Labelling of individual ependymal areas in lateral ventricles of human brain: ependymal tables

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ABSTRACT
Different types of ependymal areas were studied and labelled in the human brain lateral ventricle. Periventricular structures were included in coining the names of the ependymal areas because they represent a basic and stable part of brain nerve structures suitable for the sake of clarity of localization of the ependyma. The labelling of individual ependymal areas was composed from letters: “Lv” (lateral ventricle); “E” (ependymal area) and letters for abbreviations of the closest periventricular structure, e.g. the septum pellucidum is “sp”. The labelling for ependymal area over the septum pellucidum is thus “LvE-sp”. The studied types of ependymal areas were arranged in so-called ependymal tables for cornu anterius, pars centralis, cornu inferius and cornu posterius of the human lateral ventricle. Labelling of individual ependymal areas allows for better localization and characterisation of these areas in future studies carried out by various methods (e.g. morphological, biological, molecular) and will prevent from using misnomers with different types of ependymal areas in norm as well as in pathology (Tab. 5, Fig. 6, Ref. 22).

KEY WORDS: human, central nervous system, lateral brain ventricle, ependymal areas, ependymal tables.

Introduction

The walls of the brain ventricles are lined with ependymal cells discovered by an eminent Czech scientist Jan Evangelista Purkyne in 1836. As it was shown that ventricle walls in human brain consist of three layers – ependymal layer, layer of subependymal glial fibres and layer of subependymal glial cells (1). In some regions, however, a distinguished layer of ependymal cells or subependymal cells is not present. An occurrence of small areas without ependyma is considered to be a normal phenomenon (1, 2). The ventricle wall lining in humans is also characterized by the presence of ependymal folding e.g. in region of vena thalamostriata (3).

One of the wide-spread view points about ependymal lining is that it is a homogenous population of ependymal cells. However, several works point to the heterogeneity of ependymal covering of the human brain walls, showing variability e.g. in form and number of cells in layers of ependyma. This fact might result from many uncertainties appearing at the evaluation of ependyma and probably are also caused by the lack of uniformed classification of different ependymal areas so that results of different authors may be compared only with certain difficulties (2, 4–9).

The surface of ependymal cells is in contact with cerebrospinal fluid (CSF). Ependymal cells monitor the quality of CSF and provide the underlying periventricular nervous tissue with information about various extracellular active signal molecules (10–16).

In our work, we attempted to develop a reproducible method of labelling individual ependymal areas of the walls of lateral ventricles, involving periventricular structures, i.e a method of coining the names for ependymal areas.

In this work „ependyma“ is referred only to ependymal cells. The term „ventricular wall“ is referred to as follows:

Ependymal cells that form the most inner part of ventricle wall, Non-ependymal components localised in very close neighbourhood of ependymal cells (e.g. periventricular nerve and glial cells and other brain tissue components).

It is supposed, that the proposed method of naming the ependymal areas of human brain lateral ventricle will prevent misnomers when studied in norm as well as in pathology and in this manner to broaden our understanding of the role of individual ependymal areas.

Material and methods

Five human brains from individuals of both sexes aged from 27 to 60 years were used for the study (Tab. 1).

| Specimen | Age (years) | Sex | Cause of Death |
|----------|-------------|-----|----------------|
| B1       | 27          | female | neoplasma renis |
| B2       | 42          | male  | infarctus myocardii |
| B3       | 60          | male  | embolia trunci pulmonalis |
| B4       | 69          | female | atherosclerosis |
| B5       | 73          | male  | atherosclerosis |
The brains were removed by a standard procedure. In 24–48 hours after death, brains were fixed in 10% neutral formaldehyde. After 24 hours, fixation formalin was replaced with a fresh solution. The fixation of the brains lasted 30 days, then the brains were washed under running tap water for the next 24 hours. Fixed brains were sliced with an auxiliary device to obtain frontal brain slices equal in their thickness (0.5 cm).

The large brain slices were photographed by a standard technique. From large brain slices, small pieces of ventricle wall were excised and embedded in paraffin. Histological sections of 10 μm were stained with hematoxyline-eosine and cresyl-blue dyes.

**Results**

The brain ventricle system is composed of two lateral brain ventricles, third and fourth brain ventricles (Fig. 1 a).

The lateral ventricles (from the lateral view) resemble an irregular semi-circular cylinder, localized in each brain hemisphere and it can be divided to cornu anterius, pars centralis, cornu posterius and cornu inferius (Fig. 1 b).

