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The Identification of Rhythmic EEG Artifacts by Power-spectrum Analysis

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The identification and elimination of artifact from the electroencephalogram (EEG) are especially important when it is used in the operating room. Not only do patient movement, electrocautery, and electromechanical devices combine to produce an environment in which the EEG may be difficult or impossible to record, but incorrect decisions regarding the adequacy of cerebral perfusion could result if artifact were incorrectly interpreted as EEG. Fortunately, movement and electrical artifact can usually be identified by their characteristic waveforms, and thus are rarely confused with cerebral activity. We would like to report two cases in which low-frequency, rhythmic EEG artifacts appeared to be valid EEGs and in which power-spectrum analysis was indispensable in identifying the artifacts.

Power-spectrum analysis is a mathematical technique for quantitating the amplitudes of component frequencies during segments (epochs) of the EEG.[1] By analyzing the patterns of activity in several epochs, it is possible to identify changes in the analyzed EEG more readily than is possible in the unprocessed EEG tracing. The value of this technique in identifying intraoperative cerebral ischemia is well documented,[2,3] and it has also been used to measure changes in anesthetic depth.[4,5] Recently, Fleming and Smith[6] have developed a technique that displays the three-dimensional results of this analysis—time, frequency and power—in a convenient two-dimensional form. With this technique, the EEG activity for an epoch is shown as a sequence of dots whose size (or shade of grey) corresponds to the intensity of the frequency components in the EEG. This display (the DSA, or Density-modulated Spectral Array) is considerably more legible than the Compressed Spectral Array, an earlier graphic display technique, and has other features that make it useful for intraoperative displays of the EEG power spectrum.[7]

REPORT OF TWO CASES

Patient 1. A 55-year-old white man without a history of neurologic disease received balanced anesthesia for coronary revascularization. Just before cardiopulmonary bypass, the EEG (fig. 1*A*) showed low-amplitude activity between 10 and 14 Hz, with some very low-frequency activity (0–2 Hz), which may have represented artifact. Following the beginning of cardiopulmonary bypass, the EEG amplitude increased (fig. 1*B*). Power-spectrum analysis (fig. 1, *top*) demonstrated the presence of high-amplitude activity at 10 Hz and moderate-amplitude activity at 3.5 and 14 Hz after bypass had begun. This pattern persisted during bypass and disappeared when normal circulation was reestablished.

Patient 2. Prior to the beginning of extracorporeal perfusion for aortic-valve replacement, a 64-year-old white woman had had a normal EEG during halothane–N_2O–O_2 anesthesia (fig. 2*A*). Gradual initiation of bypass (fig. 2*B* and *C*), resulted in two bands of activity whose frequencies increased synchronously. When full pump flow was reached (fig. 2*D*), bands of activity at 3.5, 7 and 10 Hz were clearly identifiable on the DSA. This pattern continued until termination of bypass, disappeared during a 10-minute period of normal circulation, and then reappeared when bypass was reinstituted.

DISCUSSION

In previously reported studies of the EEG power spectrum during extracorporeal circulation, the presence of a new, stable EEG pattern following the initiation of bypass was not described.[2] While previously unrecognized effects of bypass on the EEG could have produced these patterns, the power-spectrum analysis of the waveforms emphasized several aspects of the patterns that were most uncharacteristic of the normal EEG. First, harmonics (*i.e.*, multiples of a fundamental frequency) are clearly demonstrated by the DSA displays in both cases,

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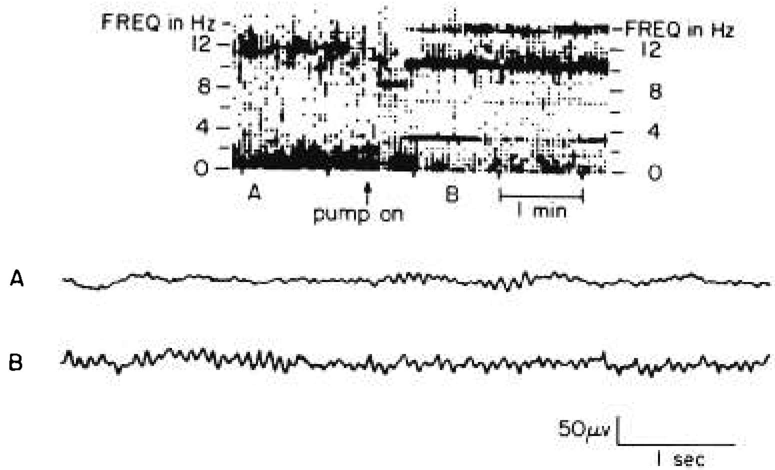

