THE CLINICAL APPLICATION OF ELECTROENCEPHALOGRAPHY

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The brain, like the heart, produces electrical waves during life. Caton, an English physiologist, was the first to measure these electrical potentials in the exposed brain of the rabbit (1875). It was not until 1929, however, that Hans Berger, a German psychiatrist at Jena, picked up electrical waves from the human brain by means of needle electrodes inserted into the scalp, and recorded them on bromide paper with a vacuum tube amplifier and a string galvanometer.

Since that time a large group of workers have developed this new field in body current physiology—called electroencephalography—to a point where it is used as a diagnostic method in many hospitals in this country. The names of Berger and Kornmuller in Germany; Adrian and Walters in England; and Gerard, Jasper, Gibbs, Davis, and Loomis in the United States are only a part of the large list of pioneer workers in this field. The reader is referred to the new and excellent Atlas by Gibbs and the extensive and complete review of this field by Davis and Jasper for details not covered in this article.

TECHNIC

With modern apparatus the procedure of obtaining tracings of human brain potentials is a relatively simple task. The subject is made comfortable in a chair or on a bed in a quiet room.

The Laboratory.—In the earlier laboratories extensive electrical shielding of the subject's room was necessary. Lead, copper sheet, copper screen, or galvanized iron, were used. In some places elaborate cages within cages were built at great expense. With present success in balanced amplifier construction, the simplest sort of Faradic cage, as these rooms are called, will suffice (metal lath screen or window screen soldered to a good ground). If electrical interference from aerial waves is at a minimum (remoteness from diathermy or...
x-ray apparatus), it is possible to operate the newer machines without any shielding at all, provided the metal boxes containing the apparatus are adequately connected to the ground.

For ordinary recording to see if the waves are normal or abnormal, four to six electrodes must be fastened to the scalp. Usually two or three are placed on each side of the head. The hair is not cut. The scalp is lightly cleansed with a little acetone at points 2 cm. in diameter over frontal, parietal and occipital regions. Onto these clean surfaces a bit of ordinary electrocardiographic electrode paste is well rubbed. A 5-mm.
or 10-mm. flat solder disk fused onto the bared end of a No. 30 enamel wire forms the electrode (Fig. 180, inset). The solder disk is placed firmly on the electrode paste area and then covered with collodion which is dried by a compressed-air jet or hair drier, or even the air from a rubber bulb. The dried collodion holds the electrode firmly to the scalp and, if one is careful, a good electric contact is made. The other end of this wire is fastened to some form of pin jack for insertion into the panel board, connected by means of a shielded multi-wire cable to the recording apparatus. There should be about 5000 to 20,000 ohms resistance, as measured with a pocket tester, between any two electrodes on the scalp. When the electrodes are in place, the pin ends are plugged into the board at the patient’s head. The subject is told to close his eyes, relax his facial, jaw and neck muscles and be as quiet as possible (see Fig. 180).

The recording and amplifying apparatus is especially built for this purpose by four engineers in this country (Lovett Garceau, Holliston, Mass.; Albert Grass, Harvard Medical School, Boston, Mass.; Franklin Offner, Chicago, Illinois; and Rahm Instruments Inc., 12 West Broadway, New York, N. Y.)

The Apparatus.—The electroencephalographic apparatus consists of one or more battery and power-operated amplifiers (each set being called a channel and in a general way like radio sets) that feed into a recorder, usually an ink-writing oscillograph. These can, of course, be made by any competent electrical and radio engineer from the various satisfactory circuits that have been published. In my opinion such homemade sets are likely to require a great deal of repair, are not standard as to characteristics, and on the whole not worth the money saved by home construction. The average cost of manufactured apparatus is around $500.00 per channel, and if well cared for it should last for two to five years before extensive overhauling or replacement is necessary. Minor repairs and general upkeep average $100.00 to $150.00 per year for the average 3 to 4 channel set.

Personnel.—The ordinary clinical operation of this apparatus requires a technician (if many cases are handled per day, two or more technicians will be necessary). The ordinary laboratory technician or nurse can become proficient in this work after two or three months’ training in an established Brain Wave Laboratory. She can by then make electrodes, attach them accurately, quickly and efficiently to the scalps of patients, run and maintain the apparatus, and recognize the more common sources of artifacts and trouble which she can correct. A laboratory secretary is nearly always essential in addition to the technician because of the need for clear, concise reports, careful filing and indexing of records, and the arrangement of appointments. The interpretation of the records themselves should be in the hands of a physician, preferably one who has had training in neurology and psychiatry. If such a doctor
has had experience in neurophysiology and elementary radio engineering, he will avoid the need of frequent consultations with specialists in these subjects and can be relatively independent. A few months spent visiting various Brain Wave Laboratories in the neighborhood, a dozen evenings spent in reading, and a conservative, cautious attitude in interpretation for the first year is probably sufficient preparation for the beginner.

