HISTORY OF EPILEPSY SURGERY:
INTRODUCTION

PETER WOLF

What is the interest in the history of epilepsy surgery or the history of any other field of medicine? It is above all that it makes us better understand the reasons for what we do today. It makes us recognize that some of our established approaches and views are due to clear decisions that have been taken at a certain moment, whereas others seem to be rather the consequences of chance, and the development could as well have taken another route.

Sometimes we believe or hope to learn from history, and hope that its study gives us a chance to avoid predictable mistakes. It is, however, questionable whether this happens frequently. Usually, people do not learn from other people’s mistakes but only from their own, if they learn at all. In the history of epilepsy surgery there certainly are lessons from which we could learn, even if we only look at the recent history, which is concerned with epilepsy surgery seuem stricta, which means brain surgery guided by the analysis of epileptic activity and aimed at the disappearance of the patients’ seizures.

THE BEGINNING OF EPILEPSY SURGERY

It is often said that the history of epilepsy surgery began on May 25, 1886, when Victor Horsley operated, at the National Hospital for the Paralysed and Epileptic at Queen’s Square in London, on a patient of John Hughlings Jackson (who was present at the operation). This patient was a man of 22 years with focal motor seizures that were caused by a depressed skull fracture, the consequence of a trauma he had suffered 15 years before (1).

At this time, trephination as a surgical remedy for epilepsy had been in use already for many centuries (2). In antiquity and the middle ages, it had been done in view of creating an outlet for pathogenic humors and vapors. However, in the nineteenth century, trephination was given a much more rational basis, and shortly before Horsley’s and Jackson’s decision to operate on the above patient, William Gowers had summed up the discussion when he said that trephination was justifiable only in cases in which the disease has followed an injury to the head, and in which either there is still a depressed bone, or the local commencement of the fit suggests that the disease causing them is at the surface of the brain, involving the motor convolutions which are adjacent to the fissure of Rolando. (3).

He went on to say that he had seen not more than one patient who fulfilled these conditions.

Gowers also worked at Queen’s Square, and Horsley had been his pupil. It was therefore probably not by chance that Horsley’s first patient presented exactly the situation that Gowers had defined, and the decision to operate was in full agreement with the state of the discussion about a time-honored procedure. At the same time, what Gowers said in the above quotation about the “local commencement of the fit” clearly reflects the thoughts of Jackson, and we get a fairly clear idea about the discussions and deliberations that provided the basis for the step Horsley took when operating on this patient.

Considering this background, I would suggest that epilepsy surgery in the true sense of the term started about 1 month later, on June 22, 1886, when Horsley operated on a second patient who had also been transferred to him by Jackson (1). This was a 20-year-old man who for 2 years had suffered from what came to be called jacksonian seizures, with onset in the left hand by clonic opposition of the thumb and forefinger. These could “often be arrested by stretching the thumb or applying a ligature” — procedures that Gowers had described in much detail in his monograph (3), and that Jackson also applied (4). Frequently, however, the seizures would develop into a “severe fit,” and this was often followed by a paralysis of the left upper limb. At investigation, there was some weakness of the left hand and a “loss of muscular sense (i.e., sense of position, etc.) in the left thumb, Deep reflexes were exaggerated in the left upper limb” (1). There were no other pathological findings, and Horsley based his intervention on monkey experiments that he had performed together with Beevor in

P. Wolf: Epilepsy Center Bethel, Klinik Mara, 33617 Bielefeld, Germany.
which they had elicited the opposition movement of thumb and forefinger by stimulation of "the ascending frontal and parietal convolutions at the line of junction of their lower and middle thirds" (1). Jackson, who had witnessed these experiments, agreed that the patient's seizures were due to "an irritative lesion of unknown nature, situated in the part of the brain thus indicated" (1). An exploratory operation was therefore decided upon, and a tumor was found at the predicted place that turned out to be a tuberculoma.

Not only was this operation guided by the exact analysis of the seizure semiology, but there is an additional reason for considering it the first true epilepsy surgery. Horsley not only took out the tumor and the immediately surrounding tissue, which was visibly altered, he also removed,

by free incision, the centre of the thumb-area... This detail Dr. Jackson and myself had resolved to carry out in the possible event of there being no obvious gross organic disease, in order to prevent, as far as possible, recurrence of the epilepsy. (1)

In a footnote, Horsley explains that the exact localization of this area was "ascertained by the use of the induction current," and that the rationale of the procedure was to remove the "epileptogenic focus." The latter term seems to appear here for the first time in the literature.

Thus, at the very beginning of epilepsy surgery, we find already a discussion of a problem that remains to be dealt with today, that is, the relation of a morphological lesion to the "discharging lesion" (to use a jacksonian term) or the seizure-generating zone. At the same time, Horsley and Jackson set an example of teamwork and interdisciplinary cooperation in the indications for epilepsy surgery that it is still highly recommendable to follow.

THE FIRST WAVE OF EPILEPSY SURGERY

The repercussions of Horsley's report (1) on three patients operated on between May 25 and July 13, 1886, were phenomenal, and can be best demonstrated by the following figures. In the 5 years from 1894 to 1898, 50 reports and seven doctoral theses on epilepsy surgery coming from nine different countries were published, and some of these reported on rather large series of patients, the largest comprising 146 cases (5).

Thus 100 years ago there was a first big wave of epilepsy surgery that is fully comparable in scale and internationality to what we have been experiencing during the last decade. This wave was carried by an enormous enthusiasm, even euphoria, which almost by necessity was followed by a decline of interest when it turned out that the successes were limited and the risks rather high, with a mortality on the order of 5% to 7%.

When, with the introduction of phenobarbital in 1912, the great period of modern pharmacotherapy of epilepsy began, the surgical approach became largely forgotten. Critical discussions of surgical interventions by conservative epileptologists such as Binswanger (5) or Turner (6) also indicate clearly that the decline was to some extent due to a loss of methodological acumen, and a dilution of the criteria for selection of patients to a stage much inferior to Gowers' above-quoted statement. Thus Turner found it necessary to point out that "in genuine idiopathic epilepsy, surgical interference is useless" (6). Only a few doctors continued to operate on patients with epilepsy, showing that this therapeutic approach had its specific value if the right patients were selected and the methodology was of good quality. The names of Fedor Krause (7) and Otfrid Foerster (8) especially deserve to be mentioned in this respect, because they carried epilepsy surgery through this difficult period. Tribute is paid to them in this volume (see Chapter 2).

LATER DEVELOPMENTS

The second wave of epilepsy surgery started in the 1940s when the newly invented electroencephalogram had helped to discover the role of the temporal lobe as an important localization of pharmacoresistant epilepsy. Wilder Penfield (9) and Percival Bailey (10) were the driving forces of this development, which came to interest many clinicians. Several groups performed epilepsy surgery on a high level, but, again, a constant standard of quality could not be introduced everywhere, and epilepsy surgery became discredited when too often, as Dr. Rasmussen of Montreal would put it, "the wrong surgeons operated on the wrong patients." At this time, however, there were more groups whose approaches were sufficiently developed not only to carry on, but to further develop the methodologies. Chapters 2, 3, and 4 are dedicated to some of the scientists whose role was sometimes not sufficiently appreciated, although they helped to lay the foundations for the third wave of epilepsy surgery, which we are experiencing at this moment.

Is it the lesson of history that we must be prepared for another decline, or is neurosurgery as a therapy for epilepsy now sufficiently established not to be subject to fashion any longer? The answer to this question will to a large extent depend upon the thoughtfulness with which we proceed. Twice in the short history of epilepsy surgery, decline was the consequence of our inability to broadly implement and maintain a high standard of methodology and procedural quality. Epilepsy surgery has again become an attractive field for ambitious neurosurgeons who are not always aware of the intricacies of this therapeutic area, and do not always realize that it is indispensable to approach it with an interdisciplinary team, for which Jackson and Horsley set the example.

In some parts of the world, patients are still being operated on without sufficient identification of the epilepsy syndrome and focus, with methods that have not been subject to critical scientific review, and with outcomes that are not systematically evaluated with generally accepted instruments. If we find no way to change this, epilepsy surgery as a whole could fall into discredit again.
REFERENCES

Epilepsy surgery usually consists of ablation of epileptogenic cortex in an attempt to ameliorate the seizures it causes. Although trepanations were performed prior to Hippocratic medicine and well into the nineteenth century in an attempt to treat epilepsy, true epilepsy surgery became possible only after the introduction of three main advancements in medicine: anesthesia, antisepsis, and cerebral localization. In 1844, Horace Wells began the use of nitrous oxide on dental patients. Two years later, William Morton introduced the use of ether anesthesia, and, in 1847, J. Y. Simpson was the first to use chloroform (1,2). In 1867, after Louis Pasteur introduced his concept of microbes and the germ theory, Joseph Lister introduced antisepsis to the operating theater with a carbolic acid dressing (3). Lister used a carbolic acid spray in 1871. Both anesthesia and antisepsis caused a significant decrease in morbidity and mortality in surgical patients. However, it was the advent of cerebral localization that allowed a few general surgeons, with a special interest in the nervous system, to begin the field of neurological surgery and to pave the way for ablative surgery as a new treatment of epilepsy.

Prior to the 1860s, the brain was believed to function as a single unit. In 1861, Paul Broca established the relationship of aphasia with a left inferior frontal lesion (4–6). In 1870, Gustav Fritsch and Eduard Hitzig reported their pioneering results with electrical stimulation of the cortex of dogs (7). Knowledge of cerebral localization grew rapidly with ablative studies by David Ferrier and the careful analysis of ictal symptomatology by John Hughlings Jackson in patients with partial epilepsies (1,2). These studies were complemented by progressively more detailed observations on the effects of electrical stimulation of the cortex in animals by Sherrington and Grünbaum, Horsley, Oskar and Cecile Vogt, and Schiff (8). The first cortical electrical stimulation studies in humans can be traced to work done by Robert Bartholow in Ohio. In 1874, he had in his care a patient with a large cranial defect exposing parts of her cerebral hemispheres. Though not stimulating the cerebral cortex directly, needles were inserted into the dura mater and, upon closing the circuit, Bartholow witnessed muscular contractions in the right arm and leg (1).

Broca himself was the first to apply the results of cerebral localization studies to actual surgical procedure. In 1871, he attempted the removal of an abscess lying approximately over Broca’s area. However, the patient did not survive the procedure (6,9). Soon other surgeons became aware of the new therapeutic opportunities that the advent of cerebral localization provided, and pioneering surgeons such as William Macewen and Rickman Godlee began performing neurosurgical procedures based on the ability to localize the lesion. One of the landmark neurosurgical cases occurred on November 25, 1884. Joseph Lister’s nephew, Rickman Godlee, resected a tumor that A. H. Bennett had localized correctly by analyzing the type of focal motor seizures and partial paralysis the tumor had produced. Unfortunately the patient expired 1 month later from infection and increased intracranial pressure. Present during this operation were John Hughlings Jackson, David Ferrier, and Victor Horsley. Soon thereafter they received a grant from the British Medical Association that led to the first surgical treatment of epilepsy at the National Hospital for Paralysis and Epilepsy in Queen’s Square, London (10). On May 25, 1886, using the information provided by localization studies by Ferrier and Jackson, Victor Horsley resected a highly vascularized scar from the motor cortex of a patient who had been suffering from posttraumatic focal seizures and status epilepticus. The patient became seizure free. Horsley presented the results of this and two other epilepsy surgery cases at the annual meeting of the British Medical Association in Brighton in August 1886 and published the results of nine epilepsy surgery cases (plus one case for migraine headaches) in the British Medical Journal in April 1887 (11,12). After that, Horsley’s interest in epilepsy

---

J. C. Lüders and H. O. Lüders Department of Neurology, The Cleveland Clinic Foundation, Cleveland, Ohio 44195.
surgery waned, and he produced no further publications on the subject after 1890 (13). At the turn of the century, the focus of neurosurgery shifted from England to Germany with the pioneering work of two men, Fedor Krause and Otfrid Foerster.

