The Retrospectroscope

L.A. Geddes

Electrocorticography

by L.A. Geddes and C. Hodge

Recording the electrical activity of the exposed brain, known as an electrocorticogram (ECoG), has had a long and storied history. That the exposed brains of animals exhibited a characteristic waxing and waning rhythmic activity was first reported by Caton in 1875 [1] in England, who used a Thomson reflecting telegraphic galvanometer with a frequency response extending to about 5 Hz [2]. Unfortunately, Caton made no photographic recordings, but his descriptions are most convincing.

The first human recordings obtained from scalp electrodes, known as electroencephalograms (EEGs) were made by Berger in 1929 [3], who used the string galvanometer created by Einthoven in1903 [4] for electrocardiography. Berger, a psychiatrist, thought that the EEG (so designated by him) might be of value in diagnosing mental disease; this proved not to be the case. Clinical EEG evolved from the confirmatory studies in 1935 in the USA by Jasper and Carmichael [5] and by Gibbs, et al., [6]. It expanded quickly in the early 1940s and found a niche in the diagnosis of the many types of epilepsy, a dysrhythmia of neurons in the brain. The EEG also permitted localization of the region of the abnormally active neurons. The EEG, however, had its limitations.

The first treatment for epilepsy was the use of depressant drugs. In the early 1940s, it was recognized that by surgical removal of the abnormally active neurons, the epilepsy could be treated. Thus there arose the need for precise localization of epileptic foci and this was achieved by recording the electrical activity of the exposed brain during surgery.

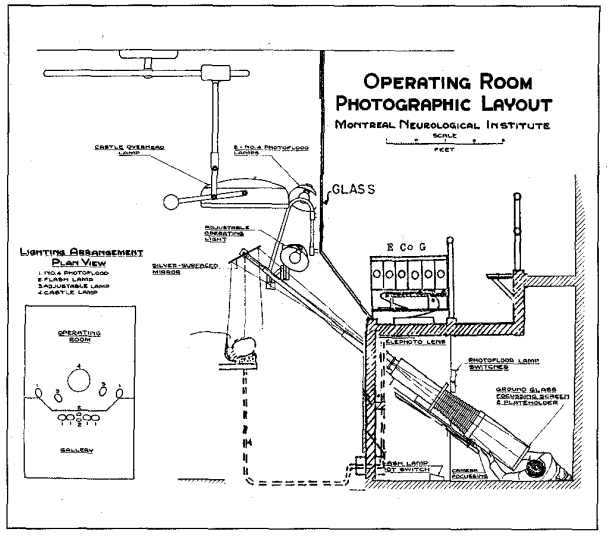
Development of ECoG

Multichannel recordings from the exposed brain cortex of conscious human patients as a diagnostic procedure to localize epileptic foci began in the early 1940s. Two centers, one at McGill University and the other at Harvard University launched this new field.

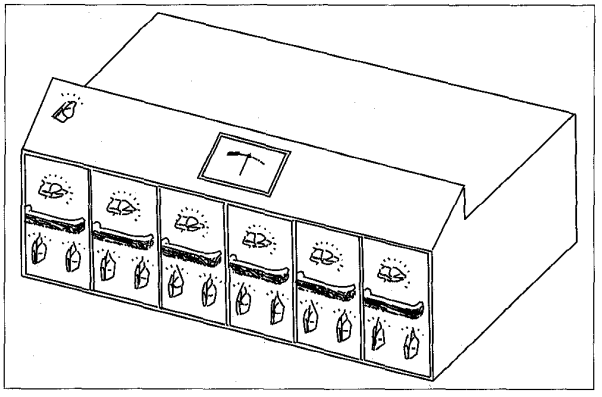
Relatively unrecognized at that time were the severe requirements for recording microvolt signals in the electrically hostile environment of the operating room. Not only did the electrodes have to be electrically stable initially, but they had to be stable and noise-free after steam sterilization. Recognizing this situation, Jasper [7], in his first paper on electrocorticography, in 1949, stated:

"During the past ten years there has been steady improvement in methods used to record the electrical activity directly from the human cerebral cortex exposed at operation."

