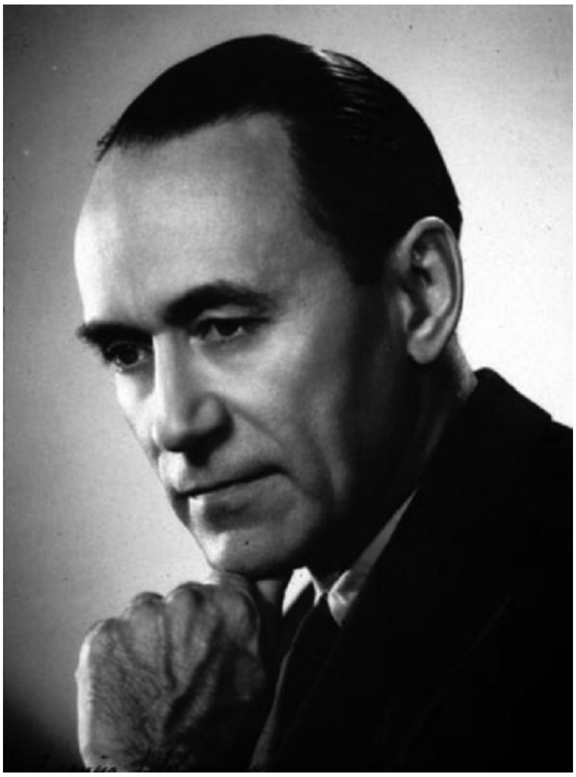

Figure 1.12 Theodore Rasmussen.

Baldwin joined the NIH after training in Montreal under Penfield where he established an epilepsy surgery program. He was succeeded by John Van Buren who also trained in neurosurgery at the MNI. Additional MNI fellows who joined the National Institute of Neurological Diseases and Blindness of the NIH included: Li, Caveness, Masland, Shy, Lord, Ajmone-Marsan, Tower, Gorman, and Stefanis. Other MNI-trained neurosurgeons who set up special units for the scientific study and surgical treatment of epilepsy include Theodore Erickson at the University of Wisconsin, Edwin Boldrey at the University of California San Francisco, Keasley Welch at the University of Colorado and later at Harvard Medical School, and Lamar Roberts at the University of Florida.

Theodore Rasmussen (1910–2002)

Theodore Rasmussen became professor of neurological surgery at the University of Chicago after a fellowship at the MNI (Figure 1.12). He then returned to Montreal in 1954 to succeed Penfield as director of the MNI in 1960. Rasmussen was a contemporary of Murray Falconer, and at a time when few centers were active in surgery for epilepsy, he treated a large number of patients with excellent operative results and very low morbidity. In 1958, Rasmussen and Jasper reported the importance of the mesial temporal structures in the temporal lobe seizure pattern. Stimulation of these structures produced fragments of a stereotypical temporal lobe seizure (34). At the Second International Colloquium on Temporal Lobe Epilepsy in 1958, Rasmussen reported the results of 244 patients operated on for temporal lobe epilepsy at the MNI as well as the use of intracarotid sodium amytal for speech lateralization (35). A more detailed analysis of the amytal test for speech lateralization was presented in 1960 (36). In 1962, Rasmussen and Branch reported the results of 389 surgically treated patients with temporal lobe epilepsy and their long-term follow-up (37). Forty-three percent were seizure free and 25% had only an isolated seizure.

Good results were also realized in surgery for extratemporal epilepsy. When Rasmussen analyzed the results of surgical therapy in the frontal lobe series, he recognized that most of these patients had large epileptogenic areas, and the best results were obtained with more extensive resection (38, 39). In total, 250 patients had been operated on for frontal lobe epilepsy. Of the non-neoplastic group, one-third was seizure free and one-third had markedly reduced seizure frequency. A group of 88 patients with multilobar epilepsy due to large destructive lesions, reported from the MNI, also benefited from surgery to control their seizures (40). A series of comprehensive papers were reported by Rasmussen in 1975 detailing the MNI experience with cortical resection for the treatment of focal epilepsy from frontal and other extratemporal areas as well as associated with brain tumors (41).

In 1958, Rasmussen presented three patients with severe, intractable focal seizures (42). Each patient had childhood-onset epilepsy that progressed to a hemiparesis. Pathology specimens and imaging showed perivascular cuffing and inflammatory changes confined to one hemisphere. Two of these patients underwent a hemicorticectomy that arrested the seizures. The progressively worsening focal seizures and hemiparesis with encephalitic changes in the affected hemisphere is now called Rasmussen's encephalitis. He advocated hemispherectomy and went on to develop the procedure of functional hemispherectomy as treatment for this disease. During the 25 years from 1955 to 1980 Rasmussen probably performed more operations for epilepsy than any other surgeon of his time (43).

Brenda Milner arrived at the MNI from the University of Cambridge in 1950 to test cognitive function in Penfield's patients undergoing surgery for epilepsy. She recognized material specific deficits for right and left temporal resections, made important new discoveries concerning the memory function of the mesial temporal structures, and described the global amnesic state that can occur with bilateral hippocampal injury (44, 45). With the recognized risk of temporal lobe surgery to worsen memory function, it became imperative to screen patients at risk for significant memory deficits. At the suggestion of Rasmussen, Milner incorporated a memory component into the intracarotid amobarbital test (46). The test has proven to be useful and now is an important part of preoperative evaluation.

William Feindel became a fellow in 1952 and succeeded Rasmussen as director of the MNI in 1972. As director of the MNI, he had a visionary perspective of the revolution that was to take place in modern imaging. He was instrumental in procuring computerized tomography (CT), positron emission tomography (PET) and magnetic resonance imaging (MRI) units (as soon as they became available) as well as developing the functional imaging program that is now of a very high caliber and has become crucial in the evaluation of epilepsy. Feindel investigated the role of the amygdala in temporal lobe seizures. Through an in-depth analysis of Penfield's cases, he found the periamygdaloid region to be important in temporal lobe seizure generation, and one of the structures that can give rise to the typical temporal lobe seizure pattern (47). Feindel also described techniques to study the microcirculation of man in vivo using fluoroscein angiography and other diffusible dyes (48, 49).

Percival Bailey and the Gibbs

Frederic and Erna Gibbs began their work in EEG at Harvard in 1934. Working with Lennox and Davis, they showed a three per second spike and wave complex in petit mal epilepsy, and went on to correlate the EEG with other epileptic and non-epileptic states (50–52). In 1944, the Gibbs moved to the University of Illinois where they began work with the neurosurgeon Percival Bailey. The Gibbs noticed anterior temporal epileptic EEG activity in many cases of what they called psychomotor epilepsy, and advocated anterior temporal resection. In a number of these cases Bailey operated under general anesthesia with intraoperative ECOG. He performed a temporal resection anterior to