EFFECT OF DEPTH OF NARCOTIC SLEEP ON CORRELATIONS OF THE ELECTROENCEPHALOGRAM

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Correlation analysis of the human EEG during ether or fluothane anesthesia showed that the stage of deep anesthesia with predominating uniform delta-activity is characterized by a single monoharmonic and stable wave pattern in different regions, with high fronto-central-occipital coefficients of correlation, the frontal region playing the leading role. As the depth of anesthesia diminishes and the pattern changes to one of polymorphic electrical activity, the almost periodic delta-component becomes less marked and the coefficients of correlation between regions of the hemisphere progressively fall. With the appearance of a dominating theta-activity in this stage, stable and generalized production of theta-waves is established.

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Correlation functions of the human EEG during general anesthesia have not yet been systematically investigated. Only one study has been published [7], and this was carried out on a patient with an organic brain lesion after injection of sodium amytal solution into one carotid artery, leading to the appearance of an almost periodic type of slow activity on autocorrelation analysis of the EEG recorded from the ipsilateral hemisphere.

The object of the present investigation was to study the auto- and cross-correlation relationships of slow waves in different parts of the cerebral cortex in neurologically healthy persons during changes in the depth of anesthesia.

EXPERIMENTAL METHOD

The EEG was recorded on a "Medicor" 8-channel electroencephalograph, fitted with an analog frequency analyzer, before and during anesthesia of the patients before the start of operations to correct cardiac defects (clinic for Cardiovascular Surgery, Moscow Regional Clinical Research Institute). Anesthesia was maintained by inhalation of ether (12 patients) of fluothane (8 patients). Auto- and cross-correlation functions were determined up to a maximum shift of $\tau_m = 3$ sec for selected 10-sec recordings of the EEG, and isolated from the integral recording of delta- and theta-waves obtained with 3 leads from the frontal, central, and occipital regions of the same hemisphere, using a combined oral or mastoid electrode as the reference electrode. Amplitudes of waves were measured graphically at intervals of 33 or 66 msec, and the digital material was fed into a "Ural-2" computer. The values obtained were normalized, and the data thus obtained used for auto- and cross-correlation analysis.

During analysis of the data, the mean period of waves (T_{mean}) and the stability of the phase relations, characterized by the attenuation factor of the correlation function, were studied. For cross-correlation analysis, in addition, the coefficient of correlation (K) and the phase shift (φ), determined by displacement of the maximum of the function along the time axis, were calculated.

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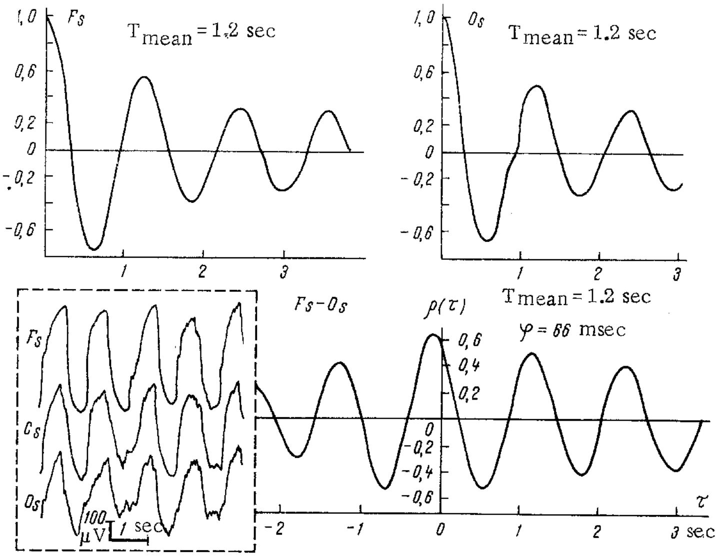

Fig. 1. Correlation analysis of EEG and EEG itself (in box) during ether anesthesia at the stage of uniform slow waves. Fs and Os—graphs of auto-correlation functions of EEG of left frontal and occipital regions; Fs—Os: graph of their cross-correlation function. Here and in Figs. 2 and 3, abscissa: time shift (τ in sec); ordinate: corresponding coefficients of correlation $\rho(\tau)$. Explanation of other symbols given in text.