Artifacts.—The clinical interpretation of these records is like that of the x-ray and the electrocardiogram. A good general training in medicine plus a knowledge of the limitation and sources of error will do more to prevent ridiculous claims of the powers of this apparatus than anything else. It is to be kept in mind that the sensitivity of the apparatus is so great that electrical disturbances in the air such as an exposed unshielded, alternating current wire or the waves from a sparking commutator of a nearby motor will introduce artifacts consisting of high-voltage, 60 per second (60 cycle) waves into the record. This type of artifact is readily identified and can usually be eliminated by suitable shielding, condensers, or grounding of the offending source of this aerial broadcast. Chewing, swallowing, frowning, tensing neck muscles, etc., introduce muscle potentials in the record that are also readily identified after a little experience, and can usually be corrected by the subject. Slow swings of the baseline with high-voltage spikes are due to gross movements of the subject that jiggle the electrodes and build up static discharges. The 2 to 3 per second, sharp-pointed waves produced by eye movements such as blinks are easily recognized after a short while, and can be stopped by having the subject fix his eyes on a point on the wall. Loose contacts, defects in the apparatus, bad batteries, short circuits and so on are identified only with experience and are not common. It is important to keep all such artifacts in mind and be thoroughly familiar with them.

Fig. 181.—A view of the Brain Wave Laboratory showing two sets of electroencephalographic apparatus. One of these is portable, on wheels, for use in the operating room or on wards for patients too ill to be brought to the laboratory.
The electroencephalograph is usually in another room from the subject, but this is not essential. The wires from the various scalp leads run to a control box on the apparatus so that any combination of leads may be examined without disturbing the patient (see Fig. 181). The actual recording, which is done on some sort of ticker tape, requires ten to forty minutes depending on how complete an examination is desired.

**NORMAL ELECTROENCEPHALOGRAM**

The normal electroencephalogram of the awake human adult obtained in this way consists of two sorts of wave patterns in various mixtures. The first, or alpha wave type, is composed of rather symmetrical, sine-shaped waves, 8 to 11 per second, having a voltage of 30 to 60 millionths of a volt. These waves have the remarkable property of becoming prominent when the subject closes his eyes and relaxes, and of disappearing on opening the eyes or doing some problem. They are found in all sorts of animals as well as human beings (see Fig. 182).

The second type is called beta waves. These are irregular, low voltage (10 to 20 millionths of a volt), occur 18 to 24 times a second, and are not affected by stimuli as are the alpha type. Normal humans and animals have various proportions of these waves. There is some evidence that easy-going people have more alphas and tense, jittery people more betas (see Fig. 183).
BRAIN WAVE PATTERNS

Normal

<table>
<thead>
<tr>
<th>Slow Alpha</th>
<th>Fast Beta</th>
<th>Mixed Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>9-11 per sec.</td>
<td>18-24 per sec</td>
<td></td>
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Abnormal

<table>
<thead>
<tr>
<th>Slow Delta</th>
<th>Fast</th>
<th>Mixed (Wave Spike)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-6 per sec.</td>
<td>16-22 per sec</td>
<td></td>
</tr>
</tbody>
</table>

- Found in
  - Fugue States
  - Epilepsy - Behavior Types
  - Convulsions
  - Deep Sleep
  - Low Blood Sugar or Oxygen
  - Convulsions
  - Deep Anesthesia
  - Severe Alkalosis
  - Brain Tumor, Abscess, Hemanoptoma
  - Encephalitis or Head Injury
  - Infiltrating Tumors
  - Light Anesthesia
  - Some Psychoses
  - Some Behavior Disorders
  - Infancy

- Found in
  - Epilepsy - Convulsions (Grand Mal)
  - Focal Seizures

- Found in
  - Epilepsy - Lapses - (Petit Mal)
  - Convulsions
  - Rare Tumors

Fig. 183.—A comparison of normal and abnormal brain wave tracings arranged diagrammatically. Note higher voltage in abnormal waves and clear difference between the normal and abnormal pattern.

