INDICES OF CORRELATION BETWEEN POTENTIALS OF SPATIALLY DISTANT CORTICAL AREAS DURING DEVELOPMENT OF HYPOXIA IN ANESTHETIZED ANIMALS

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Statistical analysis of the electroencephalogram (EEG) using characteristics of reciprocal correlation functions of electrograms of the frontal and occipital cortex showed that it is possible to identify Δ-waves under deep anesthesia and waves with similar amplitude and frequency characteristics associated with the development of cerebral hypoxia during anesthesia. It is suggested that the fronto-occipital coefficient of reciprocal correlation and the attenuation factor of the correlation function be chosen as informative parameters. The development of an instrumental method of continuous recording of the coefficient of correlation with the taking of average of finite intervals confirmed the results of analysis of the corresponding samples.

The development and subsequent domination of slow electrical activity is the most obvious electroencephalographic manifestation of severe cerebral hypoxia. The use of this characteristic as a means of monitoring the state of the organism, a particularly essential factor during operations or resuscitation, is hindered by the nature of the waves connected with the action of anesthetics because the slow Δ-waves of the EEG arising under deep anesthesia and in hypoxia are closely similar in their frequency and amplitude characteristics, and visually they appear identical [2, 4-6].

Nevertheless, the intracentral mechanisms of brain function in these states are essentially different [1, 3], so that the search for bioelectrical differences in statistical assessments of the EEG is justified.

EXPERIMENTAL METHOD

The EEG's recorded in neurologically healthy persons with congenital heart defects during operations to correct those defects (at the Clinic for Cardiovascular Surgery, Moscow Regional Clinical Research Institute) were used as initial data. To begin with, functions of reciprocal correlation were calculated between 10 sec sample recordings of the EEG in three leads (frontal, central, and occipital regions of one hemisphere). The EEG was compared in the deep stages of inhalational anesthesia (ether or fluothane) with normal oxygenation of the tissues and a normal acid-base balance, during hypoxic episodes (acute hypoxia induced by circulatory arrest for performing the intracardiac stage of the operation on a dry heart or more slowly developing hypoxia through weakening of cardiac activity), and during gradual posthypoxic recovery of the EEG.

RESULTS AND DISCUSSION

In all cases (24 persons; total number of frames analyzed 100) standardized reciprocal correlation functions revealed definite differences between the slow waves of the EEG during anesthesia without hypoxia

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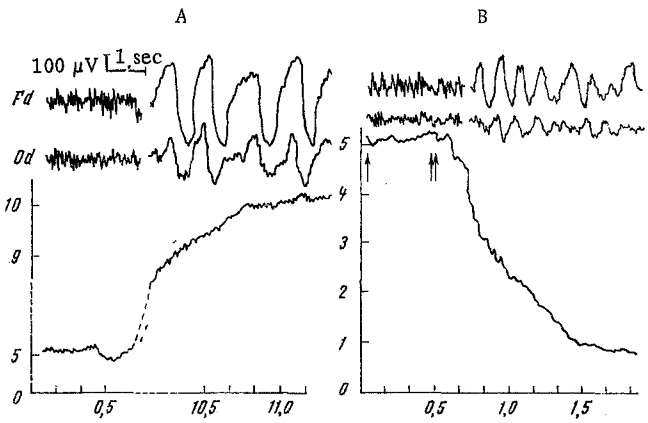

Fig. 1. Fragments of electroencephalogram of frontal and occipital regions compared with continuous recording of fronto-occipital coefficient of correlation. A) Increase in depth of ether anesthesia from stage of mixed waves (first fragment of electrograms) to stage of uniform slow waves (second fragment); B) development of cerebral hypoxia during circulatory arrest. First fragment shows EEG before hypoxia; second fragment shows slow activity during severe hypoxia. One arrow indicates moment of occlusion of inferior vena cava, two arrows indicate occlusion of superior vena cava. Abscissa, time (in min); ordinate, coefficient of correlation.

and during hypoxia associated with anesthesia. Correlation relationships between pairs of simultaneous records of electrical activity of the frontal and occipital regions were the most demonstrative. Reciprocal fronto-occipital correlation functions of the EEG under deep anesthesia, with dominant slow activity, were characterized by a well-developed and a near-periodic series of Δ-waves, whereas in the case of the Δ-waves of hypoxia (both acute and slowly-developing) the graphs were complex in character, the correlation was slight in degree, and the waves died away rapidly. The phase relationships between the Δ-waves in the frontal and occipital regions also differed. The stability of this index was typical of anesthesia: the waves were either in phase, or there was a stable shift to the left along the time axis not exceeding 60°. In hypoxia, the phase changes were unstable and variable in direction; in some cases the shift exceeded 180°.