Fedor Krause trained as a general surgeon but soon developed a strong interest in the nervous system and became well known for his surgical approaches to it (Fig. 1). He published his observations on the surgical management of epilepsy in a three-volume set in 1909, 1911, and 1912 (14–16); over 200 pages in Volume II are dedicated to epilepsy surgery (15). Krause operated before the advent of electroencephalography and relied mostly on the triggering of typical seizures by cortical stimulation for localization of the epileptogenic foci in patients under local anesthesia. Based on his observations during cortical stimulation, he published the first map of the human motor cortex. Krause spent time visiting South America and has been credited with the introduction of neurological surgery to several Latin American countries. Some of Krause’s most distinguished pupils were Emil Heyman, C. M. Behrend, and George Merrem, who continued the tradition of neurosurgery in Germany (17).

Otfrid Foerster trained as a neurologist and developed a strong interest in the surgical management of neurological pathology (Fig. 2). Frustrated with the results of general surgeons operating on the nervous system, Foerster first began operating himself during World War I. After the war, Foerster became interested in the resection of posttraumatic scars and became well known for intraoperative cortical stimulation under local anesthesia. Foerster also produced the first cortical map of the entire cerebral cortex, which he published with Penfield in 1930. Foerster was well known around the world and attracted many visitors interested in his techniques, including Wilder Penfield, Percival Bailey, and Paul Bucy. These neurosurgeons spoke very highly of their time with Foerster. During World War II, the focus of neurological surgery and particularly the advancements in epilepsy surgery shifted away from Europe and toward North America.

**FEDOR KRAUSE**

Fedor Krause was born on March 10, 1857, in a Silesian town, Friedland, Germany. As the son of a community functionary, he required the financial support of a private sponsor to study medicine (17,18). He graduated from medical school in Berlin in 1880 with an interest in ophthalmology and began working for Professor J. Hirschberg in his eye clinic. He also had the opportunity to study under Carl Friedländer, Robert Koch, the pathologist Karl Weigert, and the surgeon Bernhard von Langenbeck. Although fascinated with neuroophthalmology and the visual pathways in the brain, Krause also had a strong interest in surgery. In 1883, he moved to Halle and began work as a resident surgeon in the surgical clinic at the University of Halle, under Professor Richard von Volkmann. Volkmann, well known for his outstanding surgical skills,
was credited with the introduction and application of Lister’s antiseptic techniques to Halle (18).

Krause became good friends with Volkmann, and 4 years after arriving in Halle he married one of Volkmann’s daughters. At that time Halle was a highly industrialized town with a high incidence of head injury. In 1885, together with Volkmann, Krause reported on 36 trepanations for post-traumatic subdural and epidural hematomas with no post-operative deaths (19). Krause’s habilitation thesis in 1887 entitled “Malignant Neuromas and Their Nerve Fiber Content” was questioned by some at the university as being an inappropriate topic for a surgeon. However, with the support of the chairman of the surgical clinic—his father-in-law, Professor Volkmann—it was eventually accepted. In 1889, Volkmann died of pneumonia. Krause was made interim director of the surgical clinic for 1 year until Friedrich Gustav von Bramann was offered the position. At this point, Krause moved to Hamburg and worked as the senior surgical resident at Altona Municipal Hospital. In 1900, Krause moved back to Berlin, where he was appointed professor and head of the surgical department at the Augusta Hospital (18).

In Berlin, Krause first began working closely with Hermann Ojemann, a neurologist. Together the two studied neurophysiology and neuroanatomy. Krause described their work as a “constant harmonious collaboration” (16). In 1909, Krause published the first volume of his book Surgery of the Brain and Spinal Cord—Based on Personal Experiences (Chirurgie des Gehirns und Rückenmarks nach eigenen Erfahrungen) (14). Volumes II and III followed in 1911 and 1912 (15, 16). Volume I contains detailed descriptions of over 300 craniotomies with hand-drawn color illustrations of the procedures. These books were written in German and became well known throughout Europe (19); they were later translated into English. Included in Volume II is a chapter of over 200 pages on epilepsy in which Krause described in detail over 20 cases of surgery for the treatment of epilepsy. Krause begins the chapter with an introduction to neurophysiology. He then describes Jacksonian epilepsy, “general genuine epilepsy,” post-traumatic epilepsy, and “reflex epilepsy.” The etiology of these different epilepsies, including tumors, infantile paralysis, and injuries at birth, are described in detail. Krause also has a section entitled “Results Obtained from Operations for Epilepsy” in which he discusses the indications for surgery and postoperative outcome (16).

Krause is believed to be the first surgeon to have performed intraoperative electrical stimulation of the cerebral cortex (8). In his chapter on epilepsy, he explains an operative case of Jacksonian epilepsy. This is not necessarily Krause’s first case, but it is the first case of direct intraoperative electrical stimulation of the cerebral cortex published in the literature. The patient presented at the age of 15 years. She had suffered “severe inflammation of the brain” at the age of 2 and developed convulsions that increased in frequency with time. The seizures always began in the left half of the face, the left arm, or the left leg. They sometimes were confined to this area but frequently became secondarily generalized. They were followed by prolonged (up to hours) postictal unconsciousness. The patient had surgery on November 16, 1893:

After separation and detachment of the dura, a large quantity of clear fluid escaped from the arachnoid spaces. The central convolutions lay freely exposed. Paroxysmal irritations (which were in this case bipolar) resulted in twitches of the lower facial region (1 in Fig. 3), the shoulder, as well as the arm (2 in Fig. 3) of the left side. The centre for the lower extremity could not be ascertained. The puncture of the brain above the facial centre, immediately underneath the cortex, proved successful, and a large quantity—about 100 ccm.—of clear waterlike serous fluid was evacuated. We were evidently dealing with an encephalitic cyst, located in the sub-cortical region. (16)

The patient had not only a cure of her epilepsy but marked improvement in her mental state. At the time of publication she had been seizure free for 17 years.

Krause presented his results of cortical stimulation with faradic current in the form of a cortical map that is confined to the anterior central convolution (16) (Fig. 4). Krause believed in the use of faradic stimulation rather than galvanic stimulation, which some of his neurosurgical colleagues preferred (8). He felt only the weakest current should be used, which he believed was best achieved with unipolar faradic irritation. In Surgery of the Brain and Spinal Cord—Based on Personal Experiences, Volume II he refers to Charles Sherrington when he states, “finer localizations are possible with

---

FIGURE 3. Illustration demonstrating the first operative procedure that incorporated electrical stimulation of the human cerebral cortex. (From Krause F: Chirurgie des Gehirns und Rückenmarks nach eigenen Erfahrungen, vol. II. Berlin: Urban and Schwarzenberg, 1911.)
unipolar irritation than with bipolar faradization—hence my preference for the former mode of stimulation” (15). This is consistent with his very detailed map of the human motor cortex. He also believed in the use of very small excisions of cortical tissue in order to keep loss of cortical function to a minimum. In this chapter, Krause also described surgery on the brain without the use of anesthetics, indicating that the exposed brain was insensitive to being “cut, manipulated, and irritated” (15). In 1932, Krause published a book together with his stepsister Heinrich Shum, *Special Surgery of Diseases of the Brain (Spezielle Chirurgie der Gehirnkrankheiten)* (20). He quoted discussions with Horsley in this book and devoted an entire chapter to electrical stimulation of the cortex and cerebral localization. During Krause’s entire life, he is believed to have operated on over 400 epileptic patients, by far the largest series at that time (21).

Krause’s success in epilepsy surgery was possible not only because of his interest in the pathophysiology of the nervous system, but also because of his fastidious surgical skills and knowledge of brain anatomy and physiology. During World War I, as a surgical consultant to the German army, Krause gained much experience in managing traumatic injury to the nervous system. This work enabled him to further study neurophysiology. These skills helped him to make great contributions not only to surgery of epilepsy but to neurosurgery and even to surgery in general. Krause was originally trained in general surgery and introduced procedures such as the free transplantation of skin flaps and the reimplantation of the ureter into the bladder (17). However, Krause is best known for his surgical approaches to the nervous system, which have come to be known as the “Krause operations.” These neurosurgical approaches include exposure of the trigeminal ganglion and root, of the cerebellopontine angle, and of the pituitary (transfrontal) and the pineal (supracerebellar) regions (22). He is often credited as being the first surgeon to gaze into an opened fourth ventricle (21).

Krause was a well-liked, modest man, even somewhat shy (18,21). He has been described as a man with large hands more appropriate for manual labor than delicate surgery on the central nervous system (23). However, he was an extremely
careful surgeon. He did not like giving formal presentations at large conferences. However, he greatly enjoyed informal teaching, which he spent much time doing with medical students (18,19). He never visited North America and, since all his publications were originally in German, he was relatively unknown to English and North American neurosurgeons. Although both Cushing and Penfield visited Germany, Cushing did not spend any time with Krause, and Penfield first visited Krause after he had retired (17). After World War I, however, Krause was invited to South America, which he visited on several occasions (18). Krause spoke both Spanish and Portuguese, and many South American surgeons visited his unit in Berlin. He imparted much new knowledge to the beginnings of neurosurgery in many South American countries, such as Brazil (18). Perhaps Krause’s greatest student was Emil Heymann, who succeeded Krause in 1923 at the Augusta Hospital in Berlin. Sadly, Heymann, who was Jewish, met great obstacles during the Hitler era and committed suicide in 1936. Krause’s other disciples, C. M. Behrend and George Merrem, helped to continue the tradition of neurosurgery in Germany after World War II (17).

Krause had a great love for music and classic literature. He was an accomplished player of both the piano and the violin. Before moving to Halle, he had even considered a career in music (18). In 1923, Krause retired and, although still active as professor emeritus, his interest in the profession waned. Paul Bucy, together with his wife, visited Krause in 1930 in Berlin. He said of Krause, “We found him to be a modest, kind man. He seemed already to have lost interest in neurosurgery and we did not discuss it. Instead Professor Krause entertained us by playing the violin” (24). Krause later moved to Rome, where he devoted himself completely to the arts and music. In Rome, he performed many private concerts on the piano (18). To his delight, to some people he became better known as a pianist than a neurosurgeon (23). Krause died in Rome at the age of 80 in 1937.

OTFRID FOERSTER

Otfred Foerster was born on November 9, 1873, in Breslau, Germany (now known as Wroclaw, Poland). He was the son of an archeology professor at the University of Breslau. His mother taught him to speak French and gave him lessons in French literature. He studied medicine at the Universities in Freiburg, Kiel, and Breslau, graduating in Breslau in 1897. His interest in neuroscience began after meeting Wernicke in Breslau, who suggested he travel abroad for training in neuroscience. After graduating, he spent 2 years in Paris in Dejerine’s clinic. During this time he had contact with Pierre Marie and Babinski. Afterward he returned to Wernicke’s clinic (25). He completed his habilitation thesis in 1902 entitled “The Physiology and Pathology of Coordination; an Analysis of Movement Disturbances in Disorders of the Central Nervous System and Their Rational Treatment.”

