2 EEG Instrumentation, Montage, Polarity, and Localization

Krikor Tufenkjian

The Source of EEG

The source of the EEG potentials recorded from the scalp is the excitatory and inhibitory postsynaptic potentials of pyramidal neurons. Each pyramidal neuron has an apical dendrite and multiple basal dendrites (Fig. 2.1). Excitation of the postsynaptic membrane at the apical dendrite leads to depolarization with an intracellular shift of positive ions (Na^+). Subsequently the extracellular space nearby becomes relatively negatively charged. This is coupled by an inhibitory potential at the basal dendrites with a relatively positive charge nearby. At cortical layers III, V, and VI, neurons are aligned in a perpendicular fashion with the cortex. This allows for summation of the small potentials generated by each neuron when they fire in a synchronous fashion (Fig. 2.2).

Cortical neuronal alignment effectively creates an electrical dipole. Whether a positive or negative potential is recorded on the scalp electrode depends on the location of the recording electrode with respect to these dipoles (Fig. 2.3). Epileptiform discharges (spikes or sharp waves) are commonly surface negative. Simultaneous intracranial and scalp recordings confirmed that at least 6 cm^2 of synchronous cortical activation is indeed necessary to detect an individual epileptic spike on scalp electrodes [1].

Recording the EEG

Commonly used electrodes for scalp EEG have a contact surface made of non-depolarizing chloride-treated silver. International standards specify that electrode resistance should be between 100 and 5000 Ω. Properly applied electrodes show a resistance of a few hundred ohms.

A minimum of 21 electrodes are recommended for scalp EEG. The international 10–20 system is commonly used for the placement of these electrodes (Fig. 2.4). With this system, inter-electrode distances average from 4 to 6 cm, as the “10” and “20” mean that the distances between adjacent electrodes are either 10% or 20% of the total nasion-inion or right ear–left ear distance of the skull. In addition, only the superior lateral temporal region is covered. The 10–10 system is more extensive and includes subtemporal electrodes.

The EEG potentials are displayed in channels; each channel represents the difference in potential between two electrodes. By convention, if the difference between two electrodes is negative, then it is represented by an upward deflection, while a downward deflection represents a positive difference.

K. Tufenkjian (✉)
Department of Neurology, Creighton University, 601 N. 30th Street, Suite 5300, Omaha, NE 68131, USA
e-mail: KrikorTufenkjian@Creighton.edu

M.Z. Koubeissi and N.J. Azar (eds.), *Epilepsy Board Review*,
DOI 10.1007/978-1-4939-6774-2_2

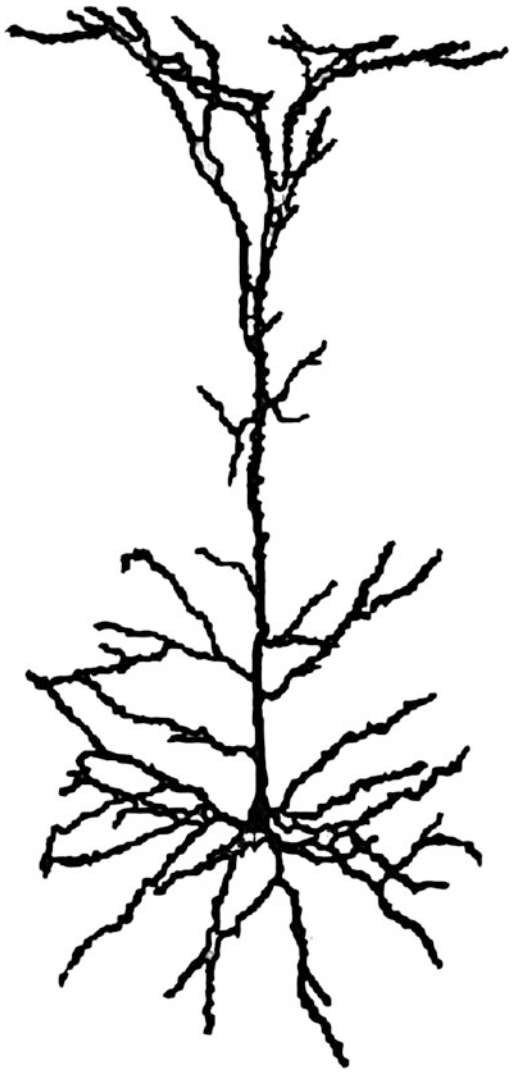


Fig. 2.1 Pyramidal neuron

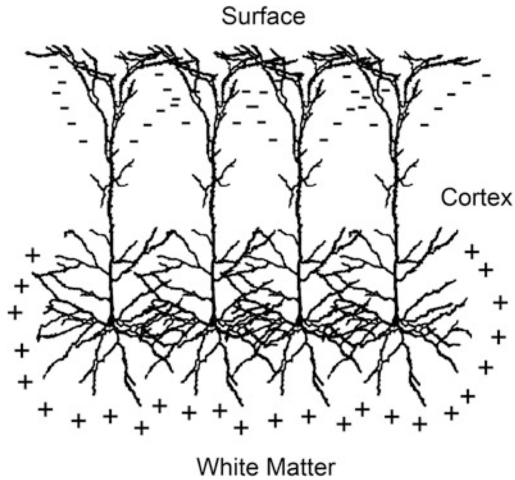


Fig. 2.2 Parallel arrangement of the pyramidal neurons allows for summation of the individual potentials

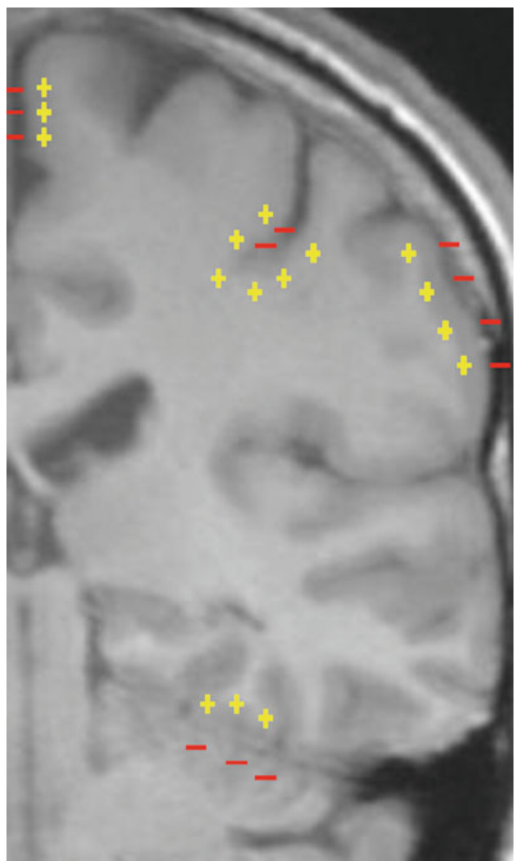


Fig. 2.3 Orientation of the sulci and therefore the dipoles determine what potential is recorded from the scalp

Montages

The 10–20 system employs 21 electrodes. Differences in potentials between these electrodes constitute channels. Combinations of different channels are called montages. The two main montage types are the bipolar and the referential.