ABNORMAL ELECTROENCEPHALOGRAM

There are three distinct deviations from the normal brain wave pattern encountered in the clinical laboratory:

1. The waves may become slower than 9 to 11 per second: waves from 1 to 7 per second are called delta or slow waves.
2. The waves may have increased voltage.
3. They may have a depressed voltage.

Pathological states of the brain are usually associated with one or more of these abnormalities. It must be pointed out here that normal electroencephalograms imply a brain awake and in an adult. Children have slower normal waves and infants may have irregular potentials as slow as 1 to 2 per second that would be grossly abnormal for an adult. Therefore, the age of the subject must be considered and corrections applied for children under twelve (Lindsley7). Furthermore, in normal sleep the waves slow down and in deep, heavy sleep around 1 A.M. (Loomis8 and Kleitman9) 2 and 3 per second waves may be encountered. The subject must therefore be awake during
this type of testing. As an additional complication, drugs affect the waves, tending to slow them, so that barbiturates and alcohol must not have been given the subject (Gibbs). With these effects on normal waves in mind, we can consider the various pathological electroencephalographic findings encountered in a hospital brain wave laboratory.

EPILEPSY

The most important condition with abnormal brain waves is epilepsy. Gibbs and Lennox have done the most extensive work in this field. During any sort of epileptic seizure very distinct abnormal patterns occur in the electroencephalogram. In minor spells (petit mal) a very characteristic slow wave and spike, both of increased voltage, occur (Fig. 184). One of the most dramatic moments in the use of the electroencephalogram occurs at the appearance of an attack of wave spikes on the apparatus. The normal-appearing waves are coming off and the pens in writing these waves make very little noise. Suddenly out of a clear sky the large, 3 per second waves with the fast spike component appear. The apparatus makes a distinctly different note in writing out these abnormal waves. The appearance of the record is so different from the normal, and the sound of the pens writing on the paper so different from the normal that anyone can recognize this type of spell without any effort. The remarkable regularity of this pattern and the uniform distribution of these waves over the entire head suggests to some observers that their origin may be deep in the cerebrum.

These spells last on the apparatus from ten to thirty seconds. During this time if a stimulus is given to the patient, as by turning on a light, no response is shown, indicating that the patient is unconscious. Furthermore, if one observes the patient carefully during the appearance of these wave spikes, often grimaces, twitching of the mouth, chewing movements and a variety of sucking, blowing and other sounds may be noticed. It is possible to take motion pictures of these attacks and synchronize them with the brain wave tracings. In fact, the author has made several motion pictures with the patient on one side of the film and the brain wave tracings on the other—
both carefully synchronized. In such a picture it is seen that wave spikes appear six to eight seconds before the movements

![Electroencephalograms](image)

**Fig. 184.**—Some examples of electroencephalograms during slight attacks.

and sounds previously described are noticeable. A great many patients are unaware of the presence of these small lapses and
would not go to a physician because of them. The electroencephalogram vividly brings out their presence and demonstrates clearly that during these attacks the patient is in a state of impaired consciousness. The importance of this finding in patients who drive automobiles is, of course, obvious.\textsuperscript{15, 18}

In convulsions (grand mal) fast spikes predominate with very high voltages and 6 per second waves. In all sorts of mixed spells (psychic or equivalent state) mixtures of 3–4 and 6 per second, slow waves are encountered. In addition to picking up abnormal waves during spells, the record of these patients in the \textit{spell-free interval} usually shows small groups of abnormal waves. Furthermore, with overbreathing such groups of abnormal waves may be induced, making a diagnosis of an \textit{abnormal record} possible without the need of producing a real seizure. It is this use of the apparatus that is most valuable to the clinician.

Fifteen hundred examinations were made with the electroencephalograph on patients with suspected or proved epilepsy. Of this number 1200 records were made on patients who had clinically proved epilepsy in some form (500 patients). In 450 of these patients, the records were abnormal when the patient was \textit{not} taking anticonvulsant drugs. It is apparent, therefore, that in 90 per cent of the electroencephalographic examinations the tracings showed abnormal waves. Thus 10 per cent of true epileptics may have a normal record even with hyperventilation at one time or another. Furthermore, the relatives of epileptics and others may show abnormal electroencephalographic records \textit{without} any clinical history or other evidence of seizures. This means that the brain wave record alone cannot be used to make the diagnosis; like all other laboratory tests, it must be correlated with the history and physical examinations, and diagnosis must be made from the combined findings.