In 1945, the author (LAG) joined the staff of the Montreal Neurological Institute and the Department of Electrical Engineering, both of McGill University, and became deeply involved with the development of ECoG equipment for permanent installation in Wilder Penfield's operating room. The design goal was that the ECoG and electrodes would function on command.



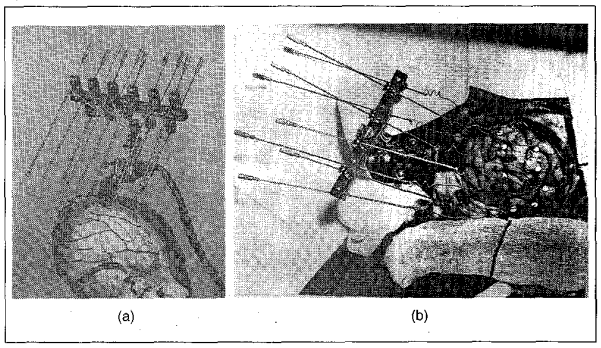
1. Penfield's operating room (Photo courtesy of C.Hodge).



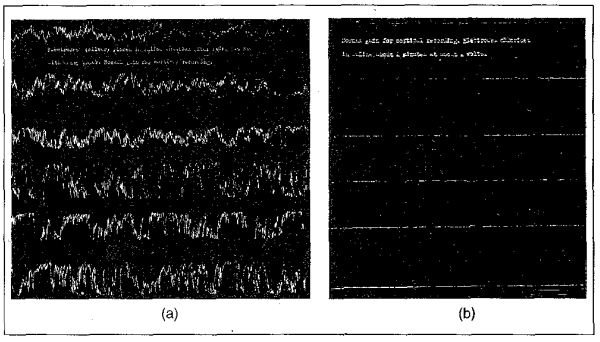
2. The six-channel electrocorticograph which was mounted in the gallery of Penfield's operating room.

Because it required less than one half hour to steam sterilize the electrodes, a surgical procedure could be scheduled at any time, providing the ECoG and electrodes would perform on command. Before describing how the design criteria were met, it is useful to describe Penfield's operating room. This was the site where an enormous amount of information was obtained on cortical localization, which led to the creation of Penfield's sensory and motor homunculus map of the human cortex.

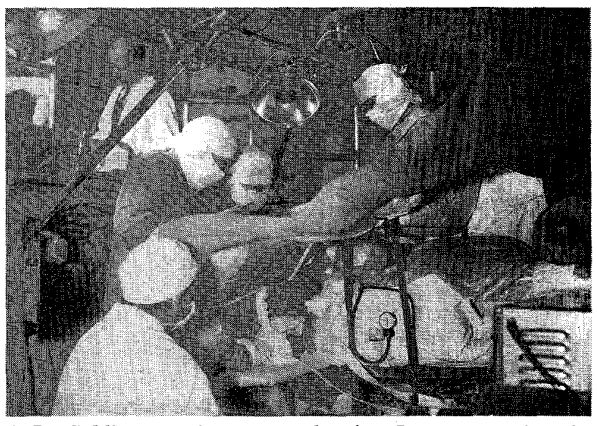
Penfield's operating room of the 1940s incorporated many features that were to become standard much later. For example, it was air conditioned and had ultraviolet lamps along the four walls to kill airborne bacteria. Wall-mounted, illuminated X-ray viewing boxes were easily seen by the surgeon. The asphalt-tile floor was covered with a thin film of glycerin to capture dust and



3. In A is shown the electrode assembly clamped to a skull. In B the electrodes are in contact with the cortex of a patient.



4. Electrode noise from polished silver-ball electrodes in saline (A) and a record obtained after chloriding the same electrodes in the same saline bath.