In a bipolar montage, channels are arranged in chains that follow an anterior-to-posterior or a transverse arrangement (Figs. 2.5 and 2.6). The chains imply that the second lead in the first

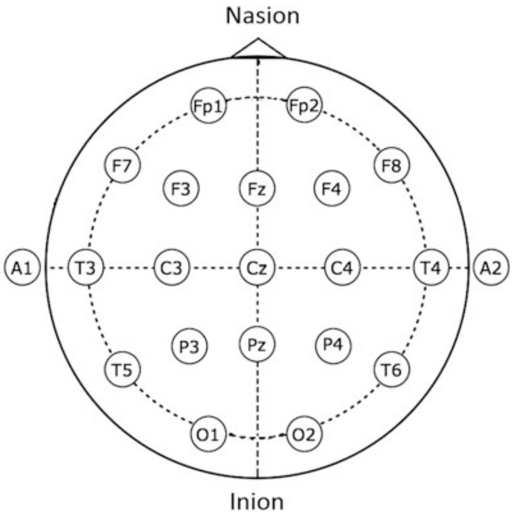


Fig. 2.4 International 10–20 system for electrode placement

channel is the first lead in the second channel, and so forth until the end of the chain. In a referential montage, each channel represents the difference of the potential of any given electrode with a single chosen electrode (Fig. 2.7).

Each configuration has its advantages and disadvantages. In a bipolar montage, external noise can easily be canceled out as it measures the difference in potential between contiguous electrodes, hence amplifying local potentials. Visual detection of differences in local potentials is easier on a bipolar montage particularly when "phase reversal" is seen, signifying a negative event taking place in the region of the electrode that is common to the two channels where polarity changes (Fig. 2.8).

A referential montage on the other hand would be highly susceptible to external noise but it would be able to detect both local (near field) and distant (far field) potentials. The amplitude of the deflection on a referential montage would be a closer representation of the absolute potential at an electrode.

Acquiring, Filtering, and Displaying the EEG Signal

Electrocerebral potentials are in the microvolt range and contaminated by significant ambient electrical noise. In order to record, isolate, and represent an interpretable tracing, certain processing of the signals is required.

Differential amplifiers and common mode rejection: Each electrode records potentials

Fig. 2.5 Bipolar montage with anterior-to-posterior chains (longitudinal bipolar or double-banana montage)

Fig. 2.6 Bipolar montage with transverse chains

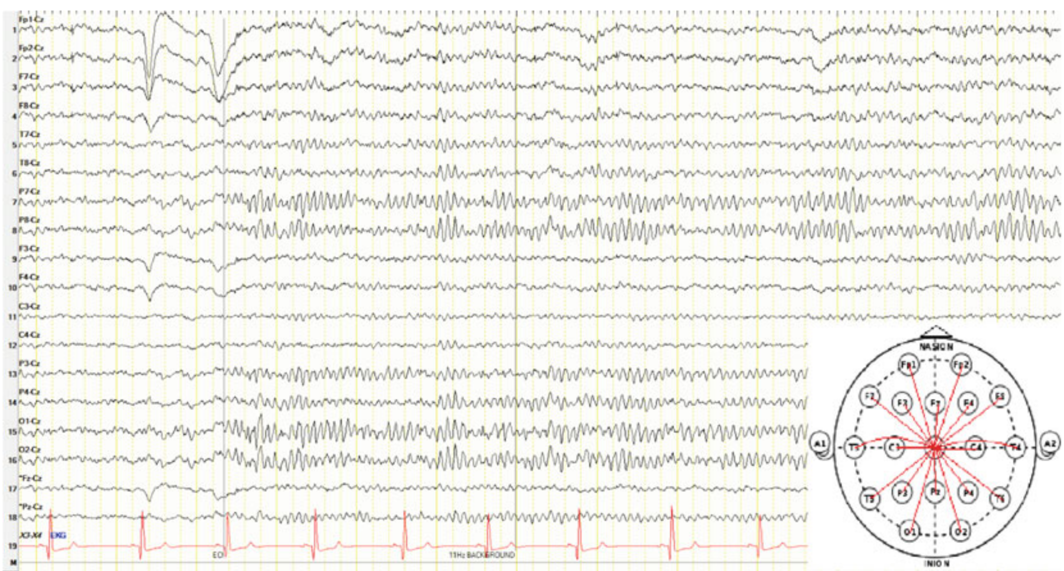


Fig. 2.7 Referential montage using Cz as the common reference

generated by both the brain and the environment. Filtering out the surrounding noise is done with a differential amplifier, which excludes the signals recorded by both electrodes in a channel and amplifies the differences in between. This function is also known as common mode rejection.

Filtering the EEG signal: Conventional EEG interpretation requires the exclusion of very low frequencies using a high-pass (or low frequency) filter, very high frequencies using a low-pass (or high-frequency filter) filter, or a specific band of frequencies using a high-pass filter.

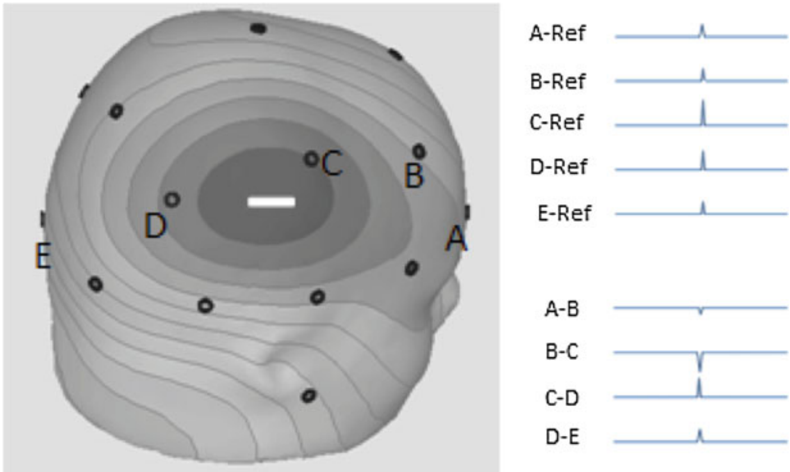


Fig. 2.8 To the *left* is a representation of a negative potential and its field as recorded from the scalp. *Right upper* is a representation of that potential as represented on a referential montage. Note that the amplitude of the spike corresponds to the proximity of the recording electrode to the negative filed maximum. *Right lower* is the same potential as recorded from the same electrodes but arranged in a longitudinal bipolar montage. Each channel represents the difference in potential between two adjacent electrodes in the same chain. The highest negative potential is recorded from contact C; this would lead to B–C to have a positive value (down-going tracing on EEG), while C–D will have a negative value (up-going). This would result in the so-called phase reversal on a bipolar montage, where the common electrode is closest to the maximum negative potential as recorded from the scalp and within that chain

A signal-filtering device is made from a circuit containing a capacitor and a resistor. A capacitor contains two conducting surfaces separated by non-conducting material. When placed as a part of a circuit, opposing charges will accumulate on each plate until each plate is "crowded" and the current stops (Fig. 2.9). If this is a part of a circuit with a direct current (DC), then no further current may pass once the capacitor is saturated. If, however, the circuit has an alternating current (AC) source, then once the polarity of the source is reversed a new current may pass in the circuit until the plates of the capacitor are once more saturated, though with opposite polarity. Increasing the frequency of the AC current above the limit of the saturation of a capacitor will allow for a current to pass continuously through the circuit.

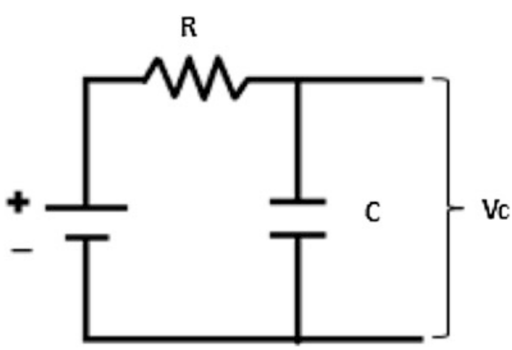


Fig. 2.9 Resistor–capacitor circuit

In the past, EEGs were obtained using analog recorders. Frequency filtering in these machines was done with devices that utilize resistor/capacitor circuits. Such filters are characterized by their time constant, which determines what frequencies will pass through.

