SPONTANEOUS FLUCTUATIONS OF OXYGEN TENSION IN HUMAN BRAIN STRUCTURES

V. B. Grechin and E. I. Krauz

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Spontaneous fluctuations of oxygen tension were discovered in patients with parkinsonism by means of electrodes implanted into the cellular structures of the brain and its white matter. Three types of processes were distinguished and differences in the duration of the periodic component of the pO_2 fluctuations with characteristic differences in the various brain structures were revealed by correlation analysis. In some cases, spectral analysis revealed significant differences between the fluctuations of pO_2 in the white matter and the cellular structures of the brain.

The study of the oxygen tension (pO_2) in subcortical formations of the human brain has shown [3, 5, 7] that the pO_2 level in some of them does not remain constant but undergoes fluctuations of varied duration.

This paper describes the results of a mathematical analysis of spontaneous fluctuations in the pO_2 level in certain deep structures of the human brain.

EXPERIMENTAL METHOD

Tests were carried out on 5 patients with chronic postencephalitic parkinsonism and 1 patient with myoclonic epilepsy, into whom 30-36 long-stay intracerebral electrodes had been implanted for therapeutic and diagnostic purposes [2]. The oxygen cathode technique, using a multichannel dc amplifier with output connected to a type N-320/9 oscillograph, was used to record pO_2. Intracerebral electrodes 0.1 mm in diameter were used as cathodes of the polarographic cell. A Ag—AgCl electrode was used for comparison. Cuts of the record of the pO_2 level, 5-10 min in duration, obtained from the patients while awake and at rest, were analyzed. The material was coded on a "Silhouette" converter. The quantization step was 1.6 sec. The correlation function and power spectrum of the process were calculated by computer using the programs of Belyaev and Orlov [1]. Simultaneously with the computer analysis, some of the material was subjected to visual analysis: the index of the pO_2 waves, i.e., the percentage of the time during which fluctuations with a duration of 4 to 300 sec were observed in a 5-min cut of the record were observed, was determined.

EXPERIMENTAL RESULTS

After the 3rd week of the postoperative period, 92% of the electrodes implanted into cellular structures and 40% of electrodes implanted into white matter detected a pattern of pO_2 fluctuations, reproducible on repetition of the investigations, as well as repeated changes in pO_2 during inhalation of oxygen and hyperventilation. After the electrodes had remained for 3-6 months in the brain, the pO_2 waves disappeared, evidently because of local changes in the neuroglial and vascular formations in the vicinity of the electrode and changes in the activity of the electrode surface.

The pO_2 level in most structures of the human brain shows spontaneous oscillations creating a pattern of pO_2 waves of different amplitudes (from 1 to 50% of the absolute pO_2 level) and shape, which in 80% of

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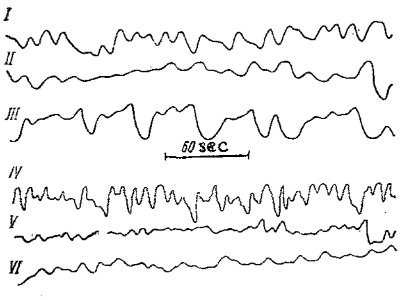

Fig. 1

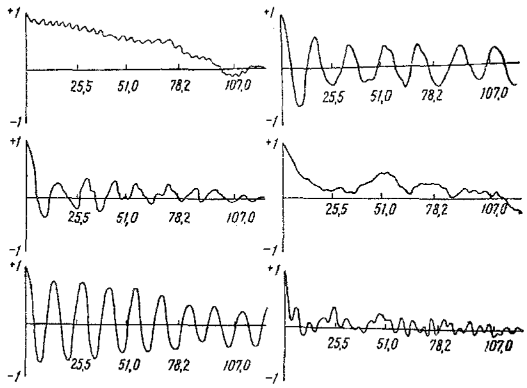

Fig. 2

Fig. 1. Spontaneous waves of pO_2 in brain structures of waking patient at rest: I) ventrolateral thalamic nucleus; II) anterior ventral thalamic nucleus; III) globus pallidus; IV) red nucleus; V and VI) region of ventrolateral nucleus bordering on internal capsule.

