CHANGES IN CORRELATION FUNCTIONS OF CORTICAL AND SUBCORTICAL ELECTRICAL ACTIVITY IN VARIOUS STAGES OF ANESTHESIA

D. A. Ginzburg, A. M. Gurvich,
E. A. Mutuskina, E. B. Pasternak,
and E. S. Tolkacheva

UDC 617-089.5-07 : 616.831.31-073.97

Continuous analog recording of auto- and cross-correlation functions of the cortical and subcortical EEG in dogs showed that a decrease in the depth of anesthesia, regardless of its type (inhalation of ether or halothane, intravenous injection of thiopental or sodium γ-hydroxybutyrate) is accompanied by a decrease in synchronization of the potentials and in the degree of periodicity of the process. Deepening of anesthesia gave rise to generalized distant synchronization and to an increase in periodicity of the activity, parallel with slowing of the EEG. At all levels of anesthesia, there was a continuous fluctuation of these correlation parameters and in their dependence on the topographic location of the recorded structures.

Previous investigations [1, 3] have shown that graphs of selectively determined correlation functions of the human EEG during deep anesthesia demonstrate a near-periodic fluctuation of activity in the Δ-band, the same in all parts of the cerebral hemisphere. A decrease in the depth of anesthesia reduced the closeness of correlation between fluctuations in different parts of the cortex and considerably increased the regression coefficient of the auto- and cross-correlation functions.

The object of the present investigation was to continue these studies with the continuous recording of correlation functions of cortical and subcortical electrical activity.

EXPERIMENTAL METHOD

Ten acute experiments were carried out on dogs using various types of anesthesia: inhalation of ether or halothane, intravenous injection of thiopental (in fractional doses of 25-50 mg/kg), or combined anesthesia with halothane and sodium γ-hydroxybutyrate (total dose of the order of 1 μg/kg) or with thiopental. Electrical activity was recorded and the auto-correlation and all combinations of cross-correlation functions of the EEGs of the somatosensory, temporal, parietal, and occipital cortex, caudate nucleus, and thalamus were determined.

The model correlation apparatus (analog filter correlometer) used in the investigation enabled the functions to be determined during a real time of observation. The instrument provided for simultaneous calculation and indication of the dispersions of both processes studied (Dx and Dy) and 20 points of assessment of the correlation functions at $\tau > 0$. Depending on the program of the instrument, the greatest shift τ_m was 0.5, 1, or 2 sec, with an averaging time of 30 sec. For comparison with the synchronously recorded electrical activity, auto- or cross-correlation functions were recorded continuously by one channel of the electroencephalograph, and photographed selectively from the CRO screen of the correlometer. Param-

Laboratory of Experimental Physiology of Resuscitation, Academy of Medical Sciences of the USSR. Department of Automation and Telecommunications Engineering, Moscow Energetics Institute. (Presented by Academician of the Academy of Medical Sciences of the USSR A. A. Vishnevskii.) Translated from Byulleten' Éksperimental'noi Biologii i Meditsiny, Vol. 71, No. 5, pp. 57-60, May, 1971. Original article submitted November 12, 1970.

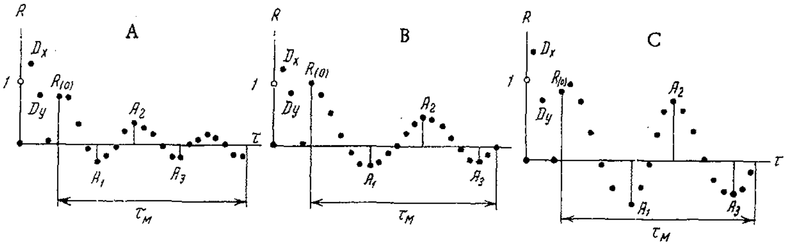

Fig. 1. Changes in cross-correlation function of electrical activity of occipital and somatosensory cortex during deepening of ether anesthesia (photographs from CRO screen): A) superficial anesthesia, level III_1 (stage of polymorphic EEG waves); B) deepening to level III_1-III_2; C) deep anesthesia at level III_2 (stage of homogeneous EEG waves); Dx and Dy represent dispersions of electrical activity of somatosensory and occipital cortex respectively; R(0) amplitude of function at $\tau = 0$; A_2 and A_3 amplitudes of secondary waves of correlation function; τ_m maximum shift, namely 2 sec.

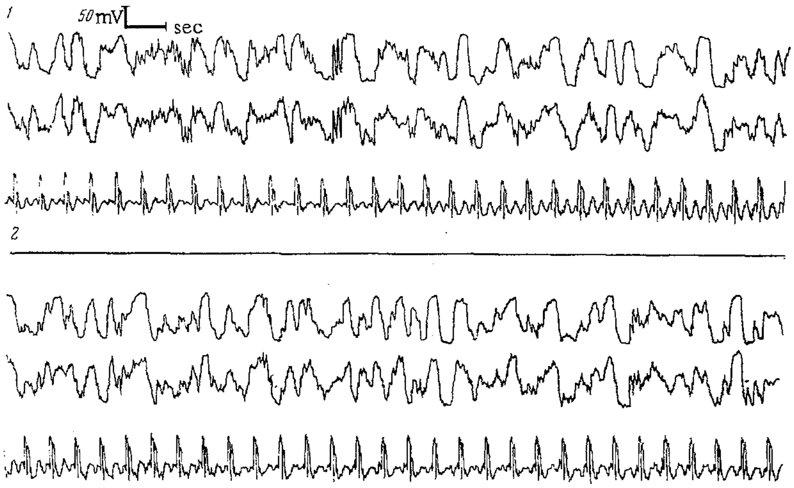

Fig. 2. Periodic fluctuations of parameters of correlation functions with a stable level of anesthesia (recorded on electroencephalograph): 1) from top to bottom: electrical activity of caudate nucleus, of thalamus, and synchronized recording of frames of right branch of cross-correlation function of these leads ($\tau_m = 2$ sec); 2) immediate continuation of 1.

eters of the cross-correlation functions chosen for assessment were the mean period of the oscillations, the phase shift, the amplitude of the function R(0) when $\tau = 0$, determined in fractions of the mean geometric dispersion of the processes ($R_0 = \sqrt{Dx.Dy}$), and the amplitude of the secondary wave of the correlation function (A_2) in fractions from R(0) (Fig. 1). Only the first and last indices were determined for the autocorrelation functions.