The time constant is determined by the amount of resistance and capacitance in the circuit. It is defined as the time needed to discharge the capacitor in the circuit to 36.8% of its initial full charge. Its value is inversely related to the frequency that will pass through the filter. For example, using a filter with a higher time constant will allow the lower frequencies to pass through. With the more recent digital machines, the EEG signal from each electrode is digitized first and frequency filtering is done using software processing.

A low-pass filter (also known as high-frequency filter) allows frequencies lower than a certain value to pass. The low-pass filter is set to 70 Hz in the usual scalp EEG reading settings. Changing this to 35 Hz will allow only frequencies lower than 35 Hz to pass through. This will filter out a lot of the faster myogenic

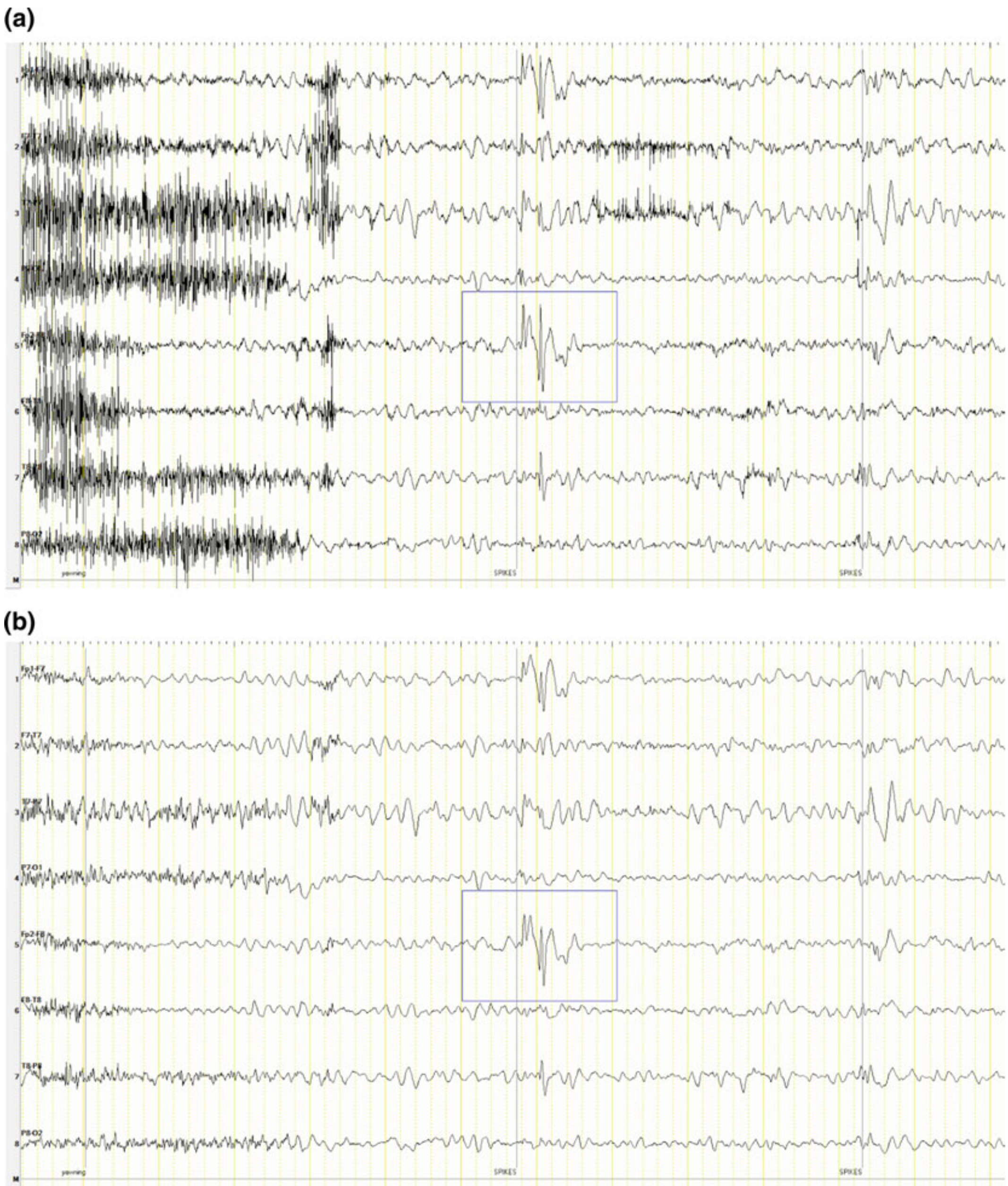


Fig. 2.10 **a** High-frequency filter set at 70 Hz. Note the abundant myogenic artifact in the first three seconds of the recording. A high-amplitude spike is also noted. **b** The high-frequency filter is changed to 15 Hz. Most of the myogenic artifacts are removed. There is a concurrent reduction in the amplitude of the spike

Fig. 2.11 **a** EEG with the low-frequency filter set to 1 Hz. **b** Same EEG with the low-frequency filter changed to 2 Hz. Note the reduction of the amplitude of the slow activity. **c** Low-frequency filter changed to 5 Hz. Only frequencies above 5 Hz pass. Note that there has been no effect on the fast frequency myogenic artifact

artifact and will also slightly reduce the *amplitude* of signals with a steep rise time, such as epileptiform spikes and sharp waves (Fig. 2.10).

A high-pass filter (also known as low-frequency filter) allows higher frequencies to pass, usually set to about 1 Hz (corresponds to a time constant of about 0.16 s) for routine scalp

(c)

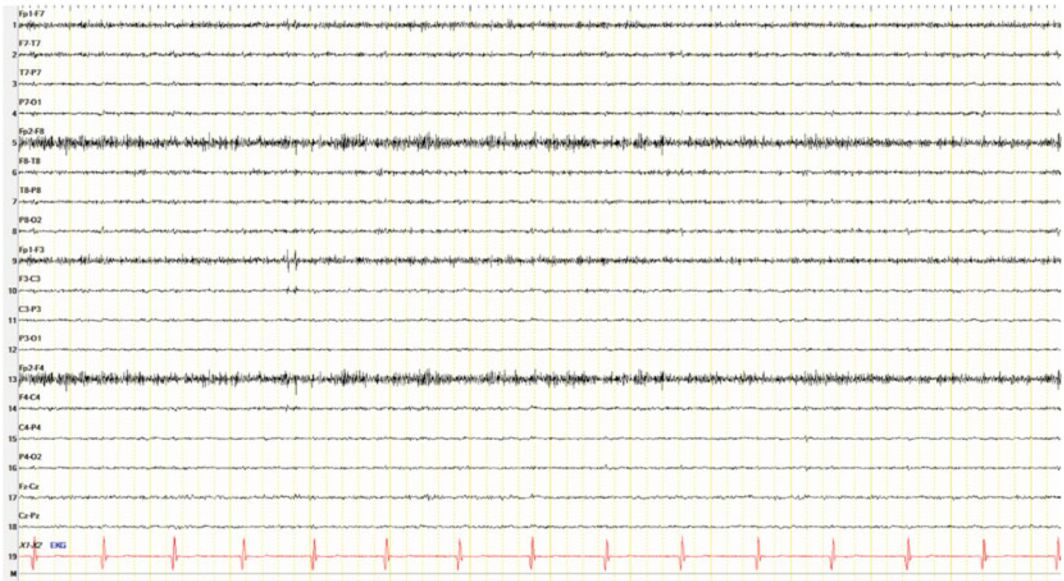


Fig. 2.11 (continued)

EEG reading. Raising this to 2 Hz, for example, will filter out some of the lower frequencies giving a more flat look to the EEG. This will also reduce the *amplitude* of the slower waveforms (Fig. 2.11).

