Electroencephalographs

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Like the electrocardiograph (ECG), the electroencephalograph (EEG) is a dedicated multichannel recording voltmeter measuring nondirect current signals. Unlike the ECG, which displays short duration pulses in the millivolt range produced by the heart, the EEG measures low-frequency alternating signals (about 1–30 Hertz [Hz]) in the 10 to 100 microvolt (μV) range produced by the human brain. The traditional analog EEG produces paper tracings called electroencephalograms. Newer digital devices store the individual readings as they are taken and construct the EEG later. The term *EEG* applies to both the instrument and the paper tracing and will be used interchangeably in this article, just as it is in the healthcare field.

Current Technology

Researchers believe that nerve cells called *pyramidal cells*, located in the outer layer of the brain, react to various stimuli and create the signals picked up and displayed by the EEG. As these cells polarize and depolarize in response to various stimuli, they create the EEG waveform. Most EEGs are taken with the patient resting or sleeping. On occasion, medical practitioners will stimulate the patient (using light, sound, electrical shock, or a combination) to elicit, measure, and document the response.

Whether the EEG instrument is an older analog or the newest digital instrument, the EEG technician must connect a number of electrodes to the scalp to detect these signals. There are several means of electrode attachment, depending on the location, skin condition, and type of study being undertaken. It is very common to use a conductive adhesive or paste resembling modeling clay or glazing putty or to use a substance like collodion (a solution of pyroxylin in ether and alcohol) in conjunction with conductive gel. Another way, especially in studies where the patient might move around, is to use a cap with electrodes embedded in it. The EEG technician must apply a conductive gel to the scalp, but no adhesive. Lastly, and least commonly, sterile needle electrodes are stuck into the upper layer of skin on the scalp, and the area is treated with a disinfectant.

The EEG electrodes are applied to the patient in an internationally standardized electrode placement scheme known as the "10-20 system" (mapped in Figure 1). Typically, 19 scalp and 2 earlobe brain test points are used to generate as many as 16 simultaneous standard traces. For studies that do not require the use of all 21 electrodes, the EEG technician may simply attach fewer electrodes to the scalp. Depending on the protocol followed, some research studies require up to 256 electrodes attached to a cap placed on the scalp.

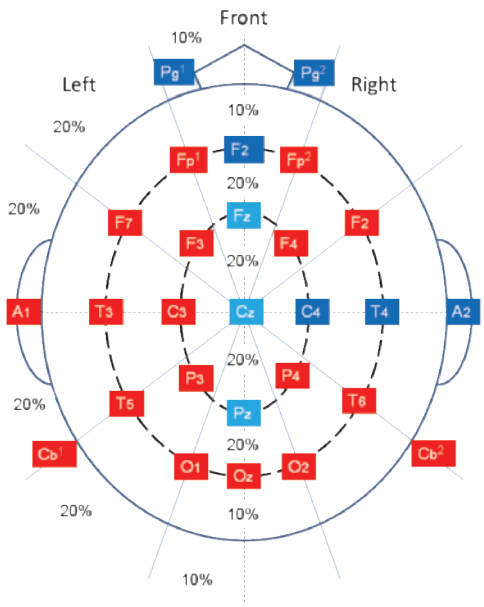

Figure 1. Electrode placement for the standard 10-20 system. It is so named because the electrodes are spaced at intervals of 10% and 20% of the distance between particular landmarks on the scalp. Only 21 of the electrodes are used for a standard 16-trace EEG.

Each electrode, which is about the size of an ECG electrode minus the adhesive disk, is connected by a wire to an EEG head box. The head box is a separate item located near the patient's head and sometimes contains a preamplifier to improve the signal-to-noise ratio. Often the box contains an illustration of a human head with lead input jacks located at the respective positions. A thicker, multiconductor, shielded cable carries the individual signals from head box to the EEG itself.

The particular combination of electrode locations

used and method of connection is called a *montage*. Different montages are used to diagnose epilepsy, coma states, other seizure disorders, encephalopathies, and general sleep studies. Each montage uses different combinations of electrodes to optimize results. Montages are either preprogrammed in the EEG at the manufacturer or are field programmable.

Once the signal is obtained by the lead wires, it must be amplified. Each of the 16 channels of an analog EEG has its own dedicated differential amplifier, each with (usually) a gain control, low and high frequency filters, a 60-Hz notch filter (to reduce power-line interference), buffers, etc. The amplifiers employ conventional Class-A amplifier circuitry and are placed side by side in front of the operator. The output of each amplifier drives a galvanometer connected to an ink pen. The pen mechanically records the EEG on paper. Up to 16 galvanometers are placed side by side along the long axis of the paper to continuously record the EEG signal from each amplifier, all referenced to time.