EXPERIMENTAL RESULTS AND DISCUSSION

Auto-correlation analysis of the EEG of the frontal, central, and occipital regions when delta-activity predominated in the recordings (deep anesthesia at the stage of uniform slow waves) revealed a powerful monoharmonic wave activity, attenuation of which exceeded the interval of maximal shift (Fig. 1). The mean period of the waves varied in different subjects from 0.7 to 1.4 sec. Differences in T_{mean} for correlation analysis of the frontal, central, and occipital regions were very small or absent. Usually higher and more stable waves were characteristic of the auto-correlation function of the frontal EEG. Cross-correlation analysis of simultaneous recordings of the frontal, central, and occipital EEG could be classed as almost periodic processes (Fig. 1), and were characterized by very slight fluctuation of consecutive periods, by a low attenuation factor (of the order of 0.02-0.05), and by high fronto-central-occipital correlations (coefficients of correlation between 0.5 and 0.8). Another typical feature of this stage of anesthesia was the stability of phase relationships of slow waves in spatially remote regions of the cortex. The waves were synphasic, or a stable shift of the order of 66-150 msec to the left along the time axis was observed, indicating earlier arrival of the signal from the anterior divisions of the hemisphere. Closely similar data were obtained during correlation analysis of the delta-component, isolated from the integral EEG by analog frequency analysis (Fig. 2A).

Weakening of anesthesia, leading to the EEG picture known as polymorphic activity or the stage of "mixed waves" [4], modified the correlation relationships significantly. Graphs of correlation functions deduced from delta-waves of the integral EEG were more complex in character, often including a number of components with different periods (Fig. 2C). The correlation was weakened between waves of different parts of the hemisphere (fronto-occipital coefficients varied from 0.43 to 0.14), and the attenuation factor of the function increased from 0.08 to 0.2. The phase relationships were unstable in character and sometimes differed in direction. All these features, indicating a breakdown of the generalized quasiperiodic delta-activity, became increasingly obvious as the depth of anesthesia was reduced. Deepening of the anesthesia had the opposite effect.

In some cases (8 of 20 subjects) periods with dominant and regular theta-activity appeared in the stage of mixed waves. This happened more frequently during fluothane anesthesia. Analysis of waves isolated from the EEG revealed a pattern of activity consisting of waves with a mean period of 150-250 msec.

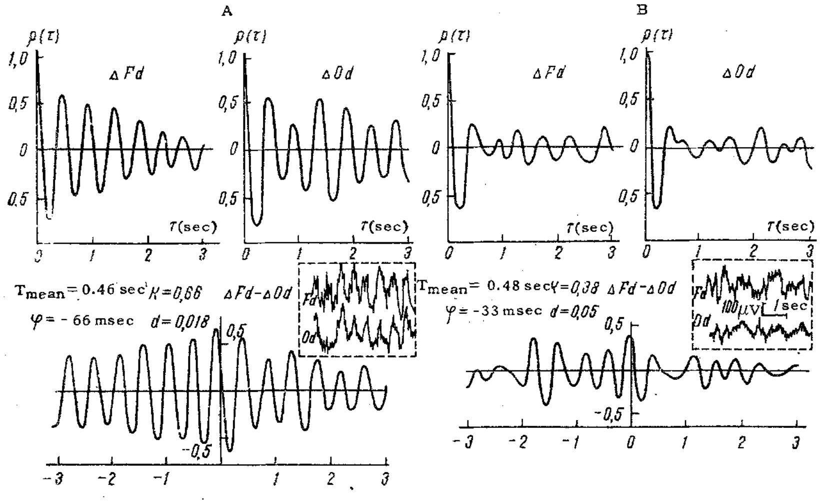

Fig. 2. Correlation analysis of delta-activity in EEG of right frontal (Fd) and occipital (Od) regions at different stages of ether anesthesia. A) Recording made at intermediate depth of anesthesia between stage of uniform slow waves and stage of polymorphic activity; B) recording (10 min later) under shallower anesthesia (stage of polymorphic activity).