A band pass or a band stop filter is also used. Commonly used such filters are notch filters, which stop a very narrow band around the 50 or 60 Hz noise generated from alternating current sources such as city power lines.

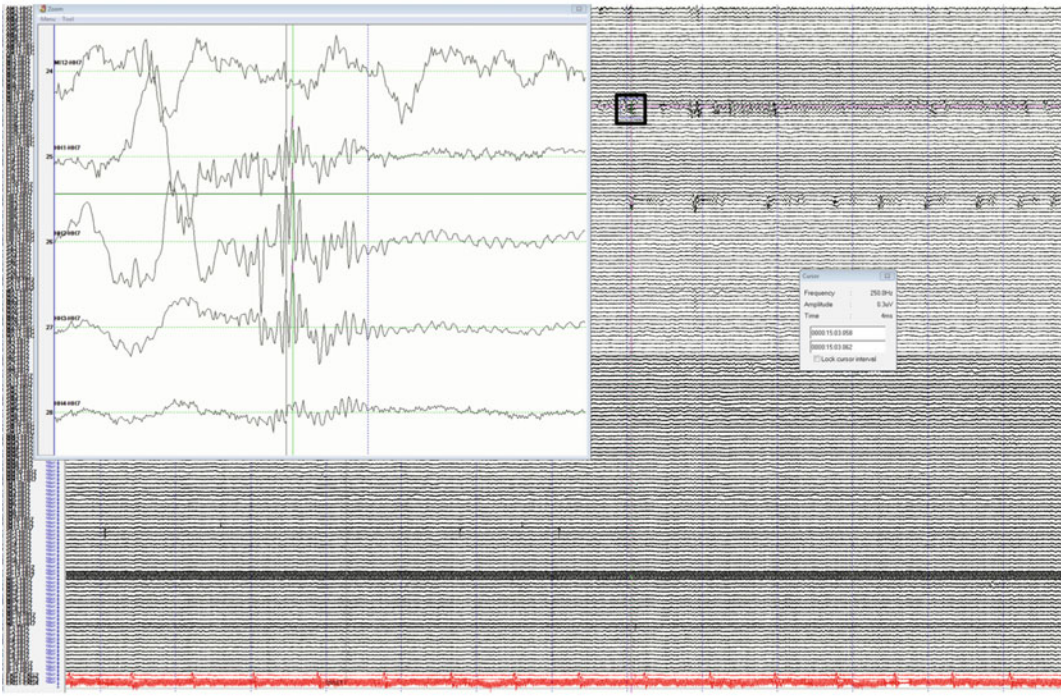
Filtering in intracranial recording: Subdural and depth electrodes allow the recording of frequencies that fall outside the usual range of the scalp EEG. These include high frequencies ranging from 80 to 500 Hz known as high-frequency oscillations (HFOs) and very slow frequencies appearing as slow baseline shifts. Specialized systems are needed to acquire these activities. High-pass and low-pass filters are manipulated to facilitate viewing the required range (Fig. 2.12).

Digital EEG Acquisition, Processing, and Display

In digital EEG machines, an additional electrode used as the machine reference is also needed. The signal from each electrode is recorded as the difference in potential between that electrode and the machine reference, which is then stored as digital data (bits). The signal from each channel is recorded and stored at regular intervals. This is reflected in the sampling rate of the EEG machine. Most current commercially available machines have a sampling rate that ranges between 256 and 1024 Hz. Higher sampling rates allow more accurate recording of brain signals and smoother appearance of the waveforms, but require higher data storage capacity.

Sampling rates determine what EEG frequencies can accurately be represented. If the

(a)



(b)

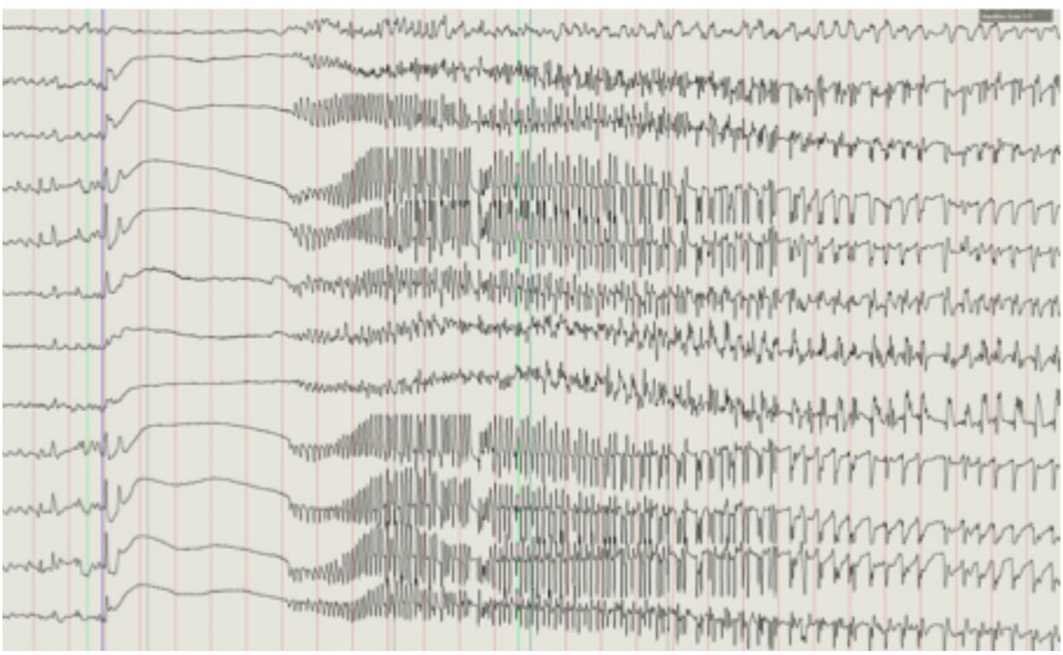


Fig. 2.12 **a** High-frequency oscillations at 250 Hz—the onset represents magnification of the boxed area. **b** Slow baseline shift at the beginning of a seizure recorded with grid electrodes

