Density-modulated t's array, a new technique of processed electroencephalogram, for monitoring the effects of midazolam and nitrous oxide during spinal anesthesia

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Abstract: We have investigated the utility of a new electroencephalogram (EEG) processing system, density-modulated t's array (DTA), which we have installed in a laptop personal computer together with density-modulated spectral array (DSA) for clinical monitoring. Ten patients scheduled for orthopedic operations on the lower extremities were anesthetized with 0.5% bupivacaine intrathecally, 50% nitrous oxide in oxygen by mask, and midazolam at a dose of 0.1 mg/kg intravenously. Immediately following the administration of the drugs, the power at the frequencies between 15 and 20 Hz increased. However, the power at these higher frequencies disappeared gradually and the power in the delta band and the smaller one in the alpha band became predominant. This pattern of dominant-band shift on the DSA and DTA was observed in all the patients. In three of the patients, the sedation level remained stable as judged by the absence of body movement, quiet, regular breathing and stable hemodynamics as well as steady EEG frequency distribution throughout the operations. They awoke from anesthesia rapidly on withdrawal of nitrous oxide, with return of the power at the higher frequencies. In the other seven patients, the power at the higher frequencies suddenly reappeared on the DSA and DTA during operation and slight movements of the head and upper limbs were observed with rises in blood pressure and heart rate. In three of these seven patients, the EEG change notably preceded the physiological activities by a few minutes. On the DTA, the occurrence of any significant clinical phenomenon was displayed in a color representing a $t$ value greater than ±3. The DTA, testing power changes in the EEG at each 1-Hz interval for significant difference, permits the visual and quantitative assessment of EEG changes.

Key words: EEG—Processed EEG—DSA—DTA—Brain monitoring—Sedation

Introduction

The usefulness of the electroencephalogram (EEG) as a tool for intraoperative monitoring of brain function has been explored since the 1950s. Although the definitive advantages are the ease with which EEG can be obtained and the non-invasiveness of the procedure, the complexity of the information contained in the raw EEG defies meaningful interpretation. Recent technical developments in processed EEG, such as frequency analysis by fast Fourier transformation (FFT) and compressed spectral array (CSA) display, have made it more amenable for clinical use.

We have achieved further refinements in processing and display techniques in density-modulated spectral array (DSA) and density-modulated t's array (DTA), which may incorporate such parameters as spectral edge frequency and mean frequency. We have applied these techniques in a clinical setting and sought to establish a method of monitoring brain function during anesthesia and possibly to facilitate an early detection of brain complications.

Methods

Instrumentation

EEGs were recorded monopolarly with the disk electrodes positioned at F3 and F4 according to the international 10–20 electrode system. The derived EEG, as shown in the block diagram in Fig. 1, was fed to an amplifier (MEG-2100, Nihon Kohden, Tokyo, Japan) for amplification and filtering (0.5–30 Hz), and inputted via a handmade main amplifier ($\pm 5$ V) and an analog-to-digital converter (CANOPUS, Analog-Pro II, Kobe, Japan) into a lap-top personal computer [PC-9801NC (CPU: 386SX, 20 MHz), NEC, Tokyo, Japan] interfaced with a digital signal processor (Flash 16, CANO-
PUS, Kobe, Japan) housed in an interface extension unit (NOTE-PAC H-2A, Contec, Tokyo, Japan).

The FFT technique used for frequency analysis in DSA is described below. Because the sampling interval was set at 10 ms, the maximum frequency was 50 Hz, but the analysis was displayed up to 25 Hz on the screen. Also, as the sample number was 512, one epoch (data length) was 5.12 s, and the frequency resolution was 0.2 Hz. A longer epoch may be undesirable because of increased spectrum errors which are large enough in FFT technique. A spectrum of longer durations through any number (n) of 5.12-s epochs was obtained by smoothing out using ensemble averaging without increasing the errors. In other words, each line in DSA is the mean spectrum for n × 5.12 s. The program was written in C language.

Our DSA display converts the magnitude of power to 8 colors, i.e., white, red, pink, yellow, green, light blue, blue, and black in decreasing sequence of power, and may be regarded as a flattened image of CSA. The colors are not equally assigned in proportion to the magnitudes of power but more preferentially to the smaller magnitudes so that minute changes in lower power can change the color readily.

Comparing two power spectra obtained by frequency analysis, it is possible to obtain the t profile [1] by Student's paired t-test to see whether there is a significant difference between the pair of powers in the same 1-Hz interval consisting of five spectral data. One of the 12 colors in Fig. 2 is assigned to each t value and these colored 1-Hz segments make up a t profile. The latter in turn is drawn on top of the other sequentially to compose our DTA (Fig. 3). In other words, if the difference between a pair of spectral data is designated as $d_i$ (i = 1, 2, ..., N), the mean of the $d_i$, i.e., $\bar{d}$, is given as:

$$\bar{d} = \frac{1}{N} \sum_{i=1}^{N} d_i$$

and the unbiased variance of $d_i$, i.e., $V$, as:

$$V = \frac{1}{(N - 1)} \sum_{i=1}^{N} (d_i - \bar{d})^2$$

and $t$ is calculated as

$$t = \frac{\bar{d}}{SQR(V/N)}.$$

The $t$ value is displayed with color for each 1-Hz interval. Furthermore, to improve the accuracy of the technique, spectral data in 1-Hz intervals on both sides of the target interval were added together to make up 15 for $N$ instead of 5. Three kinds of DTA can be made.