While working in Wernicke’s clinic, Foerster published an atlas of brain sections in 1903, edited by Wernicke (26). Although not yet a surgeon, in 1908 Foerster introduced a new method for the surgical treatment of cerebral spasticity by posterior rhizotomy (25). The same procedure could also be used for the treatment of pain. This procedure, which is still used today, made Foerster world famous and has become known as the “Foerster operation.” He further developed the procedure to include anterior chordotomy for intractable pain. He was the first to publish the dermatome borders in humans, using information gained from studying his patients.

In 1911 he was offered the position of head neurologist of a small ward at City All Saint Hospital, now named Babinski District Hospital, at First of May Square. This gave him the opportunity to work more closely with Professor Tieze and Kuttner, general surgeons whom he assisted during neurosurgical procedures (25).

During World War I, Foerster worked as a neurology consultant in Breslau, serving as chief of the neurological service at the Military Citadel Hospital. During this time he saw over 4,700 patients with peripheral nerve injuries. Although he was never officially trained as a surgeon, Foerster began operating during the war. He reported operating on over 770 peripheral nerve injuries. Near the end of World War I, he also began operating on both the spinal cord and the brain (25). Paul Bucy, who spent time with Foerster in 1930, wrote about a time when he asked him why he began operating; Foerster replied

“I had to make the diagnosis, I had to accompany the patient to the operating room. I had to tell Mieckulz (a general surgeon) where to operate. When he got inside the skull, I had to tell him where the tumor was and what to do. And then the patients all died. I decided I could do no worse.” (27)

After the war, Foerster continued to operate on the brain. The war gave rise to many patients with partial (focal) seizures secondary to scarring in the brain after gunshot wounds to the head. Foerster, as a neurologist, had the skills and knowledge to localize the epileptogenic focus. As a neurosurgeon, he removed these scars. He always used local anesthetic, which gave him the opportunity for intraoperative cortical stimulation. In 1924, Foerster was made director of the neurological and neurosurgical ward in Wenzel Hanke Hospital, in Breslau. In 1926, Foerster published his works on the operative treatment of epilepsy and on the pathogenesis of epilepsy (28,29).

Wildcr Penfield, soon after having been appointed head of neurosurgery at McGill University in Montreal, heard of Foerster’s work, and in 1928 received a grant from the Rockefeller Foundation to travel to Germany and learn Foerster’s technique of cortical stimulation and removal of brain scars (30,31). He spent 6 months in Breslau with Foerster. Observing that electrical stimulation induced epileptic seizures, they hypothesized that the seizure was the result of vasocostriction in response to the electrical stimulation. They published their results in 1930 in both German and English (32,33). In these papers, Foerster and Penfield also published
a cortical map using their results of cortical stimulation during epilepsy surgery (Fig. 5). They based it on Oskar and Cecile Vogt's results on animal experiments. While their map showed less detail of the motor cortex relative to Krause's earlier map, it encompassed most of the cortex. Penfield was very impressed with Foerster's ability as both a neurologist and neurosurgeon: "such a well balanced combination of neurology and neurosurgery is to be found nowhere" (34). Upon returning to Montreal, with another grant from the Rockefeller foundation, Penfield created the Montreal Neurological Institute (MNI) with the help of William Cone, who had also spent time in Breslau with Foerster. The MNI was created in 1934.

Foerster essentially funded his own work up until 1932, when he received financial support from the Rockefeller Foundation, which he obtained with the help of his North American friends. Foerster's resources were very limited prior to receiving this grant, and much of his work was carried out in cellars. Percival Bailey at one point called his laboratory "a hell hole which smelled like formalin" (17). In 1934, the same year as the MNI was created, the Otfried Foerster Foundation was completed, also with the help of the Rockefeller Foundation. However, the Otfried Foerster Foundation did not survive through World War II.

Foerster's work in epilepsy went beyond its surgical treatment. Although electroencephalography was first used near the end of his career, Foerster, together with Altenburger, produced the first intraoperative electrocorticogram (35,36) (Fig. 6). Other important contributions include the introduction of hyperventilation to induce seizures, which is still used today. Foerster is also credited with coining the expression "psychomotor epilepsy" (37).

Foerster's work was not limited to the study of epilepsy. As mentioned previously, his early studies on peripheral nerves and the results from his technique of dorsal rhizotomy helped him to determine the dermatome borders in humans (37). He is credited with the introduction of physical therapy in the rehabilitation of neurology patients, which remains a vital part in the treatment of such patients today. In 1922, when Lenin began suffering from recurrent right hemiparesis, the government of the Soviet Union invited Foerster to help care for him. Foerster was the head physician for a team of professors from all around the world. He remained at Lenin's bedside until his death in January 1924. Foerster was responsible for signing the death papers, including the papers for his postmortem exam (25). In 1924, Foerster became president of the German Society of Neurologists. He maintained that position until 1934, when the society joined the German Society of Psychiatry and became associated with the National Socialist Party's indoctrination of genetics (17).

Foerster had many visitors from around the world, including the United States, Great Britain, Canada, France, Italy, South Africa, China, Japan, Australia, Romania, Holland, and Scandinavia. Foerster was fluent in English, French, and

Italian. He also knew Russian, Polish, and Scandinavian languages. Percival Bailey visited Foerster in 1932 for a 4-month sabbatical. Bailey dedicated an entire chapter in his book *Up from Little Egypt* to his time with Foerster, entitled “Der Herr Professor,” in which he describes Foerster as “one of the most distinguished neurologists in the world” (38). Paul Bucy visited in 1930 and described his time in Breslaw with Foerster in a letter to Dr. Jerzy Wronski in May 1982, stating “There is no period in my life which has been as stimulating as this” (25). Penfield described his time in Breslaw and wrote about Foerster in his book *No Man Alone*: “As the professor of neurology and the neurosurgeon in the University of Breslaw, and as perennial president of the German Society of Neurology and Psychiatry, he was a rather awe-inspiring phenomenon” (31).

Many of Foerster’s visitors returned to North America to play crucial roles in the continuing development of epilepsy surgery and cerebral localization. Bucy, together with Klüver, studied the role of the temporal lobes in monkeys, and in 1939 introduced their findings of behavioral changes in primates after bilateral temporal lobectomies (10). Bailey, together with Gibbs, worked with patients with psychomotor epilepsy and published work on temporal lobe epilepsy surgery in the early 1950s (39). The most important pupil of Foerster’s, in terms of epilepsy surgery, was Penfield. The cortical stimulation technique that Penfield learned in Foerster’s lab, together with electroencephalography, helped him to further elucidate the cortical map and the role of the temporal lobe in epilepsy. Penfield was the first to describe temporal lobe surgery for epilepsy in 1950 (40).

Foerster was raised in a cosmopolitan family. He played the flute, loved playing tennis, and loved languages. As a student he was known to go to many parties, and was said to be an excellent dancer (36). In Breslaw he met and fell in love with Martha Bauer. She was a woman of culture and charm, an excellent tennis player, a good pianist, and half-Jewish. According to Foerster’s mother, he was first attracted to her for her outstanding tennis skills (38). They married in 1903 and had three daughters. According to Bailey, in the 1930s Foerster had great difficulty with the Nazi government. Foerster had described Hitler to Bailey as a hysterical and dangerous man, much more than most Germans realized. In 1937, Bailey and Foerster met in München at the German Neurological Congress. Speaking in French so they would not be understood by others, Foerster explained to Bailey his suspicions of the Nazis, and his dilemma. Foerster’s wife was half-Jewish and he felt pressured to leave her. The Nazi’s relations with Russia were poor, and Foerster had spent much time in Russia helping to treat Lenin. Foerster feared his younger daughter’s marriage to a Nazi surgeon was forbidden by the Nazis. Finally, his older daughter was being threatened with dismissal from the university. Bailey urged Foerster to leave Germany, but Foerster felt he could not get his family out safely (38). His younger daughter eventually married the surgeon, his older daughter graduated from the university, and Foerster remained with his wife.

Later Foerster traveled to a sanatorium in Switzerland because he was suffering from pulmonary tuberculosis (TB). He returned to Breslaw and died of pulmonary TB at the age of 68 in his home, on June 15, 1941. His wife died of TB 2 days later. They were buried in the same grave.

**CONCLUSION**

During the turn of the century, two men, with different backgrounds but similar interests, became pivotal in shaping what we now know as epilepsy surgery. They differed greatly in their style and their paths to becoming neurosurgeons. Although they were both lovers of culture and the arts, Krase loved music and classic literature, whereas Foerster studied languages. Krase published all his work in German and never traveled to North America or London, where he was not as well known. Krase had no pupils from North America and enjoyed lecturing only to small groups. Foerster spoke many languages, had many students from around the world, enjoyed lecturing to large crowds, and became very well known around the world.

They also differed in their approach to surgery. Krase was trained as a general surgeon before becoming a neurosurgeon. He learned aseptic technique from Volkmann and became best known for his surgical approaches to different
areas in the central nervous system ("Krause operations"). Foerster was not well known for his surgical skill, originally being trained as a neurologist. Although he spent time with Cushing (in 1930, Foerster visited Cushing at the Peter-Bent Brigham Hospital and worked temporarily as "Surgeon in Chief pro tempore"), he did not practice all of Cushing's "rituals" in Germany. Bucy described Foerster performing surgery as a primitive scene in which Foerster operated with poor illumination and no mask or cap (27) (Fig. 7). Penfield described Foerster's surgical technique:

His operative technique at present differs greatly, as might be expected, from that of American neurosurgeons. . . . He is a slow, painstaking operator who uses no bone wax, no silver clips for blood vessels, no suction in the operative field, makes no osteoplastic cranial flaps and closes a scalp in a manner not sanctioned by the school of Cushing. . . . Nevertheless his surgery is good. He shows the greatest respect for tissue in general and the brain in particular. He is radical and even brilliant in the removal of tumors and daring when occasion demands. Wound closure is meticulous and wound healing on the whole good. (34)

Although they differed in their approach to surgery, Foerster and Kraus were both highly successful in reducing the frequency of their patients' seizures (Table 1).