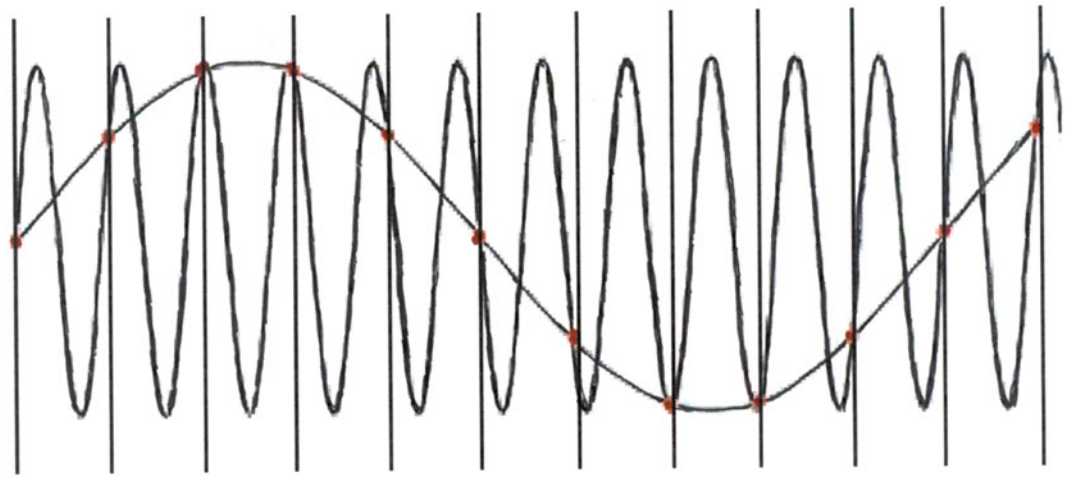


Fig. 2.13 High-frequency signal is sampled at a rate below the Nyquist rate. The resulting waveform remarkably misrepresents the original waveform, resulting in aliasing

sampling rate falls below a certain point, then the resulting waveform would no longer represent the original one. This erroneous representation is called aliasing. The Nyquist sampling theorem determines that the sampling rate should be at least twice the frequency of the original signal to avoid aliasing, or distortion of waveforms. The ACNS guidelines recommend a sampling rate at 3 times or more the frequency of the original signal (Fig. 2.13). A filter is used on the signal prior to digitizing to exclude all frequencies above a certain frequency determined by the Nyquist theorem (anti-aliasing filter).

Another important aspect is the monitor display. Most LCD monitors can display 1920 dots (pixels) horizontally. The sampling rate on the EEG machine may actually exceed the capacity of the monitor display. Low-definition monitors will give a "grainy" tracing, and this could be a particular concern with high-frequency activity (Fig. 2.14).

EEG and Patient Safety

Proper grounding during EEG is an important patient safety issue. The EEG machine should be connected to a three-pronged hospital grade outlet. The third prong ensures shunting of excess current from the EEG machine to the earth ground. All electrical devices in the EEG room should be connected to a common earth ground.

A single ground electrode is placed anywhere on the patient and connects to the appropriate jack in the input jackbox of the EEG machine. The patient should not be connected to the earth ground. In ICU setting, a patient may be connected to another electrical device with a ground connection. Double grounding should be avoided in these situations [2].

EEG Artifacts

Artifacts will be discussed in Chap. 3, but in the remaining part of this chapter we will provide some EEG examples with the purpose of further training of the reader's artifact pattern recognition. Artifacts may arise from the electrical environment as well as bioelectrical sources originating from the patient (Figs. 2.15, 2.16, 2.17, 2.18, 2.19, 2.20, 2.21, 2.22, 2.23 and 2.24).

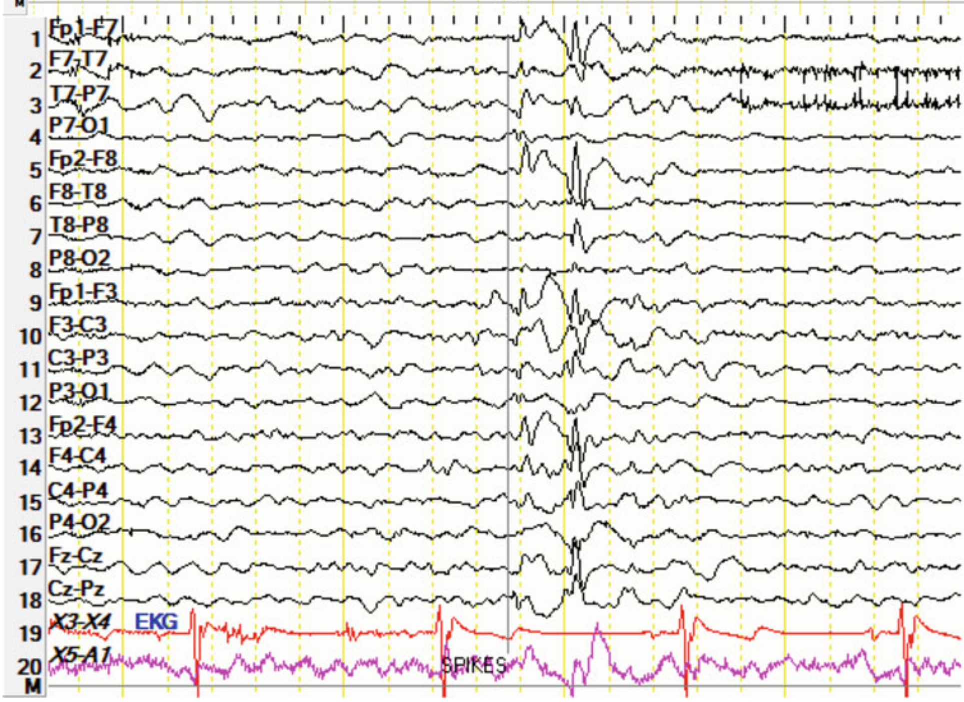


Fig. 2.14 Effect of reducing the display resolution from 1920 × by 1080 pixels (*top record*) to 1280 × by 1024 pixels (*bottom record*)