EXPERIMENTAL RESULTS AND DISCUSSION

Altogether 58 periods of known changes in the depth of anesthesia were investigated. Anesthesia of moderate depth (spontaneous respiration, pupillary and corneal reflexes present but diminished, relatively low percentage of slow waves on the EEG) corresponded to the following values of R(0): for combinations of ECoGs of different parts of the cortex from 0.2 to 0.6 R_0; for combinations of the ECoG and subcortical EEG from 0.2 to 0.4 R_0; for cross-correlation functions of activity of the thalamus and caudate nucleus from 0.4 to 0.7 R_0. The amplitudes of the second wave of the correlation functions lay between 0.1 and 0.5 R(0). Often a third and subsequent wave appeared at $\tau = 2$ sec, i.e., the mean period of the quasiperiodic process identified was 300-500 msec. Deepening of the anesthesia always gave rise to a wave-like increase in both R (0) and A_2, depending on the rate at which it took place, with an increase in the mean period of the waves (Fig. 1). The highest values of R (0) (up to 0.9 R_0) and of A_2 (up to 0.8) were observed during deep anesthesia, associated with disappearance of the corneal reflexes and dominance of uniform, slow waves on the EEG. Rapid recovery from anesthesia, on discontinuing the inhalation of ether or halothane, was accompanied both by a decrease in the degree of synchronization of the waves, in which case R (0) could be reduced by 50-75% in the course of 20-30 sec, and by a decrease in the degree of periodicity of the process (diminution followed by disappearance of the secondary wave). In addition, with a decrease in the depth of anesthesia sometimes there was a phase discontinuity of the cross-correlation function of activities of the somatosensory and occipital cortex or of the somatosensory cortex and subcortex, with a shift of R (0) to negative values.

The essential feature was that the direction of the changes described above was identical, in principle, for all combinations of cross-correlation and for all types of anesthesia used. The rates of the changes were clearly dependent on the rates of the changes in the depth of anesthesia. These results confirm findings [1] obtained by selective correlation alaysis of the EEGs of patients during surgical anesthesia, and they provide convincing proof that an increase in the depth of anesthesia not only causes slowing of the EEG waves, but also generalized distant synchronization and an increase in the rhythmicity of the Δ-waves.

Comparison of the cross-correlation functions for different combinations of cortical and subcortical leads with a stable and moderate depth of anesthesia showed a relationship between the value of R (0) and the topographic closeness of the structures tested. For instance, the amplitudes of R (0) for correlation functions of adjacent cortical regions (parietal and temporal, somatosensory and parietal, and so on) were always 50-100% higher than the corresponding values for EEGs of distant regions (for example, somatosensory and occipital). Consequently, the rule of an inverse relationship between the mean correlation coefficients of the EEGs and the distance between the points from which the potentials are recorded, established by Livanov et al. [4] in experiments on waking animals, is also valid for the state of anesthesia.

The possibility of determining correlation functions in an actual period of time during continuous observation, which was used in the present investigation, also revealed a phenomenon of a periodic change in characteristics of the correlation functions as the recording proceeded. At any stage of anesthesia there was sometimes a gradual increase in R (0) and A_2 (in the case of auto-correlation functions, only A_2), sometimes a decrease in these parameters (Fig. 2). In some cases, on recovery from anesthesia, oscillations in the magnitude of the phase shift from 0 to 300 msec also were observed. The period of these oscillations, measured from maximum to maximum, could vary from 10 to 45 sec, but was usually 18-20 sec. Oscillations of the correlation functions during deep anesthesia always occurred with higher values of the maxima and minima for R (0) and A_2 than during less deep anesthesia. Cross-correlation functions of spatially close structures were characterized by fluctuations affecting mainly the degree of periodicity, i.e., oscillations affecting the values of A_2 and R (0) showed little change; in the case of spatially distant recordings, both these parameters fluctuated synchronously. Certain stochastic properties of the EEG (degree of periodicity and synchronization of waves in different parts of the cortex and adjacent subcortex) thus show continuous cyclic changes. These may be supposed to be connected with parallel changes in the physiologically important characteristics of brain activity.

LITERATURE CITED

1. D. A. Ginzburg, Byull. Éksperim. Biol. i Med., No. 10, 15 (1969).
2. D. A. Ginzburg, E. B. Pasternak, and E. S. Tolkacheva, in: Development of Physiological Instrumentation for Scientific Research in Biology and Medicine (Proceedings of the 2nd All-Union Scientific Engineering Seminar) [in Russian], Moscow (1968), p. 42.
3. D. A. Ginzburg and V. V. Trepakov, in: Mechanisms of Nervous Activity [in Russian], Leningrad (1969), p. 25.
4. M. N. Livanov, M. N. Zhadin, T. A. Korol'kova, et al., Zh. Vyssh. Nervn. Deyat., No. 6, 996 (1969).