FIG. 1. Two samples of the unprocessed EEG, recorded before (*A*) and after (*B*) establishment of cardiopulmonary bypass, below the density-modulated display (DSA) of the power spectrum of the same EEG. The change in the unprocessed EEG from *A* to *B* appears to be largely an increase in amplitude. Only on the DSA can the presence of continuous 3.5-, 10- and 14-Hz activity be easily appreciated. The continuous and very sharply defined nature of this activity contrasts with the usual picture of a band of EEG activity, as exemplified by the 10–14-Hz activity in the DSA at *A*.

and such harmonics are not seen in the normal EEG. In addition, the very narrow, constant width of each band of activity during bypass differs markedly from the more diffuse and variable pattern of normal EEG activity, as exemplified by the 10–14-Hz band at *A* in the DSA of figure 1. Finally, the power-spectrum

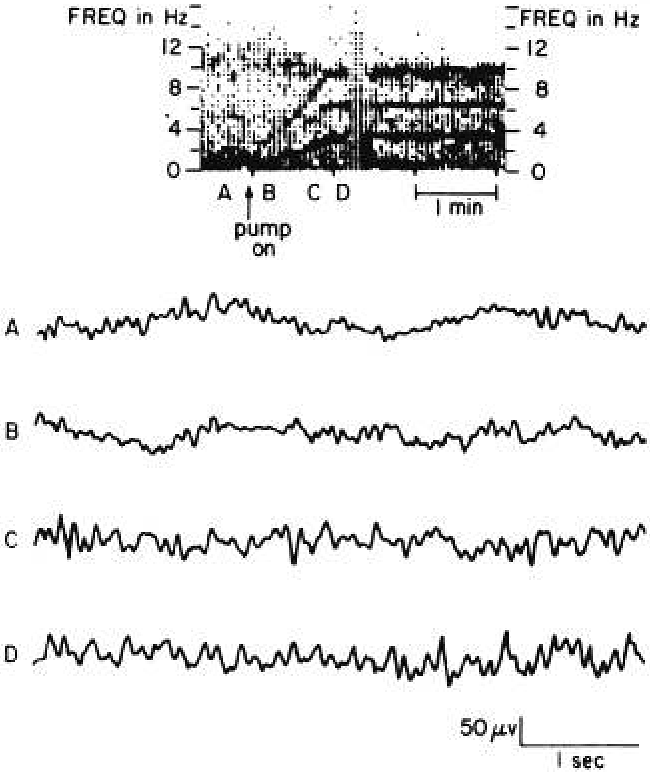

FIG. 2. Four samples of the EEG, recorded before cardiopulmonary bypass (*A*), during partial bypass (*B*, *C*), and during full bypass (*D*), below the DSA of the power spectrum of the same EEG. The emergence of two new bands of activity when extracorporeal circulation begins (pump on) and their continuity with the 3.5- and 10-Hz activity during full bypass cannot even be imagined from the unprocessed EEG tracings. Also, the 3.5-, 7- and 10-Hz artifact present at *D* cannot be appreciated in the unprocessed EEG even though it is clearly evident in the DSA.

analysis demonstrated that changes in the pattern correlated with the increasing speed of the bypass equipment (fig. 2), further suggesting an artifactual cause of these patterns.

Accordingly, we recorded electrical activity during cardiopulmonary bypass from three pairs of electrodes: one pair in saline solution (no input possible); one pair connected to the patient but without electrode paste (high impedance—more than 15 kOhms); and, just adjacent to these, one pair properly connected to the patient (low impedance—2 kOhms). The electrode in saline solution showed no activity on or off bypass, demonstrating that the EEG amplifiers were not being affected by stray magnetic fields from the bypass equipment. Prior to bypass, both low- and high-impedance electrodes showed normal EEG activity (fig. 3*A*); however, with the pump on (fig. 3*B*), the high-impedance electrode showed prominent artifact similar to that seen during the first case. Following bypass, the EEG pattern in the high-impedance lead reverted to the pre-bypass pattern.