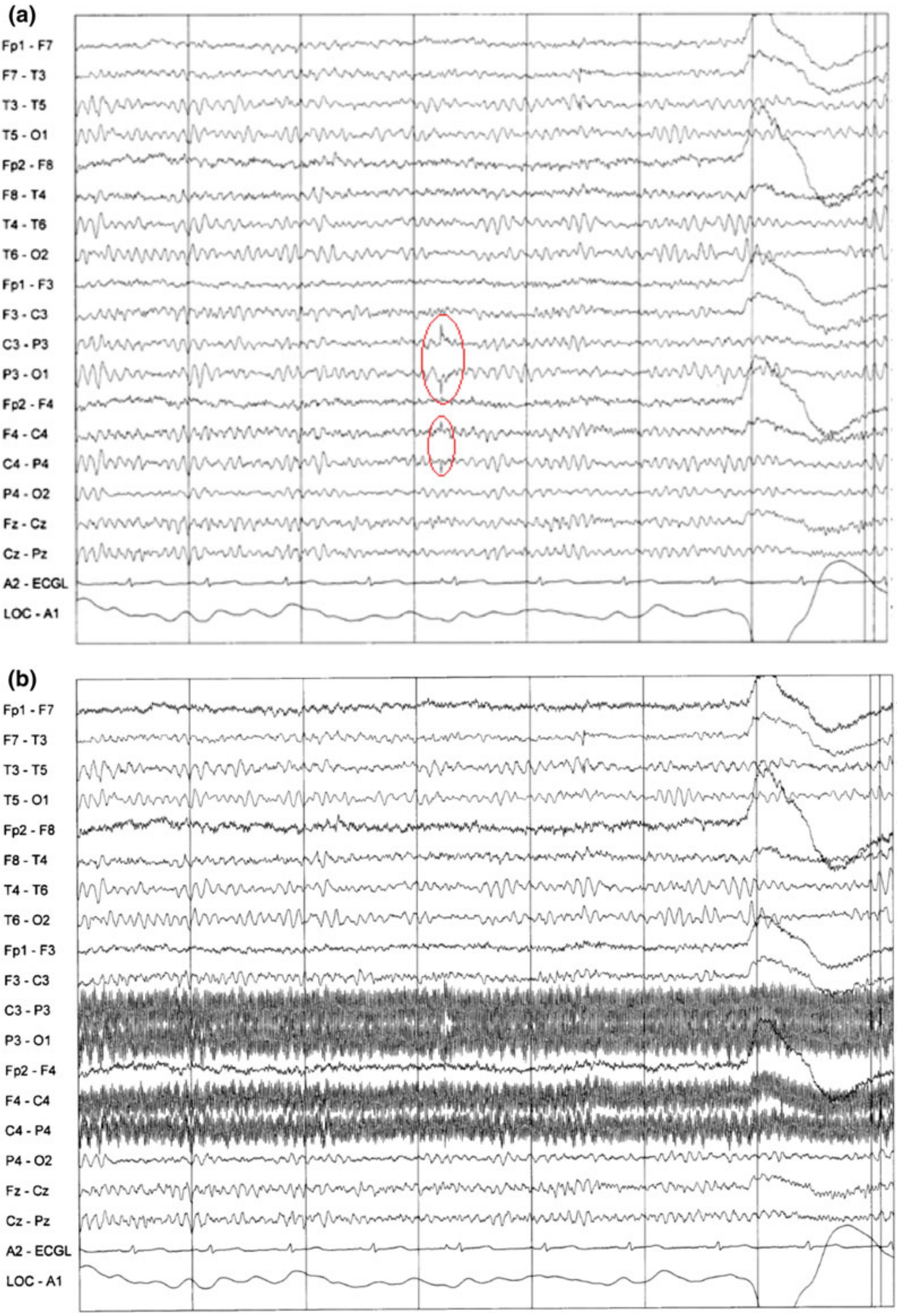


Fig. 2.15 **a** Electrode pop artifact. Poor contact at the P3 and C4 electrodes resulted in an isolated potential at these two contacts (60-Hz notch filter on). **b** The notch filter is removed and the 60-Hz artifact is now seen at the P3 and C4 electrodes, which have higher impedance due to poor contact with the scalp. The difference in impedance compared with the other electrodes interferes with the ability of the differential amplifier to reject the 60 cycle noise which actually gets amplified [3]

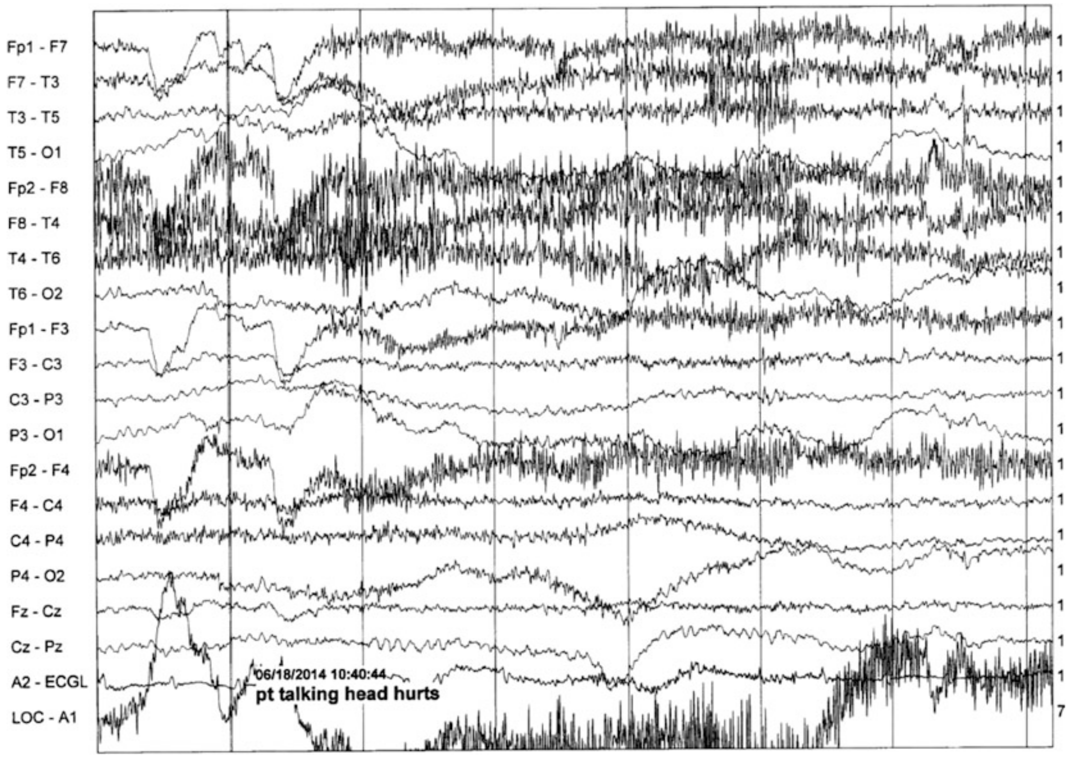


Fig. 2.16 Movement artifact. The disorganized EEG potentials do not have the typical field seen in brain-generated waveforms

