CHANGES IN STIMULATION STRENGTH–DURATION CURVE OF CEREBRAL MOTOR CENTERS IN POSTNATAL ONTOGENESIS

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UDC 612.822:612.65

Strength–duration curves of electrical stimulation of the motor cortex and subcortical motor centers were investigated in experiments on adult rabbits and young rabbits aged 1–13 days. Electrical responses in the muscles served as indices of excitation of the centers. The stimulation strength–duration curve for adult rabbits is complex and consists of "axon" and "cell" components. In newborn rabbits the axon component of the strength–duration curve of stimulation is ill defined.

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Numerous investigations of the character of changes in excitability of the motor cortex in postnatal ontogenesis are reported in the Soviet and Western literature [2–4, 9]. Cortical chronaximetry was carried out in these investigations, but the complete strength–duration curve of stimulation (SDC) of the particular object concerned was not investigated. It was found that the mean chronaxie of the cerebral cortex in rabbits, cats, dogs, and guinea pigs in postnatal ontogenesis decreases by approximately one order (variations in adults 0.08–2 msec, in newborn animals 0.8–34 msec). Our earlier investigations [8] showed that the SDC of the motor cortex of adult rabbits is complex and consists of at least 2 simple SDCs, one of which (A) reflects the electrical excitability of the axons, the other (B) the same property of the bodies (or axon hillocks) of the cortical neurons. A similar type of complex SDC is shown by the nuclei of nerve IV and their individual neurons in rabbits [7] and also by the spinal cord motoneurons of toads [11]. It can therefore be postulated that the chronaxie of the motor cortex or of any subcortical nucleus, recorded without analysis of the SDC, is an indefinite index.

The object of the present investigation was to study the significance of the sharp decrease in duration of the mean cortical chronaxie during ontogenesis, as described in the literature, and to determine the SDC of the motor cortex in newborn animals and to examine how they differ from those observed in adult animals.

EXPERIMENTAL METHOD

Experiments were carried out on young rabbits aged from 1 to 13 days and on adult rabbits. The vault of the skull and dura in the region of the cortical center of flexion of the forelimb were removed under ether anesthesia. The active stimulating electrode, a silver wire 0.1 mm in diameter coated with silver chloride, was inserted into the cortex to a depth of 1 mm*. The reference electrode consisted of an Ag–AgCl plate introduced beneath the skin of the head on the side of stimulation, or Ag–AgCl wire placed on the cortex along side the active electrode. The cortex was flooded with a mixture of mineral oil and paraffin. The anesthesia was then discontinued and the subsequent experiment carried out without anesthesia. The brain was stimulated with square pulses from 0.08 to 35 msec in duration, single and repetitive (frequency 25 and 10/sec, in series 0.5 sec in duration). The thresholds of flexion of the contralateral elbow and of the bioelectrical response in the flexors of the contralateral arm were determined. The electromyograms (EMG) of the cortical and subcortical responses were described in our previous paper [7]. The magnitudes of the thresholds were expressed in units of current strength, obtained by dividing the measured

*To determine the localization of the stimulated structures more accurately by the method of searching for the minimum threshold an active "probe" electrode, consisting of nichrome wire with a tip 55 μ in diameter insulated with glass except at the tip, was used.

Department of Normal Physiology, Leningrad Pediatric Medical Institute (Presented by Active Member of the Academy of Medical Sciences of the USSR A. F. Tur). Translated from Byulleten' Éksperimental'noi Biologii i Meditsiny, Vol. 66, No. 7, pp. 12–15, July, 1968. Original article submitted February 22, 1967.