These observations are easily explained by the effects of high electrode impedance on the sensitive amplifier system used to record the EEG. These amplifiers measure the voltage between two points (active electrodes) by measuring each with respect to a third (common electrode) and subtracting the results. When electrode impedances are low, electrical interference is equal in amplitude in both of these measurements and cancels out in the subtraction process; thus, the interference is removed and only the potential occurring between the two active electrodes is amplified. However, when electrode impedances are high (especially when they are high and unequal, as is usually the case), interaction between the electrode impedance and the amplifier electronics causes the electrical interference to differ in amplitude on the signal recorded between each active electrode and the common one. Thus, the interference will

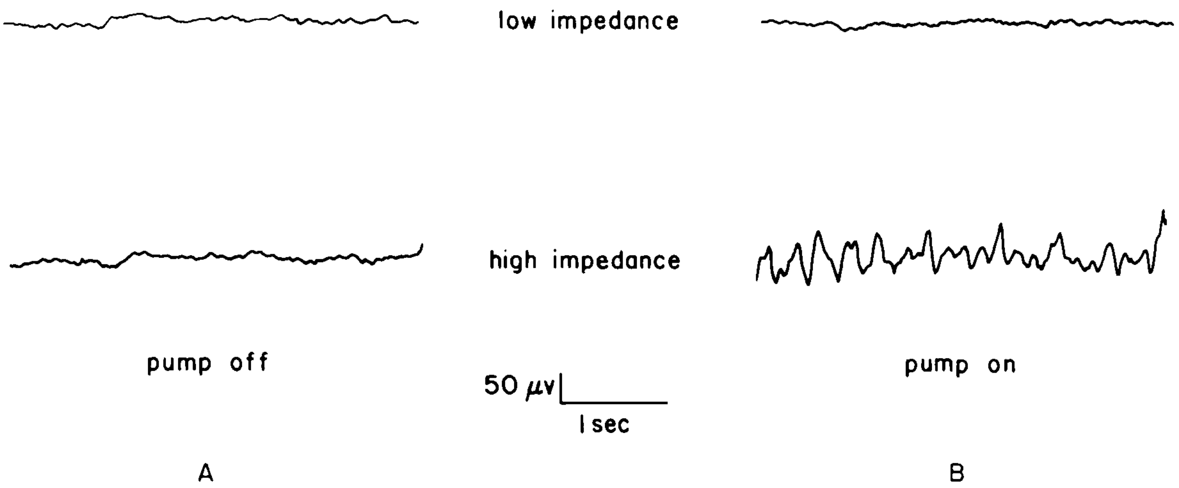

FIG. 3. EEG recordings from side-by-side electrode pairs, one of which had a normal, low impedance and one of which had a high impedance, before and after the cardiopulmonary bypass pump was turned on. Although the two tracings obtained when the pump was off are similar, only the low-impedance electrode pair continued to provide a good EEG recording when the bypass pump was running. The high-impedance electrode records artifact similar to that shown in figure *2D*.

not cancel out when the two signals are subtracted, and the residual appears in the output as artifact. In this way, the electrical interference generated by the bypass equipment was recorded as artifact by the high-impedance electrodes but was eliminated by the properly applied, low-impedance electrodes.

Because the artifact was composed of frequencies and voltages in the normal EEG range, it was not clearly identifiable as artifact in the standard EEG tracings, even in retrospect. It obscured the true EEG and could have been interpreted as normal EEG activity when cerebral hypoxia was present; however, there is no evidence that such an error occurred in either of these cases. Power-spectrum analysis cannot eliminate rhythmic artifact in the physiologic frequency range; however, maintaining an awareness of the unusual nature of this artifact does assist in its identification. It is still necessary to check electrode impedances frequently, and to replace high-impedance electrodes so that optimal EEG recordings can be obtained.

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