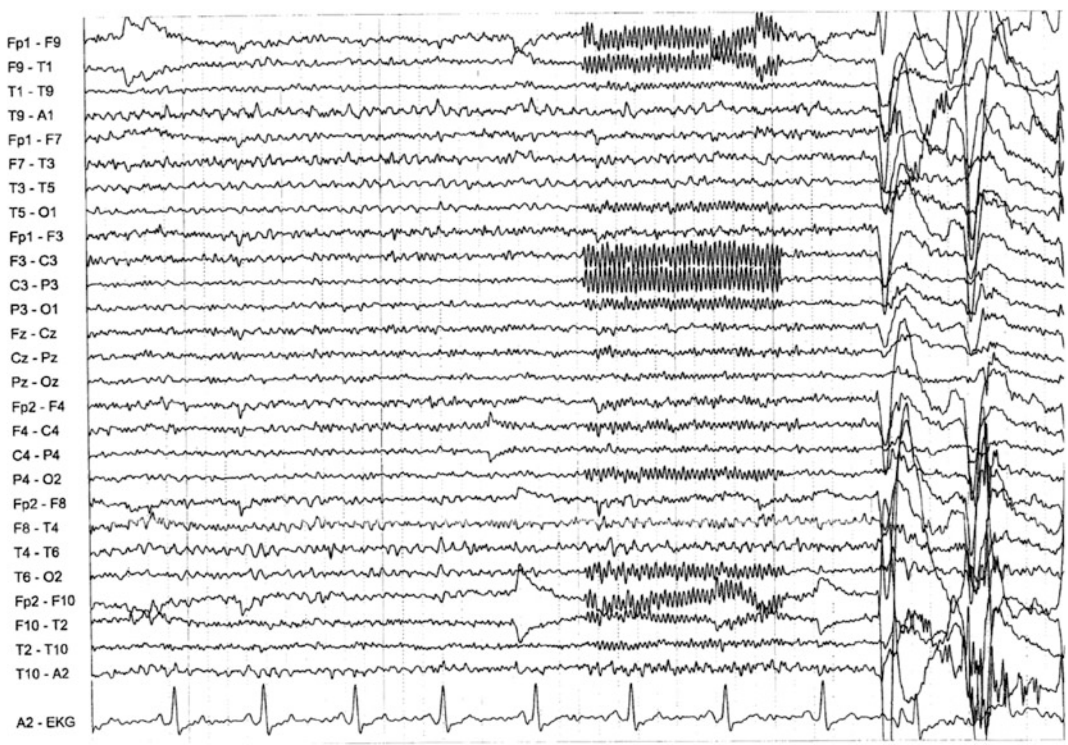


Fig. 2.17 Phone ringing artifact

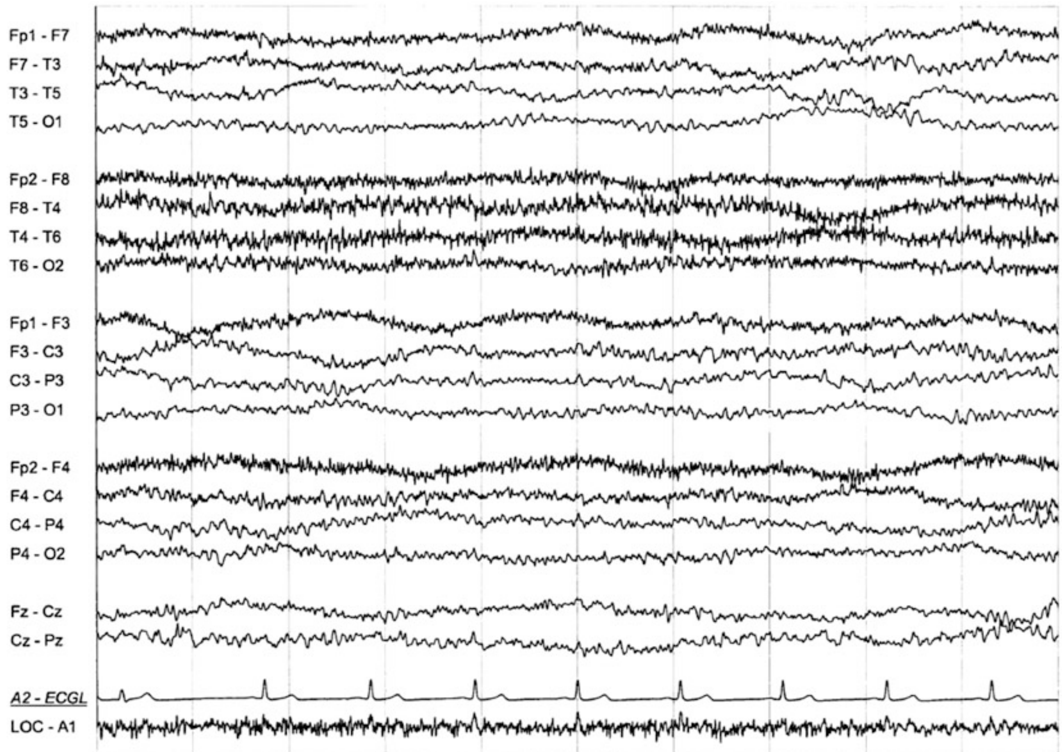


Fig. 2.18 Sweat artifact. Slow undulation (less than 1 Hz) of the EEG tracing is seen in a diaphoretic patient

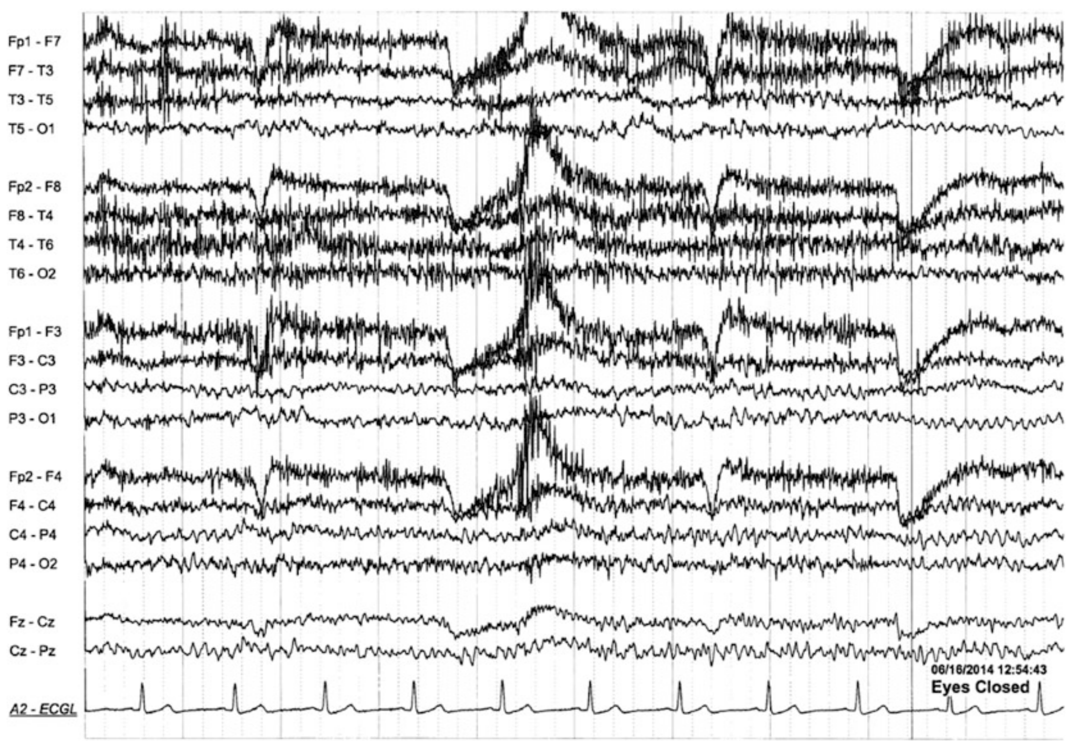


Fig. 2.19 Myogenic artifact. These high-frequency activities are generated by the frontalis and temporalis muscles; therefore, these are seen maximally in the anterior midline and temporal chains

Fig. 2.20 Rhythmic myogenic artifact is seen during chewing

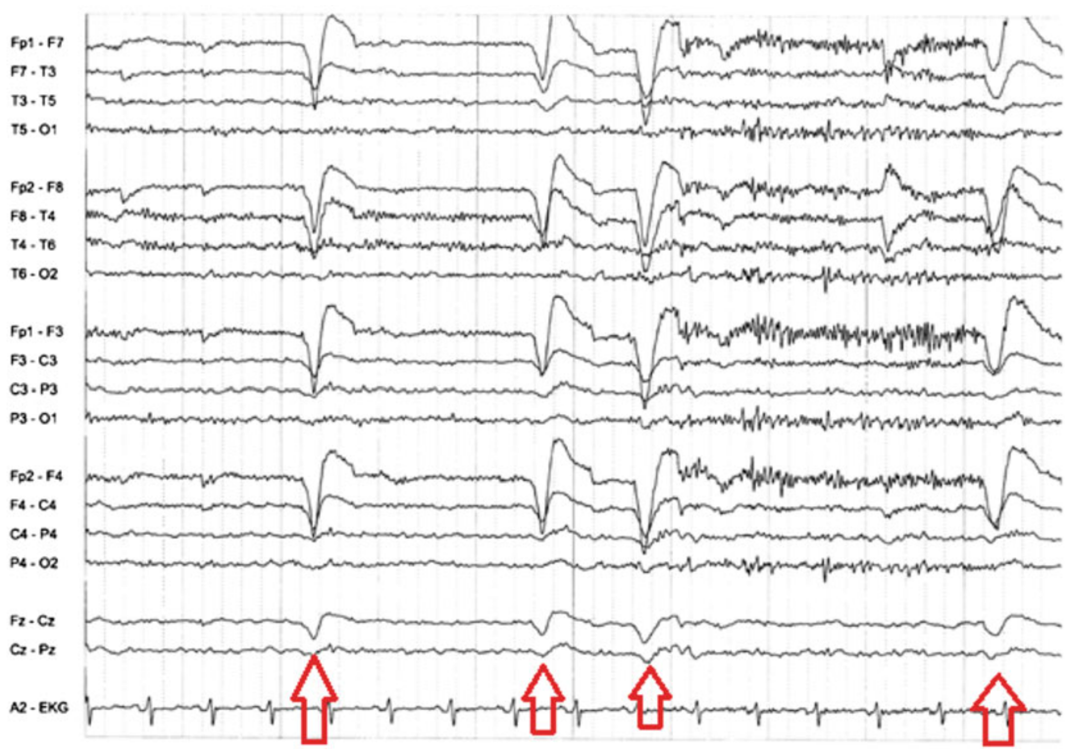


Fig. 2.21 Blink artifact. The cornea has a slightly positive potential compared to the retina. During a blink, the eyelid makes contact with cornea allowing for that positive potential to be recorded from the anterior frontal electrodes. This is represented as a *down-going* waveform, which falls in amplitude exponentially from the front to the back

