QUALITATIVE AND QUANTITATIVE ANALYSIS OF CHANGES IN CAUDATE NUCLEUS NEURONS DURING POSTNATAL DEVELOPMENT OF RATS

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A qualitative and quantitative analysis was made of changes in caudate nucleus neurons of newborn rats and rats aged 7, 14, and 30 days. An increase in complexity of structure of components of the nerve cell was found during early postnatal ontogeny. Maturation of neurons takes place most intensively during the first 2 weeks of life and is virtually complete by the 30th day of the postnatal period. The results suggest that the caudate nucleus becomes "involved" in the integrative activity of the brain in this period of development.

KEY WORDS: caudate nucleus; neurons; postnatal development.

Interest in the study of the structure and function of the caudate nucleus, to which great importance is attached in the integrative activity of the brain, has increased in recent years. However, the principles governing the structural and functional maturation of this important subcortical formation have received very little study.

It was accordingly decided to study qualitative and quantitative changes in neurons of the caudate nucleus of rats in early postnatal development.

EXPERIMENTAL METHOD

Young rats immediately after birth and at the ages of 7, 14, and 30 days were studied. The brain was treated by Nissl's method. The Klassimat electron-optical system was used for quantitative analysis of maturation of the caudate nucleus neurons: The area of cross section of the cytoplasm, nucleus, and cell body of 50 neurons was measured in each of 4 rats of the 8 groups studied (16 animals altogether). Statistical analysis of the data was carried out by a program prepared in the Laboratory of Architectonics of the Brain, Brain Institute, Academy of Medical Sciences of the USSR.

EXPERIMENTAL RESULTS

The matrix layer, consisting of immature cells, was clearly identifiable in the newborn rats in the ventromedial part of the caudate nucleus. The rest of the caudate nucleus consisted of dark small cells, lying close together. The area of cross section of the cell body was small, on average 34.78 μ^2. Most of the cell body, moreover, was occupied by a large dark nucleus, the mean area of which was 32.33 μ^2. It was surrounded by a rim of homogeneously stained cytoplasm, occupying 2.44 μ^2 of the total area of the cell body. In the dark nucleus, 2 or 3 nucleoli could often be distinguished. Among the main mass of poorly differentiated cells there were solitary neurons with clearly defined proximal portions of the basal dendrites.

On the 7th day of postnatal development the matrix layer was much smaller in size, on account of migration and maturation of its neurons. The density of arrangement of the cells was reduced, the cell nuclei were paler, and clumps of basophilic material could be distinguished in the cytoplasm. The qualitative changes were accompanied by quantitative: The cell body and nucleus were almost doubled in size, and the area of the cytoplasm was 4 times greater than in the newborn rats (Table 1).

During the next week of life the matrix layer almost disappeared alongside the periventricular zone. In this period of ontogeny neurons of the caudate nucleus grow and differentiate most intensively. The density of

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TABLE 1. Mean Area of Cross Section of Nucleus, Cytoplasm, and Body of Caudate Nucleus Neurons (in μ^2) during Postnatal Ontogeny of Rats (M ± m)

Rats	Nucleus	Cytoplasm	Cell body
Newborn	32,33±0,54	2,44±0,20	34,78±0,50
7 days old	58,57±0,67	8,24±0,33	66,98±0,67
14 days old	64,32±0,87	17,43±0,57	81,68±1,13
30 days old	64,58±1,09	15,57±0,38	80,15±1,28
P_{1-2}	<0,001	<0,001	<0,001
P_{2-3}	<0,001	<0,001	<0,001
P_{3-4}	>0,05	<0,01	>0,05

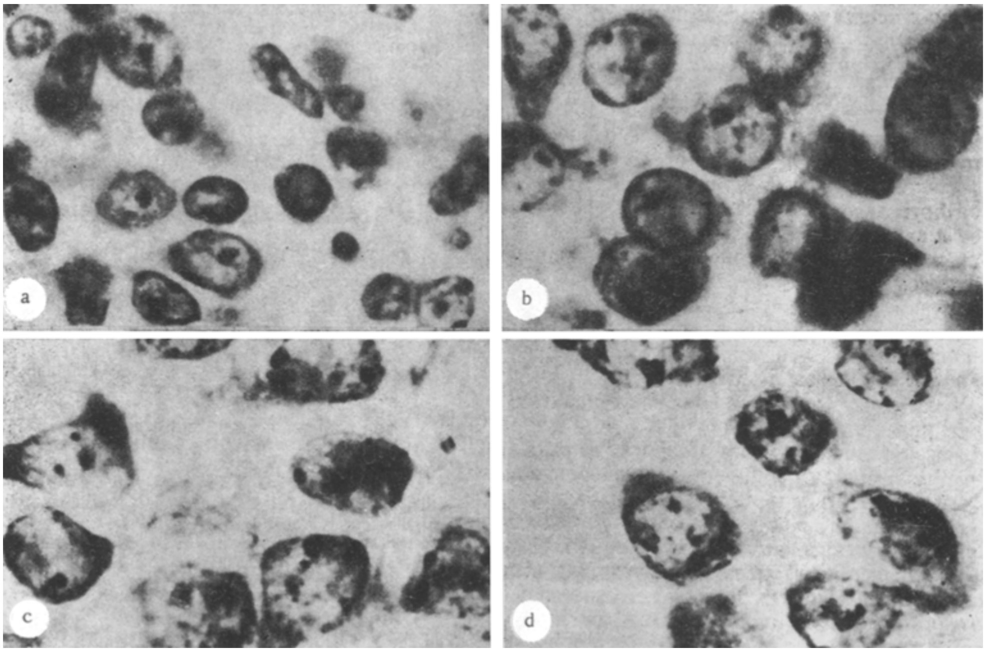

Fig. 1. Structure of caudate nucleus neurons in postnatal ontogeny: a) newborn rats; b) rat aged 7 days, c) 14 days, d) 30 days. Nissl's method, 900×.

arrangement of the cells was considerably reduced. In shape they became less uniform. The quantity of clumps of basophilic material in the cytoplasm increased. According to the quantitative measurements the ratio between the area of cross section of the nucleus and cytoplasm increased in favor of the latter. The content of cytoplasm in the cells was more than twice that at the age of 7 days, but the increase in size of the cell body and nucleus was smaller (Table 1).

