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FRACTAL DIMENSION AND VARIANT ANATOMY OF THE WHITE MATTER OF THE HUMAN CEREBELLAR HEMISPHERES

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Abstract

Introduction. Morphological changes of the cerebellar lobules are found in many congenital and acquired diseases of the cerebellum, but the information on the normal structure of the cerebellar lobules do not take into account the peculiarities of individual anatomical variability, sex and age characteristics.

Aim – to investigate anatomical variability and fractal dimension of the white matter of the human cerebellar hemispheres.

Material and methods. The study involved 100 cerebella of people of both sexes, who died of causes unrelated to brain pathology (20–99 years old). Parasagittal sections of the cerebellar hemispheres were investigated.

Results. On parasagittal sections number of main branches of white matter is very varied and depends on peculiarities of structure of the hemispheric lobules. It was found that there is individual variability of the structure of the human cerebellar hemispheres, namely white matter branching features. We described variants of the branching of the main branches of white matter of the human cerebellar hemispheres.

Fractal dimension of the white matter was determined. The white matter of the cerebellum is typical quasi-fractal structure that can be objectively described using fractal dimension. Fractal index of the white matter of the cerebellar hemispheres varies from 1.119 to 1.519; average fractal index is 1.370. Fractal analysis can be used as an objective morphometric criterion for the diagnosis of various diseases of the cerebellum and other structures of the central nervous system.

Conclusions. Described variants of the cerebellar lobules and fractal dimension can be used as criteria for modern diagnostic imaging techniques for the diagnosis of various diseases of the CNS. The data can be used as the basis for atlases of serial sections of the cerebellum.

Key words: human, cerebellum, fractal dimension, white matter, anatomical variability

Introduction. The cerebellum is one of the most important functional structures of the central nervous system, which provides statics and coordination, it is also involved in cognitive processes (learning, memory), emotional state regulation [2, 6, 9-11]. The literature describes topical distribution of the movements control functions [8] and functional topography of cognitive function and emotional control [9-11, 13].

Cerebellum has the most complex spatial configuration which is associated with the organization of the arbor vitae («Tree of Life") – tree-like branched white matter, which is structural basis of its cortex. White matter of the cerebellum consists of the central white matter and its eight branches, which form basis of ten classic lobes of the cerebellum. In accordance with the principle of mediolateral continuity, form of hemispheric cerebellar lobules is determined by the shape of vermal lobules [5]. Morphological changes of cerebellar lobules are found in many congenital and acquired diseases of the cerebellum (cerebellar ataxia, hereditary Pierre Marie Holmes cerebroolivary atrophy, cerebellar atrophy Marie-Foy-Alazhuanin, olivopontocerebellar degeneration, Dandy-Walker syndrome, Arnold-Chiari IV, Alzheimer's disease, multiple sclerosis, cerebellar alcohol degeneration, etc.). [7]. Also morphological changes of the cerebellar lobules (the change of volume segments, volume and structure of gray and white matter) at various mental disorders - autism, attention deficit hyperactivity disorder, dyslexia, schizophrenia, bipolar disorders [1, 3, 4, 12] were revealed. In recent years, thanks to modern imaging techniques (MRI, fMRI, CT, SPECT, PET) morphological changes of the hemispheric and vermal lobules that occur in these diseases can be detected in vivo, which is essential for early and accurate diagnosis. However, criteria of imaging diagnostic methods which are based on information about normal structure of the cerebellum, do not take into account the features of individual anatomical variability, gender and age characteristics.

Objective - to investigate anatomical variations and fractal dimension of the white matter of the human cerebellar hemispheres.

Material and methods

Research was conducted at the Kharkiv regional bureau of forensic medicine. The study involved 100 cerebella of people of both sexes, who died of causes unrelated to brain pathology (20–99 years old).

During the forensic autopsy the cerebellum and brain stem were separated and fixed during one month in 10% formalin solution. Parasagittal sections of cerebellar hemispheres were investigated. Were used morphological methods: anatomical dissection, fractal analysis of white matter and morphometry of the cerebellum. Midsagittal and parasagittal serial sections of the cerebellum were photographed by a digital camera. Digital images of the sections were investigated using a PC. Peculiarities of branching of the white matter, the number and arrangement of folia were investigated. Fractal analysis of white matter was conducted using the box-counting method. The data were processed by standard statistical methods.