Krause, Foerster, and Penfield were the first to publish maps of the human cerebral cortex, based on intraoperative

<table>
<thead>
<tr>
<th>TABLE 1. EPILEPSY SURGERY RESULTS FROM THE NINETEENTH CENTURY RELATIVE TO MODERN-DAY RESULTS IN EXTRATEMPORAL RESECTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surgeon</td>
</tr>
<tr>
<td>Victor Horsley (12)</td>
</tr>
<tr>
<td>(based on nine cases, published 1887)</td>
</tr>
<tr>
<td>Fedor Krause (16)</td>
</tr>
<tr>
<td>(based on 21 cases, published 1912)</td>
</tr>
<tr>
<td>Olafried Foerster (33)</td>
</tr>
<tr>
<td>(based on six cases, published 1930)</td>
</tr>
<tr>
<td>Modern-day results (42): extratemporal resection (based on 54 cases, published 1994)</td>
</tr>
</tbody>
</table>

*In Foerster and Penfield's article (33), Foerster reported having performed over 100 surgeries for epilepsy; however, he provided details of his results on only six of these patients. It is likely that this was a selected sample with better than usual results.
### TABLE 2. COMPARISON OF MAP SEQUENCES OF HUMAN MOTOR CORTEX
BY KRAUSE, FOERSTER, AND PENFIELD

<table>
<thead>
<tr>
<th>Krause, 1912 (16)</th>
<th>Foerster and Penfield, 1930 (33)</th>
<th>Penfield, 1954 (41)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Big toe</td>
<td>Toes</td>
<td>Toes</td>
</tr>
<tr>
<td>Ankle (extension and inward rotation)</td>
<td>Foot</td>
<td>Ankle</td>
</tr>
<tr>
<td>Last four toes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ankle (dorsiflexion)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knee</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hip</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shoulder</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elbow</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wrist</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Four last fingers (abduction, flexion, extension)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Index finger</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thumb</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Little finger</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(extension, abduction)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper and lower lids</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Angle of mouth</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower lip</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lateral traction of chin</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper lip</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mastication</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tibia</td>
<td>Knee</td>
</tr>
<tr>
<td></td>
<td>Femur</td>
<td>Hip</td>
</tr>
<tr>
<td></td>
<td>Abdomen</td>
<td>Trunk</td>
</tr>
<tr>
<td></td>
<td>Thorax</td>
<td>Shoulder</td>
</tr>
<tr>
<td></td>
<td>Scapula</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Humerus</td>
<td>Elbow</td>
</tr>
<tr>
<td></td>
<td>Forearm</td>
<td>Wrist</td>
</tr>
<tr>
<td></td>
<td>Hand</td>
<td>Hand</td>
</tr>
<tr>
<td></td>
<td>Little finger</td>
<td>Little finger</td>
</tr>
<tr>
<td></td>
<td>Ring finger</td>
<td>Ring finger</td>
</tr>
<tr>
<td></td>
<td>Middle finger</td>
<td>Middle finger</td>
</tr>
<tr>
<td></td>
<td>Index finger</td>
<td>Index finger</td>
</tr>
<tr>
<td></td>
<td>Thumb</td>
<td>Thumb</td>
</tr>
<tr>
<td></td>
<td>Neck</td>
<td>Neck</td>
</tr>
<tr>
<td></td>
<td>Forehead</td>
<td>Brow</td>
</tr>
<tr>
<td></td>
<td>Upper face</td>
<td>Eyelids and eyeballs</td>
</tr>
<tr>
<td></td>
<td>Face</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lower face</td>
<td>Lips</td>
</tr>
<tr>
<td></td>
<td>Tongue</td>
<td>Vocalization</td>
</tr>
<tr>
<td></td>
<td>Mandible</td>
<td>Jaw</td>
</tr>
<tr>
<td></td>
<td>Palate</td>
<td>Tongue</td>
</tr>
<tr>
<td></td>
<td>Larynx</td>
<td>Throat (swallowing)</td>
</tr>
<tr>
<td></td>
<td>Mastication</td>
<td>Salivation</td>
</tr>
<tr>
<td></td>
<td>Swallowing</td>
<td>Mastication</td>
</tr>
</tbody>
</table>


Electrical stimulation. The first map was published by Krause in 1912. Although confined to the motor cortex, Krause’s map had more detail than Foerster and Penfield’s motor cortex map published in 1930, and almost as much as Penfield’s motor cortex map published in 1954 (41) (Table 2 and Fig. 8). Foerster and Penfield’s cortical map, published in 1930, was more advanced than Krause’s because it encompassed more of the cortex, including eloquent areas in the occipital, parietal, and temporal lobes.

Krause and Foerster were similar in many other respects. In addition to publishing their cortical maps, both had many great achievements that helped to shape the progress of epilepsy surgery in the early twentieth century (Table 3 and Fig. 9). In 1912, Krause was the first to report extensively on epilepsy surgery. He was also the first to perform intraoperative electrical stimulation of the cerebral cortex. Foerster was the first to stimulate areas of the cortex outside of the motor cortex. He was also the first to perform
| TABLE 3. LANDMARK ACHIEVEMENTS IN EPILEPSY SURGERY BY KRAUSE AND FOERSTER |
|---------------------------------|---------------------------------|
| Fedor Krause                    | Otfrid Foerster                 |
| 1. First extensive report on the results of epilepsy surgery describing more than nine cases (1912) | 1. First to perform intraoperative electrical simulation of the cerebral cortex in regions other than the motor cortex |
| 2. First to perform intraoperative electrical stimulation of the cerebral cortex to determine sites of motor function and epileptogenic foci as a guide to determine site of cortical resection | 2. First to introduce a cortical map demonstrating areas of the human cortex outside of the motor cortex |
| 3. First to use the results of intraoperative electrical stimulation to develop a cortical map of the human motor cortex | 3. First to perform intraoperative electrocorticography |
| 4. Coined the phrase “psychomotor epilepsy” | 4. Coined the phrase “psychomotor epilepsy” |
| 5. Trained surgeons from North America who would return to North America to further advance the field of epilepsy surgery (such as Penfield, Bailey, and Bucy) | 5. Trained surgeons from North America who would return to North America to further advance the field of epilepsy surgery (such as Penfield, Bailey, and Bucy) |
| 6. Introduction of hyperventilation to induce seizures | 6. Introduction of hyperventilation to induce seizures |

---

**FIGURE 9.** Time line demonstrating the evolution of epilepsy surgery.
electrocorticography, he coined the phrase “psychomotor epilepsy,” and he introduced hyperventilation to induce seizures. Foerster also played a crucial role in the training of many North American neurosurgeons who continued to advance the field of epilepsy surgery, including Penfield, Bailey, and Bucy. Possibly Krause’s and Foerster’s greatest similarity was their dedication to and interest in the study of the nervous system.

REFERENCES


CONTRIBUTIONS OF JEAN TALAIRACH AND JEAN BANCAUD TO EPILEPSY SURGERY

PATRICK CHAUVEL

DEVELOPMENT OF A NEW METHOD

Stereoelectroencephalography (SEEG), a term coined in 1962, was developed by Jean Talairach, founder of modern stereotactic surgery, and Jean Bancaud, a neurologist and electroencephalographer. In SEEG, electrical activity is recorded by intracerebral electrodes, implanted stereotactically in preidentified cortical and subcortical structures (1). At the time the technique was developed, surface electroencephalography (EEG), or corticography, was only used in the interictal period, and was limited by its poor spatial resolution, due not only to the technical limitations of the equipment but also to biological factors, including the shielding effect of the scalp, skull, and meninges and overlapping potentials with variable orientation arising from the complex topography of the gyri in the human cerebral cortex. Corticography was an interictal investigation that did not provide information on the spatiotemporal dynamic of the seizure. Furthermore, corticography had to be carried out in conjunction with craniotomy, which meant that the decision of whether and how to operate had to be made in one step in the operating room. For the first time, SEEG offered a method that allowed the investigative presurgical and therapeutic surgical phases to be dissociated. Presurgical planning could now be undertaken, using data from ictal and interictal EEG recordings, and the results of electrical stimulation carried out through the implanted electrodes (2,3).

The impetus for Bancaud and Talairach to study epilepsy can be traced to H. Hécaen’s visit to the Montreal Neurological Institute (MNI), where he analyzed postsurgical patients with Wilder Penfield. After a year of study in 1952, Hécaen returned to Paris full of enthusiasm for surgical treatment for the relief of seizures. He convinced G. Mazars, a neurosurgeon at Hôpital Sainte-Anne in Paris, that he should start an epilepsy surgery program based on the MNI method. At the time, Jean Talairach worked in the Department of Neurosurgery at Hôpital Sainte-Anne, under his mentor, Professor Marcel David. Since 1946 he had been developing stereotactic approaches to functional neurosurgery for chronic pain and movement disorders. Jean Bancaud was a student of Professor H. Fischgold, and had presented his MD thesis on the relationship between neuropsychological deficits and EEG alterations in patients with cerebral tumors (4). Fischgold’s group joined David’s in Sainte-Anne. Thus Bancaud and Talairach were in a superb scientific environment, working with P. and M. B. Dell in neuropsychology and Hécaen and J. de Ajurriaguerra in neuropsychology. Hécaen was clearly a direct influence on Bancaud, who absorbed the lessons of Penfield on localization, and understood at a very early stage the complementary information provided by clinical signs and symptoms, whether due to lesions or occurring during seizures. This insight led him to look for methods more advanced than electrocorticography.

Meanwhile, Talairach was coming to a decisive turning point in his own methodological process. He regarded stereotactic methods as optimal for analysis of human brain anatomy in three-dimensional space, rather than as merely an instrument for reaching a given target in the brain. Talairach built up a coordinate system based on the anterior commissure (AC)-posterior commissure (PC) axis and studied human neuroanatomy in reference to this axis. This method also allowed the “normalization” of anatomical data from different brains such that data from the functional investigations of different patients could be displayed on the same summarizing chart. This enormous body of work led to the publication of two anatomical atlases (5,6). Bancaud became more and more attracted to Talairach’s method, which promised to localize the sources of scalp EEG discharges. However, at that time, its application was oriented toward pain, dyskinesias, parkinsonian tremor, and some otherwise unoperable tumors. Working with M. B. Dell, Bancaud became progressively more convinced of the fundamental
usefulness of epilepsy surgery, but considered that methods of investigation current at the time were poorly adapted to epileptic phenomena.

After Talairach's completion of the 1957 anatomical atlas (5), Marcel David took Talairach's view and supported a project to create an operating room dedicated to stereotactic surgery. This suite needed to be large in order to satisfy the physical requirements of tele-radiography, and allow parallel x-ray beams in order to avoid distortions of skull, vessels, ventricles, and, crucially, the frame and grids used for guiding the placement of intracranial electrodes. Thus the concept of a stereotactic surgery room was born, and such a suite was opened in Sainte-Anne in 1959. Bancaud saw the potential of a spatial conceptualization of the human brain promoted by Talairach’s method and began working with him to develop applications of stereotactic functional exploration to presurgical investigations of intractable epilepsies (Fig. 1). In the minds of Talairach and Bancaud, Penfield's localization approach could only be truly applied through EEG recording of seizures directly from the involved brain structures. This goal was accomplished in 1959 using Talairach's stereotactic method accurately to place numerous intracerebral electrodes with respect to reliable anatomical markers, and then recording the electrical activity of involved cerebral structures during the course of a seizure (7,8).

During the course of this work, Bancaud developed a careful analysis of anatomical-physiological-clinical correlations that could directly determine surgical strategy by utilizing EEG recordings of seizures accurately located in cerebral space. With these data, Bancaud studied the spatiotemporal dynamics of seizure discharges with respect to their clinical features (Fig. 2). In particular, he described the respective contributions of medial and lateral structures in the organization of temporal and frontal seizures; the role of the amygdala and hippocampus versus the temporal neocortex (2,9,10); and the supplementary motor area and area 24 of the anterior cingulate gyrus versus the dorsolateral, ventrolateral, and ventromedial frontal cortices (2,11–16). These studies had immediate repercussions on the practice of epilepsy surgery.

A NEW METHOD CREATES NEW DEFINITIONS

Intracerebral ictal recordings meant that the cortical areas to be resected by the surgeon required new definitions. The region where seizures originate, or "epileptogenic zone" (which turned out to be impossible to define as a "focus") was in the forefront of presurgical planning. The epileptogenic zone was differentiated from the space occupied by interictal activity, or the "irritative zone," and from the space occupied by any eventual morphological alteration or lesion supposed to cause an epilepsy, or the "lesional zone." Talairach and Bancaud demonstrated that the lesional and irritative zones had a variable topographic relationship with the epileptogenic zone (14,17).

Talairach developed a new type of epilepsy surgery, based on a three-dimensional representation of the epileptogenic, irritative, and lesional zones. With this new method, the surgical plan could be carefully prepared and adapted to the individual patient’s case by referring radiological, physiological, and clinical data by physical matching to the same patient (18,19).