Digital EEGs are based around a personal or sometimes even a laptop computer. Digital units generally have the head box connected to a port on the computer using a smaller cable than that used on their analog counterparts. This is because the head box contains additional circuitry to switch between leads and lead sets during EEG acquisition. Proprietary software provides the EEG image on the screen, allows instantaneous switching of matrixes, digital storage of both the acquired EEG and the individual lead signals, and other features unique to the particular manufacturer. Because the computer eliminates up to 16 separate and discreet amplifiers, galvanometers, pens, etc., digital EEGs are considerably smaller than the office-desk-sized "portable" analog units they are rapidly replacing. Large digital EEG units, complete with lead box, central processing unit (CPU), monitor screen, and on-board printer, are about the size of a traditional diagnostic ultrasound unit. Reduced size and cost, combined with more modern and effective electronics, now allow EEGs to be performed at the patient's bedside instead of in a dedicated area within a medical center.

The migration from analog to digital EEG units provides a number of advantages for the patient, technologist, and physician and represents the current state of the art. For the patient, although the number of scalp electrodes is the same, the umbilical from the lead box to the EEG unit is smaller, easier to move, and puts less stress on the scalp. Digital units do not print the entire EEG on fan-

The Evolution of the EEG

Most sources credit Hans Berger, a German psychiatrist, with the "discovery" of electroencephalography in 1929. This was considered a historical breakthrough at the time, providing heretofore unknown insight into the workings of the human brain. At best, though, Berger can be credited with performing the first crude electroencephalogram on a human in 1924, announcing his discovery to the world in 1929 and coining the current terminology of alpha and beta waves.

The previously mentioned sources fail to take into account the considerable work of his predecessors in the field of neurology—Luigi Galvani's experiments with frog's legs through which he discovered "biological electricity," and Richard Caton's 1875 paper in the *British Medical Journal*, for example. In this paper, Caton, a Liverpool physician, presented his findings of the electrical phenomena exhibited by the exposed cerebral hemispheres of rabbits and monkeys. Some 15 years later, Adolf Beck published similar observations in rabbits and dogs that included light-altered rhythmic oscillations. Early in the 20th century, others continued to study the electrical phenomena on mammals, including dogs, and one even published photographs of EEG recordings of experimentally induced seizures. Later, others capitalized on Berger's work, demonstrating epileptiform spikes, spike waves, and the unique EEG waveform pattern indicative of certain seizures. In 1936, the Massachusetts General Hospital opened the first EEG laboratory.

In 1935, Albert Grass designed three devices to amplify human EEG potentials. In doing so, Grass defined the foundation of both EEG technology and the Grass Instrument Company. A year later he designed moving coil galvanometers, which enabled the embryonic EEG instrumentation to accurately and reliably record EEG frequencies on chart paper. The addition of these new galvanometers to his early amplifiers became the Grass Model I, used by a number of physicians and researchers of the era. In 1938, the Grass Model II was developed and used by doctors to evaluate head injuries and the condition of airplane pilots during World War II.

A number of years later, Franklin Offner prototyped

folded paper as do the analog units; they display the EEG on a screen (usually a computer monitor) and simultaneously digitally record it for later review. Additionally, since many units record both the EEG and the individual lead-wire data, they allow for later reconstruction of not only the original EEG, but a digital reconstruction using different filtering and even different montages for further diagnostic use. Some digital EEGs even allow the patient to carry a device about the size of a Holter Monitor (or a small tape recorder), but instead of recording ECG signals, it records EEG data for later processing.

Since digital units record the EEG, the technologist no longer has to deal with the mechanical problems of pens (clogging, smearing, and refilling ink reservoirs) and paper (tearing, ensuring the output is folded properly). Digital units provide more channels for more extensive coverage, the ability to transmit the EEG from remote locations to a central reading site for interpretation, and the ability to produce multiple copies of the EEG through local and networked printers.

Physician advantages include the ability to centralize reading sites in large clinical practices and allow urban medical centers to better serve rural and remote hospitals. Since the EEG is digitally recorded, it can be scanned by anomaly-seeking software to highlight probable abnormal areas of the EEG for focused physician review. This allows the physician to serve more patients in the same amount of time.

Managing the Device

In many hospitals, biomedical equipment technicians (BMETs) maintain virtually all medical equipment in-house, but they should consider making an exception for modern EEG equipment. Digital EEGs are built upon very reliable computer platforms and rely heavily on proprietary software to provide results. If for no reason other than to continually use the latest software version available, maintaining a service contract should be seriously considered.

Older analog instruments use fairly straightforward and standard circuitry that experienced electronics technicians should be able to handle in house. Another plus for the BMET is the availability of service literature for the older analog EEGs. One last advantage to the analog instruments, if such literature is not available, is the convenience of having one or more correctly operating channel amplifiers with which to perform comparison troubleshooting. Of course, power supplies are common

an EEG machine utilizing a piezoelectric ink writer he developed and termed "a Crystograph" to produce a permanent paper tracing of the EEG. Offner Electronics began to manufacture electrocardiograph machines in 1938, went on to help support the war effort, and after the war produced EEG machines. In 1956 Offner produced the first transistorized EEG. Improved versions of the Crystograph were used to discover and prove the concept of rapid-eye movement (REM) sleep, a state of brain activity previously unknown to researchers.