The results of stage-by-stage analysis of the samples during recovery of the EEG after hypoxia revealed a regular increase in the relative importance of the near-periodic components, an increase in the closeness of fronto-occipital correlation, and a gradual change to the characteristic picture of the EEG under anesthesia.

These results showed that it would be useful to describe the process by a second-order regression model and by approximation of the correlation functions to a relationship of the type

$$\rho xy\,(\tau) = ke^{-\mu\tau} Cos\,(\bar{\omega}\tau + \varphi),$$

where ρxy represents the standard assessment of the reciprocal correlation function of signal y relative to signal x; τ the magnitude of the shift; k is a coefficient equal to the value of the standardized reciprocal correlation function when $\tau = 0$; μ the exponential index; $\bar{\omega}$ the mean angular frequency; φ the phase shift of the function determined by displacement of the maximum of ρxy along the time axis.

The impossibility of distinguishing the process visually or by frequency analysis eliminated any informativeness of the mean frequency, so that the specific decrease in amplitude of fluctuations of the correlation function (the attenuation index, equal to $\mu/\bar{\omega}$) and the coefficient of correlation ρxy (0) were regarded as parameters suitable for assessment. For the segments of EEG analyzed under anesthesia, the attenuation index varied from 0.022 to 0.082 (mean 0.052). For acute and slowly developing hypoxia, its values were much greater – from 0.104 to 0.164 (mean 0.134). These differences were significant according to White's criterion.

The coefficient of reciprocal correlation of electrograms of the frontal and occipital regions also proved to be informative. Under anesthesia, its values, with a probability of 0.9, lay within the interval from 0.232 to 0.732 (mean 0.482) and in hypoxia within the interval from 0.055 to 0.255 (mean 0.085). The simplicity of calculation of the coefficient of reciprocal correlation between the two continuous electrical signals [Rxy (0) or the magnitude of reciprocal dispersion of the electrograms] with averaging for a finite sliding interval T, namely,

$$Rxy(0) \doteq \frac{1}{T} \int_{t-T}^{t} x(t)\, y(t) dt,$$

enabled a synchronous continuous comparison to be made between momentary values of this assessment and the course of change in the subject's state.

To determine this parameter continously, an apparatus consisting of the multiplier unit of a low-frequency filter with controllable time constant and a recorder was constructed. Signals were fed into the multiplier unit from the outputs of corresponding channels of the electroencephalograph. Optimal values of the averaging interval were chosen on the basis of a preliminary investigation: from 15 to 30 sec. Observations on 10 operations showed that deepening of anesthesia from the more superficial stages with dominance of the EEG by α- and β-activity to stages with increasing slow activity was accompanied by an increase in the degree of reciprocal dispersion (Fig. 1A). Fronto-occipital correlation was highest in the deep stages of anesthesia when uniform Δ-waves were dominant in the EEG. The onset of cerebral hypoxia, corresponding to the same frequency transformation on the EEG, was accompanied by a decrease in Rxy (0) (Fig. 1B).

Continuous determination of the coefficient of correlation at an actual time of observation confirmed the results of correlation analysis of sample segments of the EEG. The principal result of the investigation could accordingly be expressed as follows: whereas the frequency organization of the process is the same, the Δ-waves of the EEG evoked by deepening of anesthesia differ essentially from hypoxic Δ-waves in their spatio-temporal organization. These differences can be most clearly defined by the use of fronto-occipital correlation indices. The basic parameters which can be recommended for clinical use are the attenuation index of the correlation function and the coefficient of reciprocal correlation.

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