Lesional Zone

The concept of epileptogenic and lesional zones was a working hypothesis and, as such, was submitted to continual evaluation and validation. Today, with the use of modern neuro-

![FIGURE 1. Jean Bancaud (left) and Jean Talairach (right) photographed while discussing in the stereotactic surgical suite in Sainte-Anne (early 1970s).](image)
imaging, the lesional zone in partial epilepsies is well defined. However, when Talairach was first studying this concept, he discovered numerous pseudotumoral, nonexpansive lesions that had not been shown by the neuroradiological techniques available at the time. He therefore encouraged Bancaud to find electrical criteria for detecting lesions. In SEEG terminology, the term lesional zone referred to the area occupied by various types of slow-wave activity (waveform, frequency, and reactivity) (20). The correlations were clearly superior to those given by the neuroradiological images available, and Talairach and Bancaud, using the SEEG method, were able to map better the extent and anatomical location of astrocytomas or oligodendrocytomas. This allowed them to preplan operations and avoid functional deficits as well as target stereotactic interstitial radiotherapy. The topographic transitions between electrical silence inside glial tumors, slow waves, spiking, subclinical paroxysms, and seizure activity were studied. In this context, their use of the term lesional zone presumed macroscopic alteration of neural tissue; this has since been demonstrated with magnetic resonance imaging (MRI).

**Epileptogenic Zone**

Definitions were less sharp for the cortical areas involved in producing interictal spikes and ictal discharges. When Bancaud began to record seizures using intracerebral electrodes, he noticed that the respective topography of the two types of discharge were not fully overlapping (17,21). He therefore used the terms irritative zone and epileptogenic zone to describe and differentiate the spatial extent of interictal spiking and ictal discharges, respectively. The term epileptogenic zone thus referred to the anatomical structure(s) where seizures frequently originated. Electrophysiological definitions of seizure onset were proposed: Such definitions could vary slightly from one structure to another (e.g., temporal limbic to neocortical), but all emphasized the existence of fast synchronizing discharges that might involve a single region, or distinct but interconnected regions.

The concept of the epileptogenic zone was developed in the context of epilepsy surgery, and Bancaud and Talairach decided to use this concept, rather than the location of interictal discharges, as the basis of their surgical strategy. This was because the conclusions of the presurgical investigation had to be translated into anatomical terms, regardless of the functional criteria used to define an epileptogenic brain area. Since the seizure was the symptom to be cured, it was the area of seizure onset that had to be determined. However, the correlation between the area of seizure onset and the emergence of clinical semiology was often difficult to determine in practice, because ictal signs and symptoms accumulated in order as the paroxysmal discharge propagated into different cerebral structures. Understanding the spatiotemporal dynamics revealed by the sequence of symptoms as they appeared allowed Bancaud to make an extrapolation of the anatomical origin of the seizure. With this extrapolation, the characterization of the initial symptom(s) appeared to be no more important than any other part of the sequence. Bancaud regarded the concept of order and sequence of semiological elements as crucial, and found analogies with the syntactic organization of words in a meaningful sentence. This led to the definition of seizure patterns, which was addressed in the majority of Bancaud's publications.
Bancaud and Talairach regarded the static view of seizure genesis represented by the gross topography of interictal and/or ictal abnormalities as insufficient for determining the area and volume of brain tissue to be resected. They believed that a dynamic model of the discharge should be inferred from detailed consideration of all the data giving good discrimination between pacemakers versus active and passive relays of propagation. For them, this became the prerequisite for surgical therapy aimed at resecting the smallest possible volume, and at providing detailed outcomes information for further refinement of surgical criteria.

THE NEW METHOD BECOMES ESTABLISHED

With time, the novel technique of Bancaud and Talairach evolved into a comprehensive and established method, and physiological advances were linked to increased knowledge of anatomy. Welding double guiding grids onto the stereotactic frame provided for safe implantation of intracerebral electrodes recording from lateral and medial areas of the cerebral cortex. Safety was further guaranteed by routine stereotactic angiography, allowing electrode placement that avoided vulnerable blood vessels. [That implantation carried out with stereotactic angiography is associated with a very low risk has been demonstrated (21a).] A stereotactic atlas of the telencephalon (6), containing frontal, axial, and sagittal brain slices referenced to the AC-PC axis, was used as a guide to the topography of cortical areas, and this axis had been demonstrated through the statistical analysis of the spatial distribution of cortical sulci. The accuracy of this approach was satisfactory for designing electrode implantations or for comparing patients but was insufficient for detailed interpretation of neurophysiological data. In fact, if an implantation was designed and carried out straight from the atlas, sufficiently accurate determination of the precise position of the electrode contacts after the event still required a reconstruction of the implantation relative to the individual patient’s anatomy. Fortunately Gabor Szikla (see below) had taken advantage of the need for routine stereotactic angiography and had carefully described cerebral cortical blood vessels and the close relationships of cortical arteries and veins to the convolutions of gyri and sulci (22). He showed that cortical vessels mold themselves to the form of the gyri, and was able to extract gyral form and dimensions from a meticulous analysis of vascular trajectories. This discovery led to the concept that “vascular lamina” could provide constant landmarks for interpretation of anatomical variability among individuals (23), and was a valuable tool for deducing the actual location of electrode contacts before the availability of modern imaging methods (24).

The anatomical method of Talairach has survived the development of magnetic resonance-derived stereotactic techniques and continues to be considered as reliable (25). The initial electrode placement can be determined easily using stereotactic MRI (26), which allows the matching of all the anatomical (ventriculography, angiography, computerized tomography, MRI) and physiological [EEG, magnetoencephalography, SEEG, single-photon emission computerized tomography (SPECT), positron emission tomography] data in the same three-dimensional referential system for a given patient.

SEEG offered high spatial and temporal resolution and a high power of localization. This was shown in the early 1960s, when the role of the amygdala and hippocampus in temporal lobe seizures was discovered (2,9). The largest potential pitfall was implantation at preselected targets thought to be the source of paroxysmal activity on the basis of empirical arguments. The practice of SEEG helped avoid this pitfall by displaying the spatiotemporal dynamics of seizures in relation to the anatomy. This was contingent on using multiple multilead electrodes to give a distribution of spatial sampling sufficient to capture as much of the paroxysmal activity associated with the seizure as possible. A view of ictal intracerebral activity that was too compartmentalized or restricted would have been insufficient to understand and explain correlations with clinical semiology.

The essential question of reliable spatial sampling was whether recording from too restricted a brain area would prevent SEEG from providing an accurate view of the electrical organization of the entire epileptogenic area. An ideal distribution of sites for intracerebral measurements provides the neurophysiologist with an immediate view of the dynamics of ictal and interictal events. Physiological interpolation between the recording sites would thus depend on a correct strategy of implantation, which requires that the implantation be managed within a coherent method based on the individual patient’s symptoms. In this context, a strategy of electrode implantation demands a firm hypothesis regarding the distribution of the epileptogenic and lesional zones derived from a detailed analysis of the electrophysiological features of the interictal state, the surface electrical-clinical correlations of the ictal state, and their relation to anatomical abnormalities. SEEG was thus used to validate or invalidate a principal hypothesis, and at the same time to support or eliminate an alternative hypothesis.

This “anatomo-electro-clinical” method produces types of data sets that may interact and validate one another. For example, the coincidence of clinical and electrical onset, or the appearance of clinical onset after electrical onset, both tend to confirm accurate positioning of the recording electrode. A further example is provided by intracerebral stimulation through stereotactically implanted electrodes, a technique proven reliable for showing the relationships between the irritable zone(s) and the structure of ictal semiology. Electrical stimulation can confirm topography of the ictal onset by provoking a habitual seizure, and gives useful insight into the organization of the epileptogenic zone, by separating relay and subrelay areas essential for building up individual ictal symptoms and signs, as well as their modes of clustering. Such data are helpful to the surgeon in planning a strategy of removal and/or disconnection.
The ultimate objective of SEEG is to provide the surgeon with a unifying view of the epileptogenic process, based on the definition of the epileptogenic zone and its overlap with the lesional zone. Matching of clinical, physiological, and anatomical data is essential, and stereotactic recording during preoperative planning is used to achieve this. During surgery, anatomical and physiological data that describe the epilepsy and the function of related cortical areas are referenced to three-dimensional coordinates, which allows the surgeon to perform a wholly preplanned cortectomy within predetermined functional and vascular constraints (18).

**ACCEPTANCE OF A NEW METHOD CREATES A NEW ERA**

The development of SEEG ushered in a new era that coincided with a complete structural reorganization of the Sainte-Anne Department of Neurosurgery. Alain Bonis, a neurologist and student of Raymond Garcin, joined the team, completed by Gabor Szikla, an emigrant from Hungary in 1956, who was to devote his career to anatomy and stereotactic surgery under Jean Talairach. In 1960, David and Fischgold moved away to La Pitié-Salpêtrière, and Talairach became the head of a new Department of Functional Neurosurgery at Sainte-Anne.

This was a period of intense scientific productivity, during which Talairach and Bancaud co-published more than 60 original articles. The role of temporal limbic structures, the amygdala, and the hippocampus in clinical symptomatology and electroclinical organization of temporal lobe seizures was demonstrated. Clinical manifestations that had been attributed to discharge of centrencephalic nuclei and considered as signs of generalized epilepsies by Penfield, Gastaut, and others were elicited by stimulation of frontal anterior and intermediate areas, especially from their medial aspect (exactly mimicking the spontaneous attacks) (27-30). The anatomical-functional organization of the supplementary motor area was described (2,11-13,21,31), as well as its status as part of the premotor systems and its distinction from language areas. The novel concept of the “epileptogenic zone” emerged from all these works, while a modern and dynamic view of the focal epilepsies emerged from the observations and discussions reported in a key volume of 1965: *La Stérélectroencephalographie dans l’Épilepsie*. This book marked a break with the past, and, beyond the specific questions it raised in the field of epilepsy surgery, it provided an authoritative justification of the critical necessity for studying seizures when studying epilepsy (2).

SEEG offered the opportunity of analyzing the dynamics of epileptic phenomena in humans, but also represented a remarkable tool for the study of normal neurophysiology. Pierre Buser, a neurophysiologist interested in the cerebral cortex, undertook such studies in cooperation with Bancaud after 1964. He worked on motor systems, particularly the pyramidal system and sensory polymodal afferents to the frontal cortex. One of the models he used was the startle reaction in the anesthetized cat. This led to a better understanding of startle physiology, and the startle epilepsies in hemiplegic children being investigated by Bancaud. Buser influenced Bancaud’s work on various aspects of epilepsies with motor manifestations (32-35). Besides the startle epilepsies, they worked on the connections of the supplementary motor area (33,36), and together demonstrated the cortical origin of myoclonus and seizures in the Kojenikhov syndrome (37-41), as well as the cortical origin of postanoxic action myoclonus [Lance and Adams syndrome (42)]. Buser used SEEG not only for functional mapping, but also to study corticocortical connections and their facilitation inside the epileptogenic zone (43,44). These anatomical and physiological advances eventually convinced Talairach that he should add a significant section on SEEG and neurophysiology to his new stereotactic anatomical atlas of the telencephalon (33).

The Institut National de la Santé et de la Recherche Médicale (INSERM) research unit titled “Stereotaxic Functional Exploration and Surgical Treatment of the Epilepsies” and headed by Talairach was created in 1970. Following this, Bancaud approached some basic problems in the electrophysiological investigation of the human epilepsy and set new trends in the characterization of frontal lobe seizures.

Bancaud now returned to the questions of scalp EEG interpretation raised in his MD thesis and resolved many of them on the basis of data from SEEG. The 1973 book *EEG et SEEG dans les Tumeurs Cérébrales et l’Épilepsie* (20) was specially dedicated to electroencephalographers, and collected rare and important data on simultaneous recordings of EEG and SEEG during numerous investigations of cerebral tumors and epilepsies. Fifteen years later, it remains a valuable and useful guide to understanding what we record and what we miss in surface recordings of seizures.