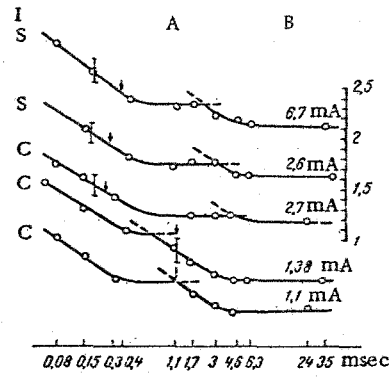

Fig. 1. Complex (consisting of components A and B) strength—duration curves of stimulation of cortex (C) and subcortex (S) of adult rabbits. Logarithmic scale. Values of the rheobase are shown on the right above the curve. Vertical lines denote positions of chronaxie points for corresponding components of the SDC (axon and cell); arrows indicate positions of "gross chronaxie" points.

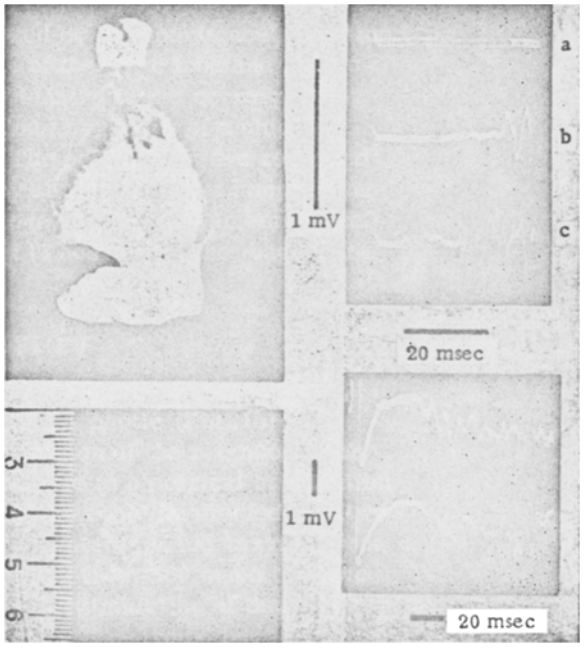

Fig. 2. Location of cortical motor areas for forelimb flexors and electromyograms (EMG) of responses to single brain stimuli. Above, brain of adult animal (B); on the right, EMG of shoulder flexors; at rest (a) during threshold local cortical stimulation (b), and during above-threshold stimulation involving the subcortex in the response (c). Below, brain of a young rabbit in the first day of life (1); on the right, EMG of responses of shoulder flexors to single over-threshold stimuli (beginning of single sweeps of the beam synchronized with stimulation).

threshold voltage by the resistance of the object (determined by a substitution method). The SDC values were plotted on ordinary and logarithmic scales [8].

EXPERIMENTAL RESULTS AND DISCUSSION

SDCs were obtained for 8 young and 8 adult rabbits. In the case of the adult rabbits, specific cortical SDCs were obtained for responses appearing on the EMG as volleys of action potentials to each stimulus (with a latent period of 20-30 msec) and a minimum threshold in cortical area 4. The cortical SDCs consisted of two components, A and B. The parameters of these components in this series of experiments (for a stimulation rhythm of 10/sec) were as follows: rheobase of A from 1.9 to 4.6 mA (mean 3 mA), chronaxie of A about 0.15-0.2 msec; rheobase of B 1.7 ± 0.4 mA, chronaxie of B 1.4 ± 0.1 msec. The parameters of curve A were less definite because its horizontal branch was partly masked by curve B (Fig. 1). Since the shape of the responses to short (A) and long (B) stimuli of threshold intensity was similar, while their mean latent periods measured in some experiments, without deduction of the "temps utile," were indistinguishable (in both cases 25 ± 2 msec for 11 measurements), it can be concluded that curves A and B reflect excitability of the axons and bodies of the same group of cortical neurons [7].

When the remote reference electrode was used (as in most of the old investigations), an increase in the strength of stimulation because of considerable "leakage" of current into the subcortex leads to direct stimulation of the subcortical structures and to the addition of subcortical, extrapyramidal responses to the cortical responses of the EMG [7]. Compared with the cortical responses, the subcortical had a much shorter latent period (5-10 msec) and in shape they consisted of a single action potential to each pulse of current. They were generated by the motor centers of the brain stem (minimum threshold in the region of the mesencephalon). The SDCs of the subcortical responses were indistinguishable in shape from the cortical, but they had higher values of the rheobase of the A and B components, in connection with the greater distance of the stimulating electrodes from the object and the lower frequency of application of these strong stimuli (once every 10 sec).