Fig. 2. Autocorrelation analysis of spontaneous pO_2 waves in some subcortical brain structures of a patient (from top to bottom: putamen, ventrolateral thalamic nucleus, and reticular thalamic nucleus) awake and in a resting state (left) and while memorizing in operative memory tests (right). Ordinate, coefficient of correlation function; abscissa, delay (in sec).

cases revealed certain special features in different brain structures (Fig. 1). The thalamic nuclei were characterized by predominance of waves 5-20 sec in duration and with a mean amplitude of not more than 15% of the absolute pO_2 level. For the central regions of both parts of the globus pallidus there were typical waves 2-5 sec in duration. The pattern of pO_2 waves in the amygdaloid nucleus is composed of waves from 1 to 40 sec in duration, dominated by high-amplitude oscillations from 8 to 10 sec in duration. The pattern of pO_2 waves in the structures of the cerebral peduncles was uniform and consisted of waves 5-10 sec in duration. In the deep brain structures and in the cortex of the patient with myoclonic epilepsy the spectrum of pO_2 waves was dominated by pointed waves of short duration (4-8 sec) and considerable amplitude (up to 40% of the pO_2 level).

Correlation analysis showed 3 possible types of processes in the pO_2 waves in the brain structures, just as in the EEG [6]. The first process was nonperiodic or random, with an exponential autocorrelation function (Fig. 2). This type of process is characteristic of pO_2 waves in the red nucleus and strio-pallidary complex. The second type of process was quasiperiodic, and was typical of the pO_2 waves in most brain structures. In some cases the periodic component consisted of 2 or 3 waves, and it was completely extinguished at $\tau = 15$ sec. In other cases, which were more commonly observed, extinction took place with a high decrement (up to 0.7). The third type of process (periodic) was found in pO_2 waves in some nonspecific nuclei of the thalamus, the ventrolateral thalamic nucleus, the outer part of the globus pallidus, and the caudate nucleus. The periodic component of the waves had a duration of 3.5 to 10 sec. Waves of pO_2 in the white matter and in the cellular structures (cerebral peduncles and globus pallidus in 15% of cases) showed pulse waves of pO_2 with a period of about 1 sec. The power spectra of the pO_2 waves in most cellular formations were approximately linear in shape with a maximum in the region of longest-period harmonics or waves with a duration of 6-11 sec. The power spectra of the pO_2 waves in the white matter showed a maximum within the region of harmonics from 1 to 6 sec in duration.

The possibility of finding a periodic component and the character of the spectrum of the pO_2 waves in the human brain were determined by several factors. The spectral composition of the spontaneous fluctuations of pO_2 level in some structures showed diurnal variations. Starting from 3-5 P.M. or later, as the time of natural sleep drew near, gradually increasing changes appeared in the pattern of the pO_2 waves in some subcortical nuclei (most clearly marked in the nonspecific nuclei of the thalamus and substantia nigra), and manifested by a marked increase in strength or by the appearance de novo of the periodic component. By 10-11 P.M. the pattern of pO_2 waves in these structures revealed nondecremental regular waves

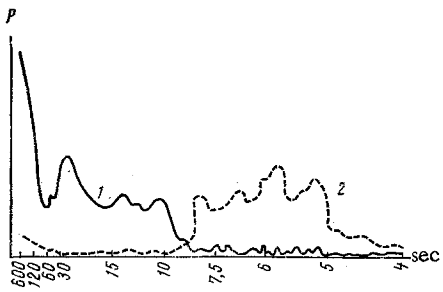

Fig. 3. Power spectra of spontaneous waves of oxygen tension in the central thalamic nucleus (1) and internal capsule (2) of a patient awake and at rest. Ordinate, power of spectral components; abscissa, duration of pO_2 waves (in sec).

from 6 to 12 sec in duration. The spectrum of spontaneous pO_2 waves of the brain was most clearly dependent on the functional state of the brain. The periodic component and spectrum showed clear changes as the patients performed mental (Fig. 3) or motor activity in response to an instruction, as the result of administration of pharmacological agents (central cholinolytics and general anesthetics), or under the influence of diagnostic and therapeutic electrical procedures. Variations in the spontaneous pO_2 waves in different brain structures are attributable to the marked nonhomogeneity (functional and anatomical) of the structures and the high lability of the parameter studied. This goes some way toward explaining the fact that investigations undertaken to give a precise description of spontaneous pO2 waves in various structures of the human brain [3, 4] have proved ineffective. Investigations in this direction using an adequate mathematical system will perhaps reveal even more reliable features distinguishing pO_2 in the various formations of the human brain of possible practical importance for neurosurgery.

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