Research results. The white matter of the cerebellum includes central white matter (corpus cerebelli) and 8 main branches of white matter, which divide into different number of secondary branches and form structural basis of 10 lobules of vermis (medial part of cerebellum) and hemispheres. I branch is the basis of the lingula cerebelli and vinculum lingulae; II and III branches form II and III lobules of the vermis and cerebellum (2 parts of the lobulus centralis and alae lobuli centralis); IV branch forms IV and V lobules (Culmen of the cerebellar vermis and anterior part of the quadrangular lobule of hemispheres). V branch forms VI and VII lobules, which also are called Neocerebellum. Neocerebellar lobules include lobule VI (Declive of the vermis and posterior part of the quadrangular lobule of hemispheres), Lobule VIIAf (Folium vermis) and Crus I (superior semilunar lobule of hemispheres), Lobule VIIAt (Tuber vermis) and Crus II (inferior semilunar lobule of hemispheres), Lobule VIIB (caudal aspect of Tuber vermis) and gracile lobule of hemispheres. VI branch forms lobule VIII (Pyramis vermis and biventral lobule of the hemispheres), VII branch forms lobule IX (Uvula of the vermis and cerebellar tonsils), VIII branch forms lobule X (Nodulus of the vermis and Flocculus of the hemispheres).

On the midsagittal section of the cerebellar vermis are found 8 main branches (fig. 1), but on parasagittal sections main branches are divided into different number of secondary branches, which depart directly from central white matter (corpus medullare). On parasagittal sections number of main branches of white matter is very varied and depends on peculiarities of structure of the hemispheric lobules.

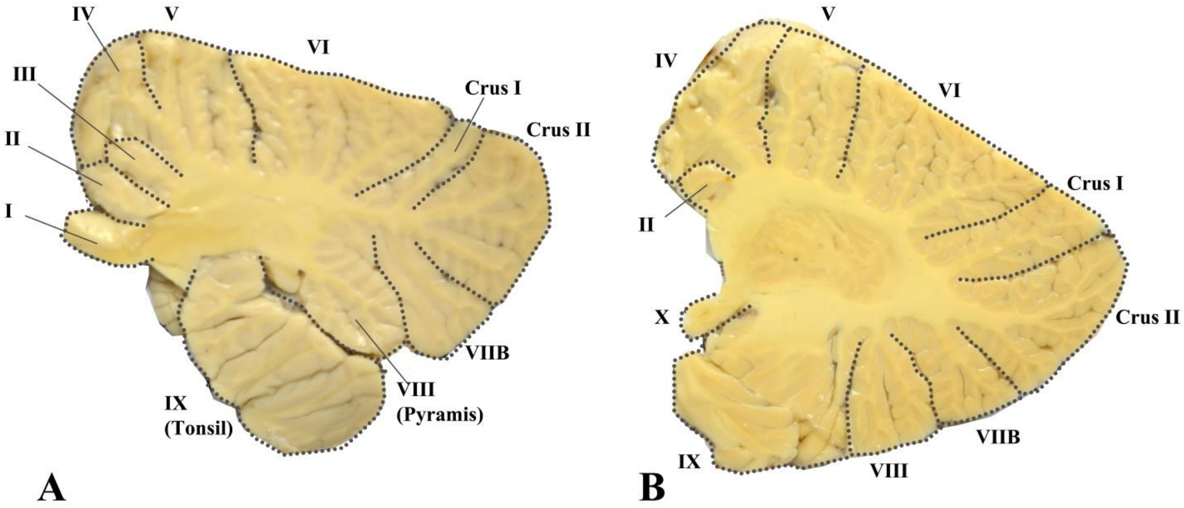

Fig. 1. Parasagittal sections of the cerebellar hemispheres: A – +5 mm to midsagittal section, B – +10 mm to midsagittal section.

I lobule (lingula) is regular lobule of the cerebellum. On parasagittal sections it is present only in medial paravermal parts of hemispheres as thin lamina of white matter, which is cowered by cortex.

II lobule (Lobulus centralis I) is regular lobule. It includes one branch of white matter, which divides into secondary branches in 7% of cases in left and right hemispheres. On parasagittal sections it is present in medial parts of hemispheres (up to 20 mm from midsagittal section).

III lobule (Lobulus centralis II) is not regular lobule; we found this lobule only in 33% of the cases. It includes one branch of white matter, which divides into secondary branches in 5% of cases in left hemisphere and 3 % in right hemisphere.

IV and V lobules (anterior part of the quadrangular lobule of hemispheres) can include 1-4 main branches of white matter. General number of the branches varies from 2 to 6 branches.

Table 1. The prevalence (%) of the number of the branches of white matter of the IV-V lobules of the human cerebellar hemispheres.

Number of branches	IV lobule		V lobule		IV and V lobules together	
	Left hemisphere	Right hemisphere	Left hemisphere	Right hemisphere	Left hemisphere	Right hemisphere
1	11	13	30	38		
2	57	65	61	58	3	4
3	31	22	7	3	31	37
4	1	0	2	1	49	48
5					14	11
6					3	0

As we can see in the data of table 1, the most common are 2 or 3 branches in the IV lobule and 1 or 2 branches in the V lobule. The number of branches in the right and left hemispheres corresponds in 43% of cases; the number of branches is different in 57% of cases.