Parameters of the "subcortical" SDCs were as follows: rheobase of A 6.2 ± 1.4 mA, chronaxie of A 0.2 ± 0.01 msec; rheobase of B 3.8 ± 0.9 mA, chronaxie of B 1.3 ± 0.14 msec. The shape of the responses to short (A) and long (B) stimuli were

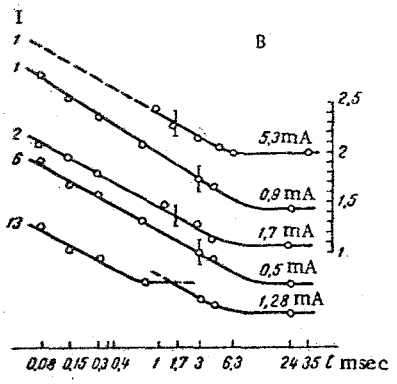

Fig. 3. Strength–duration curves of brain stimulation for young rabbits. Logarithmic scale. On the left, age of rabbit given by each curve; on the right, values of rheobase. Vertical lines denote position of chronaxie points.

similar, and their mean latent period after deduction of the "temps utile" were practically indistinguishable (7.6 ± 0.7 and 7 ± 1 msec in 12 measurements, for example), so that it may be postulated that these curves A and B reflect excitability of axons and bodies of the same group of brain-stem neurons. Coincidence of the shape and temporal parameters of the cortical and subcortical SDCs indicates the close similarity between the biophysical properties of the neurons of the cortical and subcortical motor centers. It is clear that if the chronaxie of the brain is measured, intermediate (between A and B) values must be obtained, sometimes approximating to the chronaxie values of the A or B SDCs (Fig. 1).

In 7 young rabbits during the first week of life, both in responses to local cortical stimulation and to stimulation involving the cortex and subcortex simultaneously (Figs. 2 and 3), the SDCs were almost simple in shape, and corresponded in their parameters to the B components of the SDCs of adult animals. Since entirely local stimulation of the cortex in the young rabbits was rarely obtained, we shall describe the SDCs obtained in response to nonlocal stimulation (giving a complex response in the EMG with latent period of about 40 msec). Their mean rheobase (for a stimulation frequency of 10/sec) was 2.4 ± 1.2 mA and their mean chronaxie 2.4 ± 0.2 msec. This last value is higher than that of the B component of the cortical and subcortical SDCs of adult animals by about 1.7 times ($P < 0.05$). Since the A component of the SDC from the investigated parts of the brain of newborn rabbits was absent, the brain chronaxie was indistinguishable from that stated above. In a young rabbit aged 13 days (with the power of vision) the SDC in response to nonlocal stimulation was complex, just as in adult animals, with temporal parameters of its A and B components similar to those for adult animals (Fig. 3.).

Because the physiological data [7, 11] suggest that component A in the complex SDC of the brain motor centers reflects electrical excitability of the fibers, absence of the A component in the SDC of newborn rabbits can be interpreted as evidence of the low electrical excitability of the fibers of their pyramidal and extrapyramidal systems for short stimuli, and the appearance of the A curve in the SDC of young rabbits aged 13 days and of adult rabbits as evidence of a considerable increase in electrical excitability of these fibers in postnatal ontogenesis, in connection with their myelination [1, 5]. The decrease in chronaxie of curve B in ontogensis probably indicates changes in electrical excitability of the central portions of the corresponding neurons [12]. So far as the tenfold shortening of the mean cortical chronaxie in ontogenesis, as described in the literature, is concerned, it reflects an increase in electrical excitability of the axons associated with their formation as a conducting structure [6, 10, 13].

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