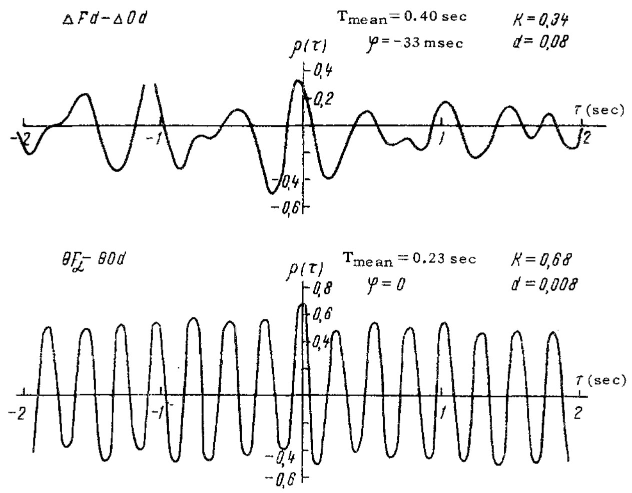

Fig. 3. Cross-correlation analysis of delta- and theta-activity in EEG of frontal and occipital regions during fluothane anesthesia at the level of mixed waves with dominant theta-activity.

The degree of stability of this activity varied significantly in different cases, with attenuation factors lying between 0.008–0.03 (Fig. 3) and 0.12. Correlation between the regions was close (fronto-occipital coefficients of correlation of the order of 0.36–0.55), and an even closer relationship was found between the theta-waves of the frontal and central regions (coefficients of correlation up to 0.8–0.9). Comparison of the cross-correlation analysis of delta- and theta-waves at the same times showed that the general activity lies in the theta-band.

Hence, below a certain depth of anesthesia, slow activity of the EEG is characterized by a special space-time organization of the cortical rhythms, with an almost periodic wave activity identical in different regions of the hemisphere, although the anterior pole of the cortex plays the leading role. High synchronization of the changes in time of potentials of remote cortical points and the closeness of fluctuations in the correlation function to a sinusoidal curve are evidently the distinguishing features of deep narcotic sleep and are not so typical of the slow activity of the human EEG in a waking stage [1, 5], in coma [8, 9], or even in stages D and E of physiological sleep [3, 6]. The results obtained agree well with experimental observations [11], according to which regular relationships between spike volleys from neurons in different parts of the cortex develop during deep anesthesia: the cells either discharge simultaneously, or neurons at the anterior pole discharge about 100 msec before occipital neurons. On the other hand, it is during deep anesthesia that a definite temporal connection is observed between the rhythm of grouped unit discharges and the particular phase of slow waves of the electrocorticogram for that part of the cortex [2, 10].

In a less deep stage of anesthesia, corresponding to polymorphic electrical activity, the delta-activity is less complex in character, the almost periodic component is less marked, and correlation between the regions is much weaker. At this stage the role of the process combining all regions of the cortex may sometimes be taken over by theta-activity.

LITERATURE CITED

1. V. V. Belyaev, in: N. P. Bekhtereva (editor), Physiology and Pathophysiology of the Deep Structures of the Human Brain [in Russian], Leningrad-Moscow (1967), p. 29.
2. V. B. Golovchinskii, Fiziol. Zh. SSSR, No. 10, 1159 (1965).
3. N. N. Danilova, Zh. Vyssh. Nervn. Deyat., No. 1, 9 (1964).
4. S. N. Efuni, Electroencephalography in Clinical Anesthesiology [in Russian], Moscow (1961).
5. V. S. Risunov and O. M. Grindel', in: Current Problems in Electrophysiology of the Central Nervous System [in Russian], Moscow (1967), p. 242.
6. A. N. Shepoval'nikov, Zh. Vyssh. Nervn. Deyat., No. 4, 699 (1966).
7. J. S. Barlow, R. L. Rovit, and P. Gloor, Electroenceph. Clin. Neurophysiol., 16, 213 (1964).
8. J. S. Barlow, Electroenceph. Clin. Neurophysiol., 22, 266 (1967).
9. L. Bergamini, B. Bergamasco, A. M. Mombelli, et al., Electroenceph. Clin. Neurophysiol., 21, 89 (1966).
10. O. Creutzfeldt, J. Bark, and G. H. Fromm, in: H. Gastaut and J. Meyer (editors), Cerebral Anoxia and the Electroencephalogram, Springfield (1961), p. 35.
11. O. Holmes and J. Houchin, J. Physiol. (London), 187, 651 (1966).