Between 1970 and 1973, with the help of Stéphane Geier, the recording period of EEG lengthened, and “acute” SEEG became “chronic.” Technically speaking, intracerebral electrodes were significantly reduced in size and adapted to the new mode of recording. At the same time, the techniques of EEG recording were evolving: telemetry was used, as well as videorecording, with EEG and video signals being retrospectively matched. These new types of recording, out of the operating room, rendered the patient free-moving, and so allowed a much better study of gestural automatic manifestations that characterize certain complex partial seizures. Particular gestural manifestations correlated with anterior frontal lobe paroxysmal discharges were identified (45,46). Their phenomenology, duration, and mode of association differentiated them from gestural automatisms of temporal lobe origin (47). Some observations made at this time suggested an epileptogenic zone distributed between frontal and temporal lobe areas, leading to the concept of frontotemporal epilepsy, and to a concomitant change in surgical strategy (48). In the
search for mechanisms of "automatisms," Bancrault and his co-workers reported the behavioral effects of anterior cingulate gyrus stimulation, which essentially consisted of complex hand-mouth coordinated movements with mood alteration toward disinhibition (15, 16).

CONCLUSION

The continuing collaborative work of Jean Talairach and Jean Bancrault culminated in the general report presented in 1974 to the French-speaking Société de Neurochirurgie, entitled "Approche Nouvelle de la Chirurgie de l'Epilepsie." This presentation specified the successive and multidisciplinary steps of the method, and made clear the importance of making the surgical operation fit the seizure symptoms (18).

So remarkably extensive was the range of research and curiosity of Talairach and Bancrault that it is difficult for this author, her student, to summarize the importance of their scientific legacy. Surely one of their most important contributions is the emphasis they have placed on the value of clinical semiology and its integration through the "anatomoelectroclinical correlations" of patient's seizures. The body of work that has been produced from these principles has transformed what was at the beginning a technique of stereotactic functional exploration into a general method of studying patient with partial seizures. In a sense, they have fashioned a tool that has turned out to be fundamental, as proven by the fact that it has survived the development of imaging and other noninvasive techniques. Indeed, not only has it survived, but it has guided modern techniques, particularly MRI interpretation, by providing a referential system perfectly suited to the task (25, 49, 50).

To claim that the practice of such an invasive method of investigation is the most reliable way to guide and design new noninvasive techniques is not at all paradoxical. A progressive evolution toward noninvasive methods should indeed be organized in successive steps, guided by constant comparison of surface EEG and functional imaging techniques derived from MRI or from nuclear medicine, with the electrical activity simultaneously recorded at depth. This process has been largely achieved for temporal lobe epilepsies, which are less and less often investigated with depth electrodes in centers using SEEG, because of the reliability of electroclinical correlations in temporal lobe seizures (47, 51) and of recently proven correlations with other measurements of ictal dysfunction, such as the ictal modifications in cerebral perfusion demonstrated by SPECT imaging. From the beginning, SEEG has not been limited to the temporal lobe epilepsies, but has been used to investigate partial epilepsies regardless of their presupposed origin in the brain. Significant advances have been achieved with this method in the study of the frontal lobe epilepsies (52). In time, these advances may allow development of reliable noninvasive strategies for all the partial epilepsies. This is surely an outcome of which Talairach and Bancrault could be proud.

REFERENCES

29. Bancaud J. Mechanisms of cortical discharges in “generalized” epi-
lepsies in man. In: Petsche H, Brazier M, eds. Synchronization of EGG activities in epi-
31. Chauvel P, Rey M, Buser P, et al. What stimulation of the sup-
32. Bancaud J, Talairach J, Bonis A. Physiopathogénie des épilepsies-
33. Buser P, Bancaud J. Bases techniques et méthodologiques de l’ex-
34. Buser P, Talairach J, Bancaud J. Potentiels évoqués, réponses paroxystiques aux stimulations périphériques et zones épile-
43. Buser P, Bancaud J. Unilateral connections between amygdala and hippocampus in man: a study of epileptic patients with depth elec-
49. Talairach J, Tournoux P. Referentially oriented cerebral MRI anat-
50. Talairach J, Tournoux P, Musolino A, et al. Stereoelectro explo-
CONTRIBUTIONS
OF HUGO KRAYENBÜHL
AND M. GAZI YAŞARGIL
TO EPILEPSY SURGERY

JAVIER FANDINO
HEINZ-GERGOR WIESER

THE FORERUNNERS

William Osler and William Halsted, at the Johns Hopkins Hospital persuaded Harvey Cushing to spend a professional \textit{Wanderjahr} (year of wandering) in Europe from July 1900 through August 1901 (1). Osler himself was in England at the beginning of Cushing’s trip, thus assuring that Cushing received many professional and social invitations that otherwise would not have been proffered to a young and unknown American. Cushing met Victor Horsley in London, Charles S. Sherrington in Liverpool, Theodor Kocher in Berne, and Angelo Mosso in Turin. During Cushing’s stay in Berne, Switzerland, from November 1900 to March 1901, Kocher stimulated him to perform a research project in the laboratory of the physiology department under the guidance of Professor Hugo Kronecker. He did research on brain stem control of systemic blood pressure during raised intracranial pressure (“Cushing response”) (2,3). Cushing arrived in Berne 1 year after Hayao Ito (1864–1929), the pioneer of epilepsy surgery in Japan and a pupil of Kocher, had returned to Kyoto. Ito’s famous work on epilepsy, “Experimentelle Beiträge zur Aetiology und Therapie der Epilepsie (Experimental Contributions to Etiology and Therapy of Epilepsy),” was published in 1899 (4). Emil Theodor Kocher (1841–1917), the only surgeon ever awarded the Nobel Prize, considered the necessity of a “chirurgische Neurologie” as a specialty. His pioneering work on pituitary surgery, brain injury, and epilepsy surgery was recognized worldwide. In relation to epilepsy surgery, he stated in 1893 that all traumatic epilepsies have to be submitted to surgery (5).

HUGO KRAYENBÜHL’S LEGACY

The history and development of modern neurosurgery in Switzerland has been linked since the early beginning to the study and surgical management of epilepsy. The idea of a ward for neurosurgical patients in Zurich, Switzerland, became a reality when the old deaconess hospital located in the Heliosstrasse, called “Krankenstation Hegibach” (Fig. 1), was given from the government to the surgery department of the “Kantonsspital Zurich.” In 1937, in the uppermost floor of the building and under the far-sighted guidance of Krayenbühl, a ward especially dedicated to neurosurgical cases was opened. In 1939 Krayenbühl officially assumed the direction of the Division of Neurosurgery, still a part of the surgery department.

Krayenbühl (Fig. 2A) was born on December 3, 1902, in Zihlschlacht, a small village located in Thurgau in Switzerland. He was the son of a well-known Swiss psychiatrist who was chief of the psychiatric hospital in Zihlschlacht. At home, during his childhood and adolescence, Krayenbühl was deeply influenced by discussions about the causes and treatment modalities of mental and neurological diseases. He started his medical training in Geneva in 1921, and continued his studies in Kiel (Germany) with the later-renowned psychiatrist Manfred Bleuler. Krayenbühl returned home and graduated from the medical faculty of the University of Zurich in 1927. He began his 9-year postgraduate training in pathology, internal medicine, psychiatry, and general surgery in Zurich, and continued in neurology with Professor K. Bonhoeffer in Berlin, and in neurosurgery (1934–1935) in London with Sir Hugh Cairns. After his return to Zurich in 1936, he worked during the year 1937 as a “Voluntäraassistent” at the surgery department in Zurich under Paul Clairmont.

Krayenbühl’s hard work during the following 2 years succeeded in convincing the faculty to establish a neurosurgical ward. Later, during the winter semester of 1944–1945, an
independent Department of Neurosurgery was officially inaugurated. With this historical milestone, Krayenbühl became the first chief of a department of neurosurgery in Switzerland. Krayenbühl was promoted to professor titulares on April 30, 1945, to professor extraordinarius ad personam on September 23, 1948, and to professor ordinarius on April 16, 1963.

Krayenbühl's interest in epilepsy surgery was already apparent in his early career as a neurological surgeon. On May 13, 1941, he received the *Venia legendi* from the University of Zurich, based on ten original publications and the monograph "Das Hirnaneurysma," an 84-page long manuscript published in the *Swiss Archives of Neurology and Psychiatry.*

**FIGURE 1.** The neurosurgical ward at Hegibach started with a few beds during the year 1937. In 1939, it was recognized as a division of the Department of General Surgery under Professor Paul Clairmont (1875–1945). Later on, in 1945, an independent Department of Neurosurgery was created under the direction of Professor Hugo Krayenbühl. In 1948, the first installation of an EEG unit took place in Hegibach as a division of the neurosurgery department. During 1952, the Department of Neurosurgery moved to the new building of the Cantonal Hospital of Zurich (University Hospital) at the Ramistrasse, where a new inpatient ward of the neurological clinic was opened. (Illustration courtesy of P. Roth.)

**FIGURE 2.** A: Professor Hugo Krayenbühl (1902–1985), founder and chairman of the first neurosurgery department in Switzerland. B: Professor M. Gazi Yaşargil, Krayenbühl's pupil since 1953 and chief of the Department of Neurosurgery at the University Hospital of Zurich from 1973 to 1993.
Chapter 4 / Contributions of Hugo Krähenbühl and M. Gazi Yagıargil to Epilepsy Surgery

45

For his "Probevortrag," an introductory lecture given to the members of the faculty, Krähenbühl chose the topic "Epilepsie und ihre Chirurgische Behandlung (Epilepsy and Its Surgical Treatment)." This reflected his interest in epilepsy and revealed the multidisciplinary nature of the disease. No other disease or condition of human suffering could bring together so tightly different medical specialties as epilepsy. Influenced by his predecessors Victor Horsley (1857–1916) and Harvey Cushing (1869–1939) as well as Wilder Penfield (1891–1976), Krähenbühl succeeded in specifying a common path for neurologists, neurophysiologists, neuropsychologists, and neurosurgeons dedicated to the study and treatment of epileptic seizure disorders.

Krahenbuhl, because of his extensive and profound knowledge in neurology and his clinical skills, was considered by his colleagues as a "neurological surgeon." Until 1952, all outpatients of the neurological clinic who required hospitalization for checkup or diagnostic reasons were admitted to the neurosurgery department. There were two reasons for this historical situation. First, the new diagnostic techniques such as electroencephalography (EEG), pneumoencephalography (PEG), myelography, and angiography were locally introduced with great impetus by Krähenbühl. Second, there was no inpatient ward in the neurology department. Only 8 years after the establishment of the neurosurgery department, the neurology department opened a ward for patients who required hospitalization for diagnostic purposes.

During the first 18 years, a total of 2,336 patients with epilepsy were assessed and treated in the neurosurgery department under Krahenbuhl. A brain tumor was causing the seizures in 343 patients (15%). A total of 608 patients suffered from a so-called Spät epilepsi (i.e., idiopathic epilepsy of the elderly) (6). These patients were described in several publications (7,8). Thereby, neurologists and neurophysiologists founded a bank of knowledge at the neurosurgical department. Based on experimental studies on "extrapyramidal epilepsy" and its pathophysiology, Krähenbuhl defined its clinical features (7). With the introduction of an EEG unit in 1948 and the facilities in the new building of the Kantonsspital (1952), surgery for epilepsy became routine in the daily activities of the department. The discovery and neurophysiological evaluation of many patients with "psychomotor epilepsy" (according to Ira van Gieson) (9) raised the interest in temporal lobe epilepsy and its surgical management (8). Krähenbühl had been performing anterior temporal lobectomies with a standard technique since 1939, and started to use intraoperative electrocorticography (ECoG) in 1949. His surgical decisions were always based on the convergence of clinical features and EEG findings. His meticulous technique did not differ much from that practiced since 1934 by Wilder Penfield at the Montreal Neurological Institute (MNI) (10,11). The posterior line of resection of a non-dominant anterior temporal lobectomy was the vein of Labbé, the temporal horn was punctured at the beginning of the operation via a small corticotomy in the middle temporal gyrus, and the uncinate gyrus was sucked away very carefully to remove the mesial structures of the temporal lobe (Fig. 3).