The brains were cut in frontal sections and individual so-called large brain sections were drawn into a scheme and numbered from 1 to 12 (Fig. 1 c).

The wall of lateral ventricle, closer to the middle of the brain is referred to as inner wall (inw) and the wall more distant from the middle of the brain is referred to as external wall (exw). In some parts of the lateral ventricles, the dorsal wall (drw) is present.

**Cornu anterius**

In section 1, the “inw” is adjacent to genu corporis callosi (gcc). It is lined with multilayered ependyma. On the “exw” of cornu anterius, close to the caput nuclei caudati (canc), largely cuboidal ependyma is present (Tab. 1).

| Section | Wall | Periventricular structure | Name | Abbreviation | Labbeling of ependyma |
|---------|------|--------------------------|------|--------------|-----------------------|
| 1       | internal | genu corporis calloso | gcc | LvE-gcc |
| 2       | external | caput nuclei caudati | canc | LvE-canc |
| 3       | internal | truncus corporis calloso | tcc | LvE-tcc |
| 4       | internal | septum pellucidum | sp | LvE-sp |
| 5       | external | stratum subcallosum | ssc | LvE-ssc |
| 6       | internal | caput nuclei caudati | canc | LvE-canc |
| 7       | external | stratum subcallosum | ssc | LvE-ssc |
| 8       | internal | nuclei septi laterales | nsl | LvE-nsl |
| 9       | internal | septum pellucidum | sp | LvE-sp |
| 10      | external | corpus fornicis | cof | LvE-cof' |
| 11      | external | caput nuclei caudati | canc | LvE-canc |
| 12      | external | stratum subcallosum | ssc | LvE-ssc |

**Fig. 1. a) Scheme of the brain ventricles (↓ – lateral ventricle, x – third ventricle, + – aquaeductus cerebri, Δ – fourth ventricle); b) Scheme of the lateral ventricle: A-A’ – line placed on the dorsal end of the interventricular foramen, B-B’ – line running in place of merging of cornu inferior with cornu posterior (ca – cornu anterius; pc – pars centralis; ci – cornu inferius; cp – cornu posterius); c) Scheme of the lateral ventricle with histological sections 1–12 (sections 1–4 – cornu anterius, sections 5–6 – pars centralis, sections 7–9 – cornu inferius, sections 10–12 – cornu posterius).**
In section 2, the “inw” near truncus corporis callosi (tcc), septum pellucidum (sp), and rostrum corporis callosi (rocc), cuboidal to multilayered ependyma covers the wall of that part of cornu anterius. The ependyma of the “exw” adjacent to stratum subcallosum (ssc) and caput nuclei caudati (canc) is largely cuboidal.

In section 3, the cross section of the ventricle has a triangular shape. The “inw” close to septum pellucidum (sp), nuclei septi laterales (nsl) and corpus fornicens (cof), is covered with cuboidal ependyma. The “exw” in region of caput nuclei caudati (canc) and stratum subellulsum (ssc) is covered with irregular cuboidal ependyma. The “drw” is covered with cuboidal ependyma in area of truncus corporis callosi (tcc).

In section 4, the “inw” adjacent to corpus fornicens (cof) and foramen interventriculare (fiv) the ependyma is one-layered to
Fig. 3. Pars centralis.

Fig. 4. Cornu inferius.
multi-layered. The “exw” close to stratum subcallosum (ssc), corpus nuclei caudati (conc), stria terminalis (st) and vena thalamostriata (vts) is lined with irregular flat, cuboidal one-layered to multi-layered ependyma. The “drw” in the area of truncus corporis callosi (tcc) is lined by cuboidal ependyma (Fig. 6 a).

Large brain sections of cornu anterius and ependymal table of cornu anterius are demonstrated in Figure 2 and Table 2.

### Pars centralis

In section 5, the “inw” is covered by cuboidal ependyma localized adjacent to septum pellucidum (sp), corpus fornicis (cof) and crus fornicis (crf). The “exw” close to the stratum subcallosum (ssc), corpus nuclei caudati (conc), vena thalamostriata (vts), nucleus lateralis dorsalis (nld) and nucleus anterior thalami (nat) is covered by cuboidal to columnar ependyma. The “drw” close to the truncus corporis callosi (tcc) is lined by cuboidal ependyma.