5. Penfield's operating room, showing Jasper operating the ECoG (between the light and the diagonal pole that supported the mirror used with the photographic equipment). (Photo courtesy of C. Hodge).

lint. All personnel in the operating room wore cotton booties over their footwear. For general anesthesia, ether was used and, despite the presence of a spark-gap (Bovie) electrosurgical unit, there never was an accident in the seven years that the author was there. All equipment was grounded to a central 110-volt, multiple-outlet box at the end of a cable; the term "spider" was used to describe the wiring, which it resembled when the cords to all instruments were plugged in.

The ECoG was displayed in a specially designed, glassed-in gallery, which also was used during the surgery to house Dr. Penfield's secretary (Dawson), the electrophysiologist (Jasper), and viewers. The equipment was arranged so that Penfield could see the evolving ECoG record from the operating room. In addition, a mirror on a pole allowed the photographer (Charles Hodge, who was lying under the gallery) to take pictures of the exposed cortex with the electrodes applied and any sterile numbered markers that Penfield placed on the cortex to identify significant events. Figure 1 is a sketch showing the essential features of the operating room and gallery.

The six-channel electrocorticograph, sketched in Fig. 1 and shown in Fig. 2, incorporated many unique features to maximize utility. Each channel amplifier was mounted in a drawer that could be pulled out so that a replacement unit could be plugged in immediately if a malfunction occurred. The amplitude controls were calibrated directly in units of V/mm of pen deflection (10,20,40,80, etc.) The input stage of each channel consisted of a matched pair of type 1620 pentode tubes in rubber-mounted, antimicrophonic sockets. All pairs of resistors in the input stage were carefully matched. A high common-mode rejection ratio (10,000) was achieved by using a high resistance in the common cathode of the input stage. In addition, negative feedback for common-mode signals was provided by joining the mid point of the input stage grid resistors to the common point of the cathodes of the second stage. The first method was described by Matthews in 1938 [8] and the second was reported by Offner in1937 [9]. Two double triodes followed the input stage and fed a double, screen-grid power amplifier which drove the ink-writing pen. At first, the Crystograph developed by Offner and Gerard in 1936 [10], a direct-writing piezoelectric recorder was used; but it was later replaced by a Grass 6-channel moving-coil d'Arsonval-type inkwriter. The ECoG record, which emerged toward the sloping glass partition, is shown in Fig. 1.

The electrode assembly, shown in Fig. 3A, was mounted on a scissor-type, locking surgical clamp that was affixed to the skull at the perimeter of the craniotomy, which usually measured about 4 by 4 inches. This clamp served to ground the patient. Figure 3B shows the electrodes on the cortex of a patient.

Each cortical electrode consisted of a ball, heat formed at the end of a silver wire that was mounted to a silver rod in a ball-and-socket bracket (actually a manipulator for the cat's whisker from a crystal-set radio). To eliminate the potentially variable-resistance contact between the electrode and the manipulator which resulted from corrosion due to steam sterilization, a coil of braided wire was wrapped around the silver rod that supported the electrodes. The wire was connected directly to the cable that was plugged into the wall in the operating room to connect the electrodes to the ECoG in the gallery (Fig. 1). The eight silver-ball electrodes were polished, covered with cotton wool, then chlorided. Sterilization was accomplished by mounting the assembly in a wire basket that was wrapped with a towel and placed in the steam autoclave for 30 minutes.

The author was concerned about the ability of d'Arsonval's chlorided silver electrodes, developed in 1886 [11], to withstand steam sterilization. Therefore, tests were conducted on the electrical stability of these silver-ball electrodes in a bowl of saline. It was found that newly polished silver-ball electrodes produced the equivalent of a grand-mal electrogram when in saline, as shown in Fig. 4A. To solve this problem, the electrodes were first cleaned electrolytically by making them negative with respect to a silver plate in a saline solution. Then they were chlorided (electrodes positive) with a 1.5-v battery for a few minutes which

produced very stable electrodes, as shown in Fig. 4B. Happily the same stability was retained after steam sterilization, proof of which came from stability tests in saline following the recording session in the operating room.