The brain wave machine is also useful in following the therapy of the patient with epilepsy, by measuring the degree or amount of abnormality with different anticonvulsant seizures.\textsuperscript{14} Of seventeen patients with epilepsy carefully followed with many electroencephalographic examinations it was possible to adjust the anticonvulsant drug dosage in twelve, so that the records even with hyperventilation were nearly normal.
MENTAL AND NEUROLOGICAL DISORDERS

A second group of patients who show abnormal brain waves are behavior problem children; 40 per cent of all psychotics; and patients with a variety of diffuse cerebral diseases such as chorea, encephalitis and general paresis. The apparatus here simply confirms the impression that structural damage to the brain is often seen in these disorders, and gives an indication of how extensive this may be.

A fifty-six-year-old woman was admitted to the private wards because of bizarre behavior, temper outbursts, and carelessness in her personal appearance. There was a long history of psychogenic difficulties and family trouble. The findings of neurological, spinal fluid and x-ray studies were normal. Electroencephalograms showed 3 to 5 per second waves all over the head greatly increased with moderate overbreathing. Subsequent air studies showed cortical atrophy.

BRAIN TUMORS

A third field is of interest to the neurosurgeon. Tumors, abscesses and clots usually cause a local disturbance in the brain wave pattern. By means of a multi-channel machine and the use of sixteen scalp electrodes it is possible to localize the region of this abnormal electrical activity (Williams and Gibbs, Fig. 185).

A forty-three-year-old man was admitted to the neurological service with weakness of his left leg and attacks of numbness on his left side. Electroencephalographic examination showed a sharp focus in the upper left parietal region. Operation revealed a meningioma in this area. A month later a normal brain wave record was obtained.

In this case the neurosurgeon felt that the neurological examination, x-ray of the skull and positive electroencephalogram were enough for surgery without the need of air studies.

A woman of thirty-five was admitted to the hospital in 1938 with focal seizures in her right hand. The findings from lumbar puncture, air encephalography, and x-ray examination were normal. Just after a seizure the right arm was weak and the patient showed some aphasia. Electroencephalograms showed a sharp area of high voltage, and fast activity over the left temporal-frontal region above the ear. Elsewhere the record was normal. Operation under this area revealed a malignant infiltrating tumor. Direct cortical potentials from this area recorded in the operating room from the exposed brain showed the same fast activity seen from the surface electrodes. Five cm. away, over the normal cortex, normal waves were found.

Recently at the Massachusetts General Hospital Brain Wave Laboratory a group of 417 electroencephalographic localiza-
Fig. 185.—A, x-Ray of skull. Arrows show presence and location of tumor. A large vessel in the left parietal area following the direction of the middle meningeal artery leads to the posterior parietal parasagittal area, where there are many other smaller vessels.

B, Electroencephalographic tracings of the same case. Upper show slow, high voltage, out-of-phase waves; tumor localized in the position marked by circle. Lower tracings show normal waves, same patient, eighteen days after successful removal of the tumor.

...tions were carefully followed up to determine their accuracy. It was found that in 115 cases in which a definite, clear-cut localization was made, 84.5 per cent were in the correct spot.
Of eighty-nine doubtful or poor localizations, 44 per cent were correct. Where no electrical focus was found, the subsequent course showed a 91 per cent correct result (213 cases). In three other laboratories similar results have been reported. It is to be emphasized here that this new method of localizing intracranial lesions must not be regarded as a substitute for other methods, such as a careful neurological examination or air studies, but as a check and additional tool to aid the surgeon at his task.

NEW FIELDS

The changes in the brain wave records are closely related to states of consciousness. When the low oxygen—or low blood sugar—or anesthetic agents of various kinds are tried on subjects, or even animals, recording of the brain wave record proved valuable indication of whether the cerebral cortex is normal or abnormal. In the examination of aviators and automobile drivers, testing with this sort of apparatus may provide important data regarding misfits and failures.

SUMMARY

In 1937 the Brain Wave Laboratory of the Massachusetts General Hospital was opened. About twenty patients were examined each month. In 1941, 240 to 260 examinations are being made each month, and the test is firmly established as a part of the diagnostic procedures patients may require. It is extremely useful in aiding the diagnosis of epileptics and in following their therapy. It may differentiate abnormal behavior or psychosis of structural origin from purely psychogenic disorders. It is helpful in localizing intracranial lesions of all sorts. It is a useful tool in physiological research on the cerebral cortex, being an indicator of the level of consciousness.

BIBLIOGRAPHY