The American EEG Society was founded in 1947 and in that same year the first international EEG congress was held. Thus EEG began to become an accepted medical specialty. In 1957, a British physician and engineer named Gray Walter assembled a bank of 22 cathode ray tubes (CRTs), each connected to a pair of electrodes attached to the skull. When the CRTs were arranged in a particular pattern, and photographed from the front in this pattern, they simultaneously showed what rhythm was present in a particular part of the brain. When Walter asked his test subjects to perform certain tasks, the EEG rhythm was altered in different ways, at different times, and in different parts of the brain. Unfortunately, this arrangement was very complex, too cumbersome for widespread use on patients, and never became a commercial success. It did, however, plant the seed of what was to become the standard 10-20 system of EEG electrode placement.

Vacuum tube amplifiers, multiple galvanometers, and paper chart EEG recordings remained the standard means of evaluating brain activity, diagnosing seizure disorders, and assessing post-traumatic brain injury until the advent of the computer and microprocessor. Over the next few years, they were replaced first by solid state (transistorized) amplifiers, then by PC-based EEGs.

When CT arrived on the scene, it provided even better images of brain trauma than flat plate x-rays, but did not indicate brain activity as the EEG did. Very few seizure-related anomalies could be visualized on the CT, but the EEG clearly showed seizure-related events as they occurred. Meanwhile, EEGs continued to prove their value in sleep studies where computer-based units were employed; fully eight hours or more of data could be recorded and electronically examined for events.

to all channel amplifiers and are also of fairly standard design and construction.

Regulations

There are no U.S. Food and Drug Administration (FDA) regulations pertaining specifically to EEGs; however, there are a number of national and international conventions and organizations that promote and self-regulate neurophysiologists and electroencephalographers. Beyond normal electrical leakage tests prescribed by the National Fire Protection Association (NFPA) in NFPA 99, neither they nor the National Electrical Code prescribe special tests on EEG leads as stringent as those for ECGs.

Risk Management Issues

Aside from the normal risks (slips, trips, nosocomial infections, etc.) encountered when one enters a healthcare facility, risk management issues are minimal with most EEGs, but increase in studies using needle electrodes. Normally, EEGs are performed on ambulatory patients who are minimally compromised by external medical and surgical disease processes. When needle electrodes are employed, the patient is at risk for several post-procedure infections. Although the risk still remains low, since EEG technologists must apply a topical antiseptic to the electrode locations, the needle sites must be monitored for any sign of infection after the study.

Troubleshooting

The electronics found in both analog and digital EEG units are remarkably stable, and the units rarely experience a hard failure. Many problems appearing as equipment failure can be traced back to improper electrode application. In many cases, either the skin received inadequate preparation, the electrode did not adhere well to the scalp, or the electrodes were not placed correctly. Inadequate preparation and poor adhesion cause degraded signal strength and quality, as well as increased noise. Even electrode placement that is off by as little as 1 cm can result in misleading waveforms. These problems are often remedied by the EEG technician and are seldom brought to the attention of the biomed. Increased electrical noise in the testing environment, caused by arcing brushes in a centrifuge motor, a thermostat in a hydrocollator in physical therapy, or even a nearby copy machine, can be picked up by an EEG as artifact. One of the most frustrating problems for the BMET is tracking down and eliminating the source of interference.

For More Information

- ECRI Healthcare Product Comparison System for EEG Monitors and Electroencephalographs (www.ecri.org)
- American Board of Clinical Neurophysiology (www.abcn.org)
- International Federation of Clinical Neurophysiology (www.ifcn.info)

Training and Equipment Needed to Service EEGs

If in-house maintenance is involved in EEG maintenance, device-unique training—preferably provided by the manufacturer—is highly desirable. This is especially important for maintainers of digital EEGs since they are so software dependent. In the long run, these instruments are best covered by first-call contracts with a factory-trained in-house technician. This provides the best combination of contained maintenance cost, maintainer on-site (response) time, and equipment downtime. Alternatively, if the facility can tolerate more downtime, maintenance can be handled in-house in the normal manner, relying on experience, good manufacturer literature, telephonic troubleshooting assistance, and the occasional one-time repair contract. Software maintenance could then be a separate issue handled by the EEG clinic personnel.

Future Development of EEGs

Further development of EEG technology is likely on two fronts. The first is related to the pure technology and software of the device itself. That is, advanced circuitry and software will provide the ability to more precisely measure both the frequency and amplitude of EEG signals, thus allowing them to be displayed in different formats, allowing neurologists to compare statistical variables, map brain activity and graph changes, and interface the EEG with other devices. The second front is the correlation of EEG to magnetic resonance imaging (MRI), especially functional MRI, to better understand and map deep brain function. ■

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