In October 1951, Krähenbühl revealed his passionate interest in psychomotor epilepsy in a lecture he gave to the medical faculty of the University of Zurich. He presented his surgical series of patients with lesional and nonlesional epilepsy and increased his pupils’ interest in temporal lobe seizures.

Getrouffene Patienten haben wir heute eine elektroneurologische Untersuchung mit großer Sensibilität durchgeführt, welche die Diagnose der "psychomotorischen Epilepsie" sicherte. Die Patienten wurden nach den Kriterien der "psychomotorischen Epilepsie" behandelt, und die Ergebnisse zeigten, dass die Operation eine zufriedenstellende Besserung der Symptome brachte. Die Patienten wurden dann in einem speziellen Zentrum für Epilepsiebehandlung unter Aufsicht der neurochirurgischen Abteilung behandelt.
epilepsy. Krayenbühl developed his own concept of epilepsy surgery, and he expressed his estimation of the work of his colleagues in London (12), Paris (13,14), and Montreal (10, 11). Nevertheless, some differences were evident related to the surgical concept. The integrity of the brain and its surrounding structures had to be preserved and carefully handled as a unit. Krayenbühl was skeptical and showed distrust toward new invasive diagnostic methods until he proved them and was convinced of their safety. During the time that Penfield and his co-workers performed innumerable cortical stimulations (11), Krayenbühl’s absolute priority was to limit the exposure of the brain surface during surgery.

After 22 years as chairman of the Department of Neurosurgery, Krayenbühl retired in 1973, dedicating his last years to finishing ongoing projects and meditating about his life as a neurosurgeon, teacher, and philosopher. Professor Hugo Krayenbühl died on January 1, 1985, at 83 years of age.

The Brain Anatomy Institute, later called the Brain Research Institute, of the University of Zurich is also indebted to Krayenbühl (Fig. 4). After the retirement of Minkowski as chief of the neurological clinic and director of the institute in 1945, the prestigious Brain Anatomy Institute was almost shut down. Throughout the decade, with continuous negotiations with the University of Zurich and the medical faculty, Krayenbühl was successful in his efforts to keep it open, and an additional academic position was created for the guidance of the institute. Konrad Akert was appointed chairman in 1960, and the traditional research at the institute was complemented with research in the pathogenesis of epilepsy (15).

In association with distinguished neurosurgeons of Europe and the United States, Krayenbühl engineered and founded the publication *Advances and Technical Standards in Neurosurgery*, its first issue appearing in 1972.

Krayenbühl was a gentle individual who stimulated his pupils and transmitted his philosophy to them. He left an indelible trace in all of them. His strictness and harshness, as well as his constant demonstration of authority, sometimes led to outbursts of rage. According to Krayenbühl, “One has to say to the people what they did wrong, what they did right is self-evident.” Many of his pupils and colleagues discovered a paternalism coming from their teacher. Striving for excellence in his daily work was Krayenbühl’s main occupation. His authoritative behavior was used only to serve. In 1995, at the commemoration of Krayenbühl’s death, Yaşargil expressed, “I still continue to learn from my teacher in my daily activities and decisions, and I am often involved in discussions with him, even in my dreams.”

**The EEG Unit at the Neurosurgery Department**

Krayenbühl, considering the new development of advanced neurosurgery, installed an EEG unit at Hegibach in 1948. Very soon he recognized the strong relationship between epilepsy and neurosurgery (6,7). Intraoperative EEG recording from the brain (EECoG) was already considered an important tool for definition of the “epileptic focus” as a result of the pioneering work of Penfield and Jasper in Montreal (11). At that time in Zurich, about one-third of the patients admitted to the neurosurgery department presented with seizures. In 15% of the cases a tumor could be diagnosed as the cause of epilepsy.

The historical context at that time was optimal for the development of electrophysiology in Zurich. One decade of surgical experience in neurological surgery, the cumulative number of patients with epilepsy, an independent neuro-

---

*FIGURE 4. Hugo Krayenbühl during the celebration of his 80th birthday in Zurich, accompanied by his pupil M. Gazi Yaşargil (left) and Konrad Akert, Director of the Brain Anatomy Institute (later the Brain Research Institute) of the University of Zurich (right). (Photo courtesy of P. Roth.)*
surgery department, as well as the support of many brilliant colleagues, such as neurophysiologist and 1949 Nobel Prize winner Walter Rudolf Hess, allowed Krayenbühl to initiate a very fruitful era of EEG in Switzerland. Krayenbühl assigned this task to Rudolf M. Hess, who was trained in 1947 and 1948 by Dr. W. A. Cobb at Queen’s Square National Hospital in London and Dr. Grey Walter in Bristol, and in 1957 by Dr. Herbert Jasper in Montreal. Rudolf M. Hess was responsible for the development of electrophysiology in Zurich and remained loyal to the neurosurgical interests there. He recorded the first scalp EEG (in a 31-year-old patient, K. G., born in 1917) on October 8, 1948, and the first intraoperative ECoG on May 18, 1949. Krayenbühl performed this operation, while Rudolf Hess was fortunate to record a spontaneous ictal event (Fig. 5).

Hess himself pushed the only existing eight-channel EEG apparatus of that time from the ward to the operating room until the department moved to a modern building at the Rämistrasse in 1952. The operating room at this hospital, later called University Hospital, was designed and built.

**FIGURE 5.** First well-documented ECoG performed in Zurich. Professor H. Krayenbühl was operating for seizures, with Professor Rudolf Hess recording electrocorticographic activity with a spontaneous seizure, on May 18, 1949 (patient Elisabeth, born in 1932). (Photo and drawing courtesy of H. P. Weber.)
according to modern standards and well equipped for intraoperative EEG recording and electrical stimulation. Epilepsy surgery became a routine procedure. More than 500 lesional, nonlesional, temporal, and extratemporal resections were performed throughout two decades.

The method of stereoelectroencephalography (SEEG), as pioneered in Paris by Bancaud and Talairach in 1965 (13), was introduced in Zurich with the cooperation of Christoph Bernoulli, an epileptologist, and Jean Siegfried, a functional neurosurgeon. Bernoulli had been trained with the Saint-Anne's team in Paris, and Siegfried at the same time in Montreal. The first, at this time "acute," SEEG exploration was done on February 20, 1970 (patient M.S., born in 1959) with the help of Gabor Szikla (from the Saint-Anne's team) who did the so-called repere (i.e., the neuroradiological examination under stereotactic conditions, consisting of PEG, angiography, and ventriculography), and performed with the patient's head fixed in the Talairach frame. Seven years later, in 1977, Bernoulli et al. reported a person-to-person transmission of Creutzfeldt-Jakob disease after SEEG exploration (16).

The popularity of this technique hid under the shadow of this fatal experience, and less invasive and less risky presurgical evaluation methods were looked for, developed, and favored whenever possible. Nevertheless, SEEG had allowed for a deepened understanding of the phenomenology and electroclinical features of partial epilepsy syndromes and in particular temporal-limbic seizures (17). These SEEG studies inspired the development of new surgical techniques for the treatment of the so-called mesial temporal lobe epilepsy syndrome. The good results obtained in Zurich with the microsurgically performed selective temporal lobe resections simulated and inspired the later development and introduction in Zurich of the foramen ovale (FO) electrode, a seminvasive method for preoperative assessment of limbic epilepsy, in 1983 (18). Between 1984 and 1998, FO electrodes were used in Zurich in 214 patients. Most of them were studied with radiotelemetry, which was introduced in 1986. The FO electrode technique became popular worldwide.

Cerebral Angiography and the Study of Cerebrovascular Anatomy

Krabenbühl learned the angiographic technique from Cairns in Oxford (Cairns, who had worked at the London Hospital, returned to Oxford in 1937) and introduced it in Zurich in 1939. In 1941, he reported the first angiogram of a saccular aneurysm of the basilar artery, and, in 1952, he published his experiences in the monograph Cerebral Angiography together with Dr. H. Richter (19).

On January 4, 1953, M. Gazi Yaşargil began his training in neurosurgery with Hugo Krabenbühl and Gerhard Weber. Krabenbühl assigned Yaşargil to develop the technique of percutaneous cerebral angiography. From then until 1965, Yaşargil performed percutaneous carotid, vertebral, and orbital angiography on several thousand patients (Fig. 6). The analyses of these angiograms and those of injected arteries and veins in 200 cadaver brains with respect to their variations and courses have been published in several books, among them Die vaskulären Erkrankungen im Gebiet der A. vertebralis und A. basilaris (Vascular Diseases of Vertebral and Basilar Arteries) (20) and Cerebral Angiography (21).

In this way, the pioneering work of Krabenbühl and Yaşargil on cerebral angiography converged again with the study and surgical treatment of epilepsy. Fifty years after the introduction of cerebral angiography in Zurich, another remarkable contribution of neuroradiology to epilepsy surgery was reported. In 1989, the introduction of the selective and supraselective amygdal memory tests in Zurich allowed more exact presurgical language and memory investigations. The selective catheterization of the anterior choroidal artery in the so-called selective temporal lobe amygdal memory tests (22), as well as branches of the middle and posterior cerebral arteries supplying eloquent cortices in the so-called selective language (Wada) tests (23), was performed by Professor Anton Valavanis, chief of the Institute of Neuroradiology. Such selective co-injections of anamy and a single-photon emission computerized tomography (SPECT) tracer became a routine procedure for selective Wada tests in Zurich (24). Preoperative diagnostic and postoperative follow-up computerized tomography after epilepsy surgery in the Zurich series was replaced by magnetic resonance imaging (MRI) in 1983. The inclusion of new functional imaging methods such as SPECT and positron emission tomography (PET) in the presurgical evaluation of candidates for epilepsy surgery started in February 1988. More recently, magnetic resonance speci-
troscopy (MRS) and functional MRI (fMRI) have been added. For all these reasons, the contributions of Krayenbühl and Yaşargil to epilepsy surgery through the impetus of neuro-radiological methods cannot remain unstated.

GAZI YAŞARGIL AND THE INTRODUCTION OF MICRONEUROSURGERY

Krayenbühl highlighted "the place of microsurgical technique in neurosurgical surgery" during the Fifth Sir Hugh Cairns Memorial Lecture of the British Society of Neurological Surgeons in London on May 30, 1969: "I wish to emphasize, with Hugh Cairns, that surgery is and must be always an art, but its progress and thus its vitality depend on the maximum application to it of the methods and discoveries of science" (25). This statement showed the immense foresight of a man who was already 67 years old. In fact, it is easy to imagine how difficult it would be for a surgeon, after 30 years of surgical experience, to accept a better "new way to do it." In 1962, the Swedish cardiovascular surgeon Professor A. Senning, active in Zurich, was worried about thrombotic complications of leptomeningeal arteries after heart surgery using extracorporeal circulation. He inquired whether a microvascular technique could be applied to repair the iatrogenically embolized arteries. Krayenbühl decided to send Yaşargil to the United States to learn the microsurgical techniques, at that time mainly applied to peripheral neuro- and vascular surgery. Theodor Rasmussen, director of the MNI, recommended Professor R. M. Pearon Donaghy from Burlington, Vermont. Donaghy was already a pioneer in reconstructive vascular surgery, initiated at his clinic in 1960 by J. H. Jacobson. Yaşargil went to the United States in 1965 and spent a year in Donaghy's laboratory. Here, he learned and developed microtechniques for the reconstruction of brain arteries.