By the age of 30 days differentiation of the neurons was virtually complete. The matrix layer had disappeared and the intracellular structure of the neurons had reached the definitive state. The areas of cross section of the cell bodies and nuclei were almost unchanged and the cytoplasm was actually a little smaller than in the rats aged 14 days.

Intracellular differentiation of caudate nucleus neurons thus takes place most intensively in the first 2 weeks of life.

Previous investigations [4] showed that caudate nucleus neurons in newborn rats have basal dendritic trunks with rudiments of secondary branches. Synapses are present on the trunks of large and medium-sized dendrites and contain few synaptic vesicles, evidence of the immaturity of the synaptic structures in rats of this age. The structural immaturity of the neurons and of the interneuronal connections of the caudate nucleus in newborn animals correlates with the functional immaturity of the brain, manifested as the inability to form conditioned reflexes during the first 5 days of life [2].

During the first week after birth a sharp increase in the mean size of the cells and of their nucleus and cytoplasm is observed and is a quantitative indicator of differentiation of their intracellular structure. In this period of ontogeny the structure of the dendrites becomes more complex and the number of dendritic spines which can form synapses with the axon branches increases [3]. Axo-somatic contacts can be detected for the first time electron-microscopically, although, like the axodendritic synapses, they still contain few synaptic vesicles [7, 4].

During the first 14 days of life the brain of young rats grows intensively, so that by the age of 2 weeks it has increased more than 5 times in weight [1, 10]. At this age differentiation and mitosis cease in the matrix layer [6], and in the period between the 14th and 20th days after birth the caudate nucleus of rats has its greatest cell population [8]. By the 14th day after birth the structural organization of the caudate nucleus neurons is basically at the definitive stage. The quantity of cytoplasm in the cells of the caudate nucleus is almost doubled between the ages of 7 and 14 days. The dendrites of the neurons are covered by numerous spines, many of which have a well-marked pedicle and head [3], an indication of the functionally mature state of the cell. In the period from 13 to 17 days numerous contacts are formed in the caudate nucleus between axon terminals and spines, and a spinous apparatus is found in the latter [7]. Meanwhile cortico-subcortical connections are formed, myelin sheaths develop along the axons [10, 8], and cholinergic mediation appears [3]. Starting from the 17th-19th day of life, conditioned reflexes can be formed in rats [2].

In animals aged 1 month, growth of the brain is practically complete, and it weighs about 91% of the weight of the adult rat brain [1]. This agrees with quantitative data on relative stabilization of the size of the caudate nucleus neurons in rats aged 30 days. The quantitative decrease discovered in the size of the cytoplasm in the caudate nucleus cells at this age can evidently be connected with the continuing growth and myelinization of the axons.

According to the most recent data [8], by the 30th day after birth the structure of the caudate nucleus neurons is indistinguishable, as regards the morphology of their processes, from that in the adult rat. However, the statement that in the course of postnatal ontogeny (from the 8th to the 30th day) the density of the neurons in the caudate nucleus increases is not in agreement with the results of the present investigation or with numerous ontogenetic studies which have revealed a decrease in the density of the cells during postnatal ontogeny in several parts of the brain, mainly on account of an increase in the number and lengths of the dendrites and in the complexity of ramification of the dendrites and axons. There is also evidence of a linear relationship between the increase in weight of the brain and the decrease in density of arrangement of the cortical neurons in a phylogenetic series of animals up to and including man [11].

Maturation of caudate nucleus neurons, in accordance with morphological and histochemical features [3, 9], by the age of 1 month suggests that the caudate nucleus becomes involved in association functions at this stage of postnatal development.

LITERATURE CITED

1. N. I Dmitrieva, in: Development of the Brain in Animals [in Russian], Leningrad (1969), p. 132.
2. É. F. Panchenkova, Zh. Vyssh. Nerv. Deyat., No. 2, 312 (1962).
3. É. N. Popova and A. M. Vavilov, Arkh. Anat., No. 3, 65 (1975).
4. L. E. Frumkina, in: Functional and Structural Bases of the Activity of Brain Systems and Mechanisms of Brain Plasticity [in Russian], No. 2, Moscow (1973), p. 197.
5. J. Bures, Csl. Fysiol., 8, 244 (1959).
6. M. Hamburgh, Curr. Top. Dev. Biol., 4, 109 (1969).
7. T. Hattori et al., Exp. Neurol., 38, 70 (1973).
8. E. J. Lu and W. J. Brown, J. Comp. Neurol., 171, 261 (1977).
9. E. McGeer, H. Fibiger, and V. Wickson, Brain Res., 32, 433 (1971).
10. H. McIlwain, Practical Neurochemistry, London (1962).
11. D. B. Tower, J. Comp. Neurol., 101, 19 (1954).