VI lobule (posterior part of the quadrangular lobule of hemispheres) includes 2-4 branches of the white matter. Depending on the number of branches, all lobules can be divided into three types. The first type includes lobules that have two big branches of white matter. This type is found in 13.5% of cases (in the left hemisphere - 12%, in the right - 15%). The second type includes lobules with three major branches of the white matter and is found in 49% of cases (left - 53% right - 45%). A lobule of the third type has four major branches of the white matter. This type is found in 37.5% of cases (left - 35% right - 40%).

VI-VII lobules are formed by fifth main branch of the white matter. Secondary branches of this lobule form three lobules: Crus I (superior semilunar lobule of hemispheres), Crus II (inferior semilunar lobule of hemispheres) and gracile lobule of hemispheres. Crus II is continuation of the main branch, Crus I deviates from main branch in the rostral (upper) direction, gracile lobule deviates in the caudal (lower) direction. We described three types of the branching of white matter of the neocerebellar lobules (fig. 2). In the first type, Crus I deviates in proximal part of the main trunk, gracile lobule deviates in distal part. This type is found in 40% of cases (left - 41% right - 39%). In the second type, gracile lobule deviates in proximal part of the main trunk, Crus I deviates in distal part. This type is found in 46,5% of cases (left - 46% right - 47%). In the third type, main trunk is divided in one location into three branches: rostral (upper) branch forms Crus I, middle branch forms Crus II and caudal part forms gracile lobule. This type is found in 13.5% of cases (left - 13% right - 14%). The types of branching are similar in both hemispheres in 54% of cases; in 46% cases the types are different in right and left hemispheres.

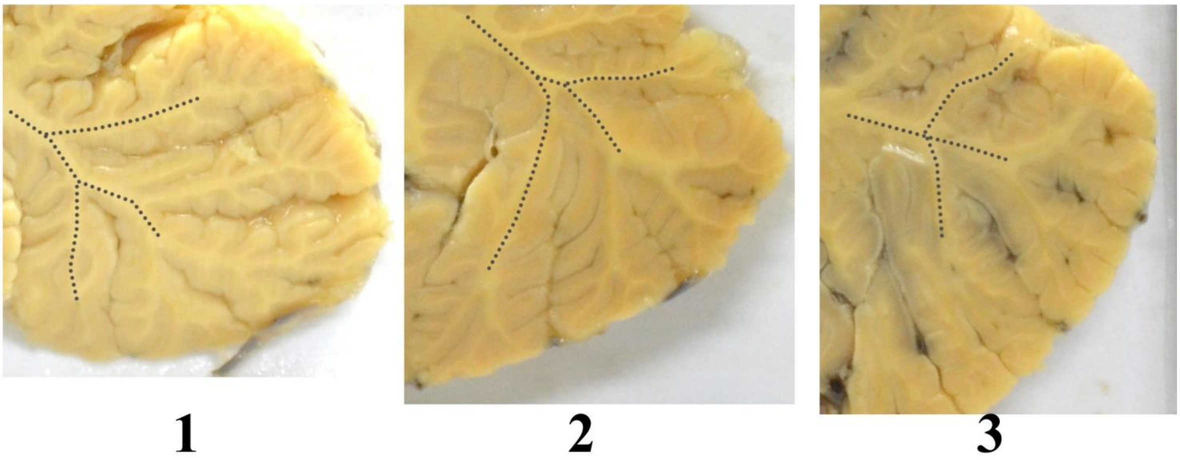

Fig. 2. Types of branching of the V main branch of the white matter of the cerebellum (Crus I, Crus II and gracile lobule); description in the text (+5 mm to midsagittal section).

VIII lobule of the hemispheres divides into 2 parts: rostral (VIIIA) and caudal (VIIIB). Both parts of the lobule include 2 branches of white matter. We described 3 variants of branching of white matter of lobule VIII. First variant of lobule consists of main trunk of white matter, which is divided into two secondary branches. The white matter is Y-shaped. This type is found in 10.5% of cases in rostral part (left - 12% right - 9%) and in 53.5% of cases in caudal part (left - 54% right - 53%). Second variant of lobule includes two branches of white matter which are connected only in the basal part. The white matter is V-shaped. This type is found in 41.5% of cases in rostral part (left - 40% right - 43%) and in 38% of cases in caudal part (left - 37% right - 39%). Third variant of lobule includes two branches of white which are not connected. This type is found in 48% of cases in rostral part (left - 48% right - 48%) and in 8.5% of cases in caudal part (left - 9% right - 8%).