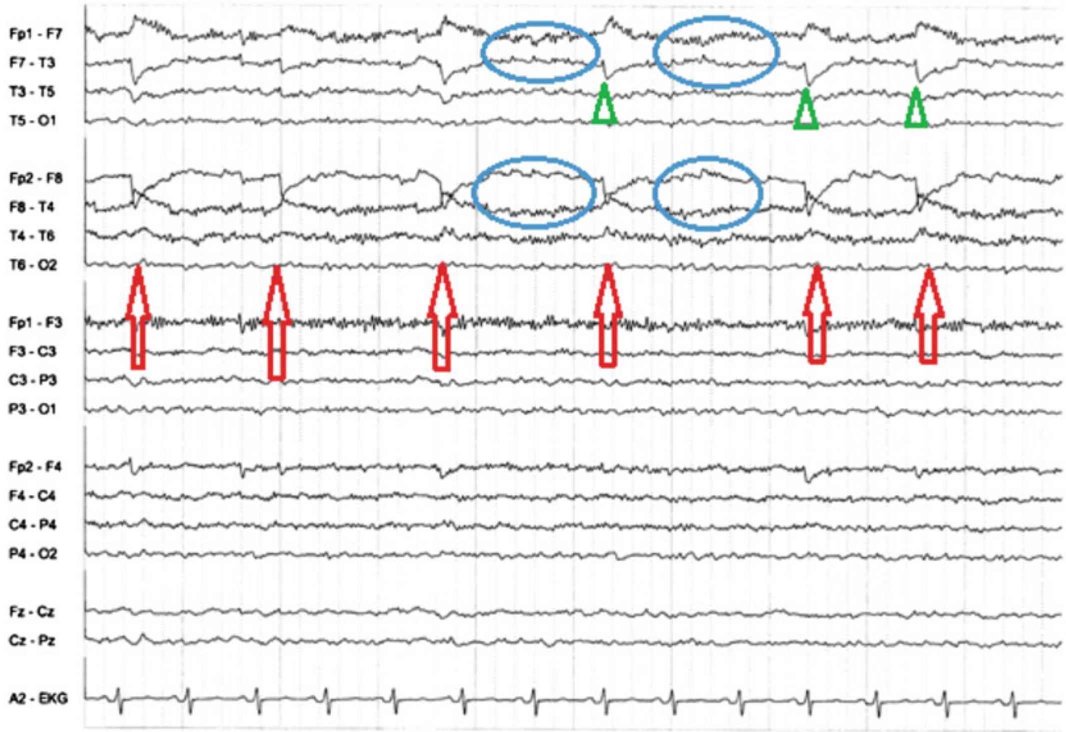


Fig. 2.22 Lateral eye movement artifact and lateral rectus spike. In this example, the patient is reading a book, the rapid saccade to the left brings the positive potential of the cornea closer to the left frontal channels producing a positive phase reversal at F7 and away from the right with a resulting negative phase reversal at F8 (*arrows*). This is followed by a slow rightward movement of the eyes with the potentials slowly shifting to the opposite direction (*ovals*). A small spike preceding the saccade is noted which is generated from the left lateral rectus muscle (*arrowhead*)

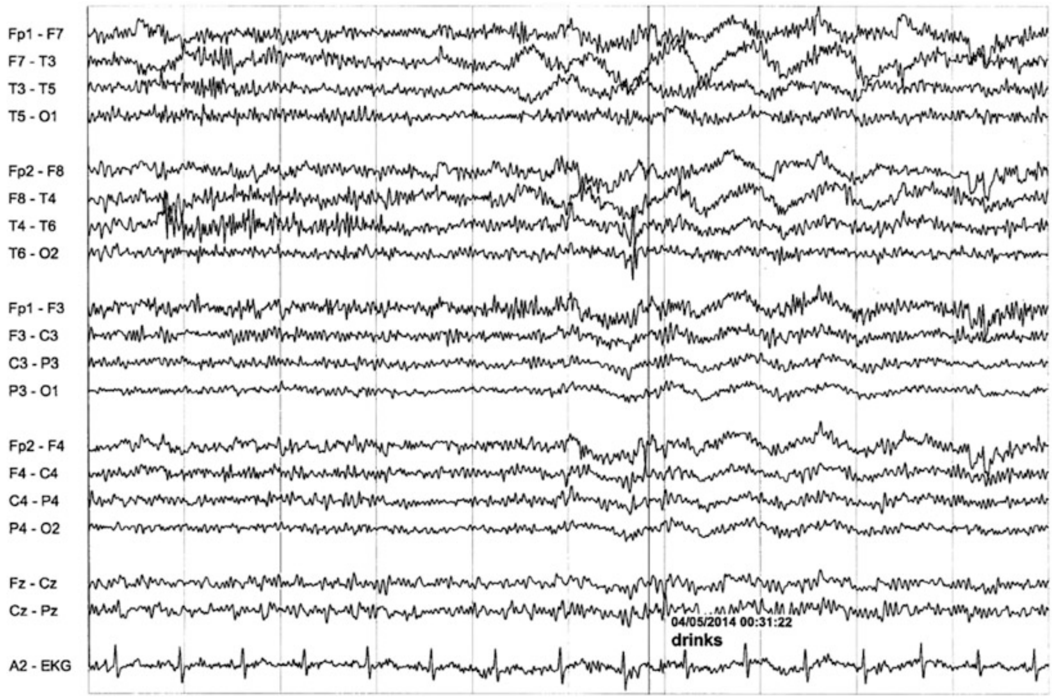


Fig. 2.23 Glossokinetic artifact. The difference in potential between the tip and the base of the tongue produces diffuse, slow waves with a frontal maximum

Fig. 2.24 ECG artifact. Small sharp transient can be seen time locked to the ECG QRS potentials. The lower tracing shows this ECG contamination during an EEG performed for the evaluation of electrocerebral inactivity

References

1. Ebersole JS. Current practice of clinical encephalography. 4th ed. Philadelphia: Wolters Kluwer Health; 2014.
2. American Clinical Neurophysiology Society. *Minimum technical requirements for performing clinical EEG*. 2006.
3. Aminoff MJ. *Aminoff's electrodiagnosis in clinical neurology*. 6th ed. Elsevier Saunders; 2012.

Springer
http://www.springer.com/978-1-4939-6772-8

Epilepsy Board Review
A Comprehensive Guide
Koubeissi, M.Z.; Azar, N.J. (Eds.)
2017, XII, 375 p. 159 illus., 89 illus. in color., Softcover
ISBN: 978-1-4939-6772-8