In section 6, the “inw” in the region of the crus fornicic (crf) is formed by irregular cuboidal ependyma. The “exw” adjacent to stratum subcallosum (ssc), caput nuclei caudati (canc), vena thalamostriata (vts) and nucleus lateralis dorsalis (nld) is covered by cuboidal to columnar ependyma. The “drw” close to truncus corporis callosi (tcc) is lined by cuboidal ependyma (Fig. 3 and Tab. 3).

### Cornu inferius

In section 7, the “inw” is adjacent to the hippocampus (hipp). The flat to cuboidal ependyma covers the ventricle wall in that part of cornu inferius. The “exw” close to cauda nuclei caudati (caunc) is lined with cuboidal ependyma.

### Cornu posterius

In section 8, the “inw” is adjacent to the septum pellucidum (sp), corpus fornicis (cof) and crus fornicis (crf). The “exw” close to the stratum subcallosum (ssc), caput nuclei caudati (canc), vena thalamostriata (vts), nucleus lateralis dorsalis (nld) and nucleus anterior thalami (nat) is covered by cuboidal to columnar ependyma. The “drw” close to truncus corporis callosi (tcc) is lined by cuboidal ependyma (Fig. 4 and Tab. 4).
In section 8, the “inw” is adjacent to the hippocampus (hipp) and is covered with cuboidal ependyma. The “exw” close to cauda nuclei caudati (caunc) is covered by cuboidal ependyma.

In section 9, the “inw” close to the hippocampus (hipp) is covered by multi-layered ependyma over. The “exw” adjacent to cauda nuclei caudati (caunc) and stria terminalis (st) is lined with one-layered to multi-layered ependyma (Fig. 4 and Tab. 4).

In section 10, the “inw” in the region of hippocampus (hipp) and crus fornix (crf) is covered with one-layered to multi-layered ependyma. The “exw” is close to the tapetum (tap) and lined with cuboidal ependyma. The “drw” close to the splenium corporis callosi (scc) is formed by multi-layered ependyma.

In section 11, the “inw” is close to hippocampus (hipp) and crus

Fig. 5. Cornu posterius.

Fig. 6. Type of ependyma: a) cuboidal regular ependyma; b) multilayered ependyma.
formix (crf). The ependyma is multi-layered (Fig. 6 b). The “exw” close to the tapetum (tap) is lined by multi-layered ependyma.

In section 12, the “exw” close to the tapetum (tap) is covered by multi-layered ependyma (Fig. 5 and Tab. 5).

The ependymal Tables 2–5 summarise the studied ependymal areas, including Latin names and abbreviations of periventricular structures as well as the labelling of ependymal areas.

Because it was found that e.g. cuboidal ependyma is present in all parts of the lateral ventricle, it was difficult to name the studied ependymal area only by its structure e.g. cuboidal ependyma of the lateral ventricle. It is suggested that coining the name for the wall of the studied parts (studied horn) of the ventricle as it is shown in ependymal tables, will help to localise better the individual ependymal areas.

Discussion

Labels for individual ependymal areas of the wall of the human lateral ventricle were not composed on the basis of their histological structures but rather on their localization relative to the closest periventricular nerve structures (17). These structures as basic parts of the brain are characterised by their stable localization.

It is known, that the periventricular nerve tissue belongs to the basic morphological structures of the brain (as such they are easily reproducible) and therefore they were included into the process of coining the names for individual ependymal areas of the walls of human lateral ventricle.

The principles of suggested method, (i.e. labelling of ependymal areas by means of periventricular brain nerve structures) can be applied also for other human brain ventricles in adults as well as during the development.

However, also other terms are used for naming the ependyma in the brain ventricles, e.g. neural type of ependymal cells, standard type ependymal cells, ependymal region, ependymal zone, specific subtypes of ependymal cells, tanyocytes (9, 15, 18, 19).

It is expected that this work can assist in obtaining the answer to the question whether certain pathological changes of ependyma are related only to one or all types of ependymal areas of the walls of lateral ventricle in adult human brain.

It is possible to suppose that in spite of a very similar morphological arrangement of ependymal areas (ependymal cells) in the human lateral ventricles, these may differ, for example in the presence or absence of various receptors or active molecules on cell membranes (11).

In CSF and periventricular nervous tissue, various extracellular signal molecules (hormones, cytokines, growth factors) are present (13, 20–22). According to the place of effectiveness of these molecules in ependymal areas located over various types of periventricular structures, they could react via different mechanisms.

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