IX lobule (cerebellar tonsil) is formed by one branch of white matter, which forms 4-9 secondary branches. 4 branches are found in 7.5% (8% in left hemisphere and 7% in right hemisphere), 5 branches are found in 23.5% (23% (left) and 24% (right)), 6 branches are found in 27.5% (28% (left) and 27% (right)), 7 branches are found in 21.5% (21% (left) and 22% (right)), 8 branches are found in 16.5% (17% (left) and 16% (right)), 9 branches are found in 3.5% (3% (left) and 4% (right)). The number of branches on the right and left hemispheres corresponds in 43% of cases, is different in 57%, it indicates the presence of interhemispheric asymmetry.

X lobule of the hemispheres (Flocculus) is formed by VIII branch of white matter. This lobule is anatomically and functionally connected with lobule X of the cerebellar vermis (Nodulus). This lobule includes only one branch of white matter and is covered by cortex, which can be divided into some folia.

Fractal dimension of the white matter. Fractal index is used as measure of the complexity of spatial fractal structure, index of the space filling. Fractal index (FI) ranges from 1.0 to 2.0. The object with fractal index 1.0, is a simple straight line, practically fills the space. The object with fractal index 2.0, fills all available space.

Fractal index values of the white matter of the hemispheres are shown in Table 2.

Table 2. Statistical evaluation of fractal dimension of the white matter of the human cerebellar hemispheres

Section (distance to midsagittal section, mm)	Cerebellar hemisphere	M	m_m	σ	*Cv, %*	m_{cv}	*min*	*max*
5	Left hemisphere	1.369	0.011	0.108	7.889	0.558	1.274	1.492
	Right hemisphere	1.371	0.010	0.098	7.148	0.558	1.212	1.501
	Average FI	1.370	0.010	0.103	7.518	0.558	1.243	1.497
10	Left hemisphere	1.365	0.010	0.101	7.399	0.523	1.199	1.511
	Right hemisphere	1.368	0.010	0.104	7.602	0.558	1.223	1.504
	Average FI	1.367	0.010	0.103	7.538	0.558	1.211	1.508
15	Left hemisphere	1.370	0.011	0.105	7.664	0.542	1.243	1.519
	Right hemisphere	1.367	0.010	0.103	7.535	0.558	1.233	1.516
	Average FI	1.369	0.010	0.104	7.600	0.558	1.238	1.518
20	Left hemisphere	1.368	0.010	0.097	7.091	0.501	1.212	1.498
	Right hemisphere	1.366	0.010	0.096	7.028	0.558	1.209	1.497
	Average FI	1.367	0.010	0.096	7.023	0.558	1.211	1.498
25	Left hemisphere	1.364	0.010	0.102	7.478	0.529	1.215	1.502
	Right hemisphere	1.368	0.011	0.105	7.675	0.558	1.211	1.511
	Average FI	1.366	0.010	0.103	7.540	0.558	1.213	1.507
30	Left hemisphere	1.371	0.010	0.097	7.075	0.500	1.214	1.497
	Right hemisphere	1.367	0.010	0.101	7.388	0.558	1.209	1.489
	Average FI	1.369	0.010	0.099	7.232	0.558	1.212	1.493
35	Left hemisphere	1.369	0.011	0.106	7.743	0.548	1.206	1.503
	Right hemisphere	1.371	0.011	0.108	7.877	0.558	1.199	1.507
	Average FI	1.370	0.011	0.107	7.810	0.558	1.203	1.505
40	Left hemisphere	1.370	0.010	0.096	7.007	0.496	1.208	1.499
	Right hemisphere	1.372	0.010	0.098	7.143	0.558	1.211	1.492
	Average FI	1.371	0.010	0.097	7.075	0.558	1.210	1.496

As seen from Table. 2, fractal index of white matter varies from 1.119 to 1.519. Fractal indexes of the corresponding sections of the left and right hemispheres were compared using Student's test; the difference between symmetrical sections was not statistically significant. The difference between all parasagittal sections located at different distances from midsagittal section was not statistically significant (the comparison was conducted using the Kruskal-Wallis test).

Findings. Thus, it was found that there is individual variability of the structure of the human cerebellar hemispheres, namely white matter branching features. We described variants of the branching of the white matter of hemispheric lobules. Described shape variants of the cerebellar lobules can be used as criteria for modern diagnostic imaging techniques for the diagnosis of various diseases of the CNS. The data can be used as the basis for atlases of serial sections of the cerebellum.

The white matter of the cerebellum is typical quasi-fractal structure that can be objectively described using fractal dimension. Fractal analysis can be used as an objective morphometric criterion for the diagnosis of various diseases of the cerebellum and other structures of the central nervous system. Fractal analysis can be used for morphometric studies of other biological structures with complex spatial organization.

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