Mahmut Gazi Yaşargil (Fig. 2B) was born in Lice, Turkey, on July 6, 1925. In order to study medicine, he left Turkey in 1943 and went first to Vienna and then to Jena, where he studied in medical schools for two semesters, and then moved to Basel, Switzerland, where he graduated in the fall of 1949. According to his intention to become a neurosurgeon, he spent 3 months at the Basel Institute of Anatomy "Vesalianum" and learned from Professor Josef Klingler the special dissection technique of the formaldehyde-fixed cadaver brain. He continued these studies during his postgraduate training in the following 3 years.

His basic medical training was complemented with a year of psychiatry and neurology (with Professor Max Müller in Münisingen), internal medicine (with Professor W. Baumgartner), and general surgery (with Professor W. Bandi) in Interlaken. In January 1953, he joined the Department of Neurosurgery at the University Hospital of Zurich and started his training in neurosurgery with Hugo Krayenbühl and Gerhard Weber. His first paper on neurosurgery, titled "Vertebralangiographie," was published in 1955 (26). Yaşargil's contribution to neurosurgical literature culminates with his latest book in the series Microneurosurgery in 1996 (27).

Yaşargil envisioned the field of microneurosurgery, developed for reconstructive neurovascular procedures (introduction of extracranial-intracranial anastomosis), gradually encompassing other vascular lesions, aneurysms, arteriovenous malformations (AVMs), and brain tumors and, eventually, involving the whole realm of neurosurgery. During difficult vascular procedures, he expressed to Krayenbühl the necessity "to see better." Good illumination, unobstructed vision, and a view of the whole operative field are essential to the surgeon. In the foreword of Yaşargil's famous book Microsurgery Applied to Neurosurgery, Krayenbühl pointed out, "It is astonishing that the operating microscope came to be employed so late in the field of neurosurgery, since it has been an indispensable tool in the routine otologic surgery for four decades" (28). The historical invention and development of bipolar coagulation by Leonard I. Malis (chief of the Department of Neurosurgery, Mt. Sinai Medical Center, New York, from 1970 to 1991), accompanied by the introduction of a counterbalanced operating microscope stand and numerous microinstruments designed or redesigned by Yaşargil (presented in a Zurich course in microsurgery, November 14–20, 1968), allowed the application of microtechniques in neurosurgery (Fig. 7). The development of the subarachnoid approaches allowed noninvasive explorations and complete elimination of extrinsic and intrinsic lesions of the central nervous system: "the subarachnoid pathways are the route maps for microneurosurgery" (27).

Yaşargil retired in 1993 after completing 40 years of activity at the University Hospital of Zurich. He was appointed in 1994 at the University of Arkansas in Little Rock as professor of neurosurgery (Department of Neurosurgery; chairman, Professor Osana Al-Mefty), where he continues his academic and surgical activities. He received the Medal of Honor of the World Federation of Neurosurgical Societies during the Xth International Congress of Neurological Surgery held in Amsterdam in 1997.

Selective Amygdalohippocampectomy

Prior to 1969, resective surgical therapy of temporal lobe epilepsies in Zurich was done by means of anterior two-third resections. Patients who underwent this operation met the following criteria: (a) drug-resistant complex partial seizures, and (b) spike foci well and consistently lateralized to one temporal lobe in surface EEG. Patients usually underwent PEG and ventriculography as well as carotid angiography; intraoperatively, the spike focus was confirmed by ECoG and the extent of resection approximated according to it (8). This approach had several shortcomings, and the results did not entirely satisfy. Therefore, the method of SEEG, as mentioned before, was adopted and introduced in Zurich in 1970. From 1970 to 1974, the criteria, mode of exploration ("acute"), and stereotactic techniques, as well as the analysis
methods of the depth EEG, were more or less identical to the Parisian approach (13,14), that is, a broad spectrum of patients with various types of focal epilepsies (temporal and extratemporal) were evaluated.

In patients with temporal lobe epilepsy, particularly in those cases in which a seizure origin had been identified within the mediobasal temporal lobe structures, the question arose in 1973 of performing a selective amygdaloparahippocampectomy using a microsurgical technique. Gastaut had already stated in 1950 that the origin of temporal lobe epilepsy is in most cases rhinencephalic (29). Paulo Niemeyer presented his experiences on 19 patients at the Second International Colloquium (Bethesda, Maryland, 1958): He had successfully removed through a transventricular approach the mediobasal temporal lobe structures. In the subsequently appearing book based on this colloquium (edited by M. Baldwin and P. Bailey), Niemeyer (30) gave credit to Riechert and Jung, who interrupted the fornix stereotactically; to J. Viana, who had removed the hippocampus in unselected epilepsy patients; and to Seoville and Milner.

A review of the history of epilepsy surgery documents that the surgical procedures for the treatment of epilepsy were dependent on, and related to, the precise definition of the seizure focus (30–33).

The microsurgical technique introduced by Yaşargil is the result of the experience gained since 1967 by microsurgical approaches in the treatment of aneurysms, AVMs, and especially mesiobasal temporal tumors (35–37). Yaşargil was influenced by two main issues. First, he found that gangliogliomas, ganglioneuromas, astrocytomas, and AVMs confined to the mediobasal temporal lobe could be radically extirpated without recourse to lobectomy. Second, he noted that local removal of mediobasal temporal tumors and AVMs had been accompanied by fewer postoperative fits if the amygdala and parahippocampus were resected simultaneously (36,37).

The development of the preional craniotomy and its various refinements provided familiarity in exposing the proximal sylvian fissure just above the limen insulae. The transylvian route was readily adapted for exploration of the mediobasal superior lobe with approach to the amygdala and parahip-
pocampal cortex. After gentle opening of the sylvian fissure using sharp dissection, a 1- to 2-cm cortical incision in the sulcus insulae circularis pars inferior, lateral to M1 and the inferior trunk of M2, is done to reach and remove the amygdala, to open the pia-arachnoidal layers, to explore the ambient and crural cisterns, and to identify the courses of the anterior choroidal and P1 segments of the posterior cerebral artery, the optic tract, and the oculomotor nerve. The temporal horn is identified and dissected, and the hippocampus and parahippocampal gyrus are removed (Fig. 8B). This technique requires considerable microsurgical experience and, above all, familiarity with the regional anatomy, which can only be gained after "meticulous cadaver microdissection" (37). This technique has been somewhat underestimated by neurosurgeons who do not have enough experience in vascular microneurosurgery, not realizing the great benefit of this selective technique considering its outcome with respect to seizures and neuropsychology. The manipulation and recognition of the vascularization of the amygdala, gyrus parahippocampalis, uncus, and hippocampus, as well as their regular variability, has to be kept in mind during surgery (34–36).

The criteria considered for the "curative or causal" selective amygdalohippocampectomy include (a) unequivocal unilateral mesial temporal focal seizure onset at these structures associated with typical clinical symptoms, and (b) contralateral hippocampal functions intact (special neuropsychological testing for learning and memory performance, selective temporal lobe amobarbital testing, and presence of signs indicative of hippocampal atrophy and/or Ammon's horn sclerosis). A "palliative" operation of this type might be indicated in cases where the primary seizure-generating zone in the lateral posterior temporal neocortex cannot be removed without anticipated intolerable functional deficit, and where the ipsilateral hippocampal formation is rapidly involved by the ictal discharges acting as a "secondary pacemaker" (39, 40). In the time period from 1973 to 1992, besides many lesional cases presenting with limbic tumors and epilepsy (41), 100 patients with nonlesional limbic temporal lobe epilepsy were microsurgically treated by M. Gazi Yaşargil (42). Approximately 70% of the patients who underwent curative and palliative amygdalohippocampectomy for nonlesional limbic epilepsy are seizure free. Postopera-

---

**FIGURE 8.** A: M. Gazi Yaşargil (right) and Heinz-Gregor Wieser (left) in the operating room in Zürich after finishing a selective amygdalohippocampectomy in April 1996. (Photo courtesy of R. Stillhard.) B: Artistic description of the selective amygdalohippocampectomy described in 1975. After incision into the inferior insular sulcus (lateral to M1, anteriomedial to M2) and removal of the amygdala (dotted lines), the entire temporal horn, anterior choroidal artery, basilar vein of Rosenthal, and optic tract are exposed. The direction of the arrows indicates the dissection steps around the hippocampus. (Illustration courtesy of P. Roth.) (From Yaşargil MG, Teddy PJ, Roth P. Selective amygdalo-hippocampectomy; operative anatomy and surgical technique. *Adv Tech Stand Neurosurg* 1985;12:93–123, with permission.)
tively, no neurologic and mental deficits, no clinically significant memory impairment, and no changes of personality were observed (40,42,43).

NEW PERSPECTIVES AND FINAL REMARKS

Professor Krayerbühl will be remembered as a teacher whose forethought and encouragement allowed many advances in neurosurgery and the professional development of his pupils. Epilepsy, as the common meeting point of many medical disciplines, has allowed neurosurgery to develop smoothly through the fields of EEG, neuroradiology, and microtechniques throughout the last six decades.

New functional neuroimaging methods such as SPECT, PET, MRS, and fMRI, as well as less invasive surgical methods and techniques supported by real-time imaging during surgery (e.g., open MRI or frameless computer-assisted stereotactic localization), have been introduced in Zurich in recent years without ignoring the tradition and legacy of the predecessors. The Zurich team, in order to master neurosurgery, remains aware of Yasargil’s statement: “each surgical action comprises not only science, experience, knowledge, and techniques, but also artistic, philosophical, and religious attitudes from a neurosurgeon” (27).

ACKNOWLEDGMENTS

The authors express their gratitude to Professor Yasuhiro Yonekawa (chief of the Department of Neurosurgery at the University Hospital of Zurich), Professor Rudolf Hess, Dr. Christoph Bernoulli, and Herbert Silvianus, M.D., Ph.D., for their assistance and contributions to this manuscript. The authors are also indebted to Mr. Peter Roth, scientific artist, whose silent work has helped many neurosurgeons understand the concept of microsurgery, and to Mr. Roland Stillhard for the preparation of photographs.

Addendum

During the editorial process of this book, Harvey Cushing (1869–1939) and M. Gazi Yaşargil were selected as the Neurosurgery’s Men of the Century by the Editorial Board and the International Liaison and Advisory Panel of Neurosurgery, the official Journal of the Congress of Neurological Surgeons (44).

REFERENCES


We dedicate this book to Dr. Claudio Munari, our dear friend, who symbolized epilepsy surgery.

There is no one else whose life was so absolutely identified with epilepsy surgery as Claudio Munari. Epilepsy surgery was his primary reason of being and he gave all he had, even his own life, to it. In continuous pursuit of excellence in epilepsy surgery, Claudio's incomparable drive and energy led him to work unbelievable schedules. Though he had a multitude of admirable attributes, the ones that made him such a valuable friend and colleague, were his neglect of material goods in his search for the scientific truth and his compassion and deep respect for the patients as human beings. The emptiness of his leaving will be felt with deep pain by all of us for a long time. It certainly is a great honor to dedicate this book to him.