The gallery of Penfield's operating room was an exciting place during surgery to remove an epileptic focus. A microphone in the operating room was open at all times, and a loudspeaker in the gallery allowed viewers to hear what transpired. A microphone in the gallery allowed a viewer to talk to the operating-room personnel by depressing a lever. However, during a recording session, the main conversation was between Penfield in the operating room and Japser in the gallery who monitored and interpreted the ECoG as it was being recorded. In Figure 5, Jasper (in the white coat) can be identified between the Castle light and the diagonal, chrome-plated pole that supported the mirror that allowed photography of the cortex.

Prior to surgery, the patient would have had an EEG to localize the epileptic focus. When in the operating room, the patient was conscious and the shaved scalp was infiltrated with a local anesthetic, then a scalp flap was formed surgically. Four burr holes were made in the skull and a Gigli saw was used to join them; the bone flap was then turned, being wrapped with the scalp flap. The dura mater was then excised to expose the cortex and the skull clamp affixed to support the eight electrodes, which were then adjusted so that they encompassed the epileptic focus previously localized by the scalp EEG. Bipolar recording was used; channels 1, 2 and 3 were connected to the upper four electrodes; and channels 4, 5 and 6 were connected to the lower four electrodes. The epileptic focus was usually identified during the first electrode placement. If not, electrical stimulation with a Rahm thyratron (capacitor-discharge) stimulator was used to activate the cortex to enhance localization. With each stimulation, a sterile, numbered plastic marker was placed on the cortex and photographed. In addition, the patient was asked what he/she perceived, and this information was recorded by Penfield's secretary. Very frequently, the aura that precedes an epileptic siezure would be produced. Hyperventilation and drugs were sometimes used to activate the brain. It was a remarkable experience to hear what the patient said when different areas of the brain were stimulated. In some cases, the patient would describe a scene vividly and become irritated because those in the operating room could not see what was being described.

When the epileptic focus was identified, the record was shown to Penfield. Then the patient was placed under general anesthesia and the focus was removed surgically, the exposure was closed, and the patient was recovered. The electrode tips were washed with saline and the electrodes were returned to the author, who tested them for electrical stability in saline, being greatly relieved by the remarkable stability of chlorided-silver electrodes. d'Arsonval was right; chlorided silver electrodes are stable!

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Leslie A. Geddes is the Showalter Distinguished Professor Emeritus of Bioengineering and former Director of the Hillenbrand Biomedical Engineering Center at Purdue University (1974-1991). Born in Scotland and educated in Canada, Dr. Geddes holds the Bachelor's and Master's degrees in Electrical Engineering from McGill University (Montreal, Quebec, Canada) and the Ph.D. degree in Physiology from Baylor University College of Medicine, (Houston, Texas). He was awarded a D.Sc. Honoris Causa by McGill in 1971. While at McGill, he was an instructor in electrical engineering and in neurophysiology. While at Baylor, he was Assistant, Associate, and Full Professor of Physiology and Director of the Division of Biomedical Engineering. Address for correspondence: Dr. L. A. Geddes, The William A. Hillenbrand Center for Biomedical Engineering, 1293 A. A. Potter Engineering Center, Purdue University, W. Lafayette, IN 47907.

C.F. Hodge has been the Director of Photography at the Montreal Neurological Institute since 1945, and has been awarded many biophotography awards. He is a Registered Biological Photographer. Honors include Fellow of the Biological Photographic Association , Honorary Fellow, Royal Photographic Association, Great Britain, and Honorary Fellow, Institute of Medical Illustration , Great Britain. In 1992 he was awarded a member of "The Order of Canada" for his photographic work in the study of cerebral blood flow.