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Paradigm of aqueducts in the structure of human encephalon. Implications in pathology

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Abstract: The presence of hemorrhagic fluids originating from cerebral ventricles (III, IV) preferable inside cerebellum-medullary and quadrigeminal subarachnoid cisterns in fetus and new born, determined the authors to make a macroanatomic analysis of fluid pathways from III and IV ventricles to adjacent subarachnoid spaces. The study was achieved on human biologic material: embryos, fetus, new born deceased before or after birth and on adult encephalon. The authors analyzed the variable topographic distribution of vertebral-basilar arterial system branches, the location for lateral aperture Luschka and the extraventricular part of choroid plexus of the fourth ventricle, the location and relations of subarachnoid cisterns and especially the quadrigeminal cistern ant they also performed an analysis of phenotype changes undergone by rhombencephalon structures during ontogenesis. Based on the results of personal observations, the authors consider that hemorrhagic fluids of the fourth ventricle flow through lateral aqueducts Luschka to cerebellum-medullary cisterns and though an aqueduct demonstrated by Bichat that opens in quadrigeminal cistern.

Key Words: aqueducts, aperture lateralis (Luschka), Bichat's duct, quadrigeminal cistern, cerebellum-medullary cistern.

Phenotype changes of neural tube during ontogenesis dynamics determine changes of the relations between telecenphalon, mesencephalon and rhombencephalon neuronal structures and the formation of intra and extra-ventricular spaces for the circulation of cerebrospinal fluid. Incongruences between encephalon neurovascular structures and the structures derived from cordomezoblast and ectomenix have as consequence the formation of some intercommunicating compartments. The delay in time and space between the genesis of leptomeninges (pia mater and arachnoid) from ectomesenchym derived from neural crests and the formation of dura mater from ordinary mesenchyme lead to the appearance of a wide communication space between the base of telencephalon and superior face of rhombencephalon.

The variable space distribution of hemorrhagic areas around rhombencephalon and the simultaneous existence of intraventricular hemorrhagic determined us to make a macro and mezoscopic anatomic study on the genesis and differentiation of ventricles and subarachnoid cisterns, correlated to the stereodistribution of arterial branches in vertebral-basilar system.

The purpose of the paper is to know the morphology of aqueducts system inside encephalon structure in order to evaluate the cerebrospinal fluid circulation pathways. We proposed to identify the anatomic location and the relations of rhombencephalon vascular and neuronal structures and the location of aqueducts for the communication between ventricular and extraventricular subarachnoid spaces. These

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objectives were determined by the heterogeneity of anatomic terms and the lack of a demonstrative imagery of anatomic specimens.

MATERIAL AND METODS

The study was carried out on human biologic material respecting the medical deontology and medical research criteria. The macroscopic analysis was performed on three 8 weeks old embryos, five 16 weeks old fetus, seven 20 weeks old fetus, three new born and two adults aged 50 and 62 years old. The encephalon was harvested from the skull by classical methods and fixed in 5% saline formaldehyde solution. Using macrodissection, we visualized the parts of rhombencephalon, location and relations of choroid plexus inside the fourth ventricle, space distribution of vertebral-basilar arterial system and the relations of cerebrum transverse fissure. The study of the evolution during ontogenesis dynamics of the relations between telencephalon, mesencephalon and rhombencephalon was made on median and sagittal sections through cephalic extremity of embryos, fetus, new born and adult individuals.

Macroanatomic imagery was achieved using canon Digital Camera EOS Mark II equipped with Macro Ultrasonic Lens EF 100 mm, F/28. Image processing was possible using Professional Digital Photo Software and Adobe Photoshop CS4.

RESULTS

The variable location of spaces for the circulation of cerebrospinal fluid, of hemorrhagic or purulent effusions determined us to make a multifactorial analysis of the topographic distribution of vertebral-basilar arterial system inside rhombencephalon, of location for the recess and lateral aperture Luschka, of location and relations of subarachnoid cisterns and of phenotype changes involving rhombencephalon structures during ontogenesis.

1. Analysis of variable topographic distribution of vertebral-basilar arterial system inside rhombencephalon

The macro anatomic analysis was performed on basal face of encephalon as a whole (Fig.1) and on the ventral and dorsal faces of rhombencephalon after detaching it from telencephalon by sectioning cerebral peduncles (Fig.2). We noticed that in all anatomic specimens, arteria superior cerebelli originates in the close vicinity to basilar artery bifurcation (Fig. 2A). In two cases out of the ten studied, we noted the existence of an anatomical variant for arteria cerebelli superior sinistra, that is the existence of two arteries originating in basilar artery (Fig. 2 A, B). Arteria inferior anterior cerebelli had a great variability regarding its origin and diameter (Fig.1 and 2). In 90% of the specimens there is an asymmetry in its emergence and thickness such as: on the right side, the artery originates caudal (Fig.1 and 2A); in 10% of cases, the origin of the two arteries is coplanar. Equally, we observed a certain specificity in the space distribution of arterial branches: on the dorsal face of cerebellum for arteria cerebelli superior (Fig. 2 C), on the ventral face and on the circumference of cerebellum for arteria inferior anterior cerebelli and only on the ventral face of cerebellum for arteria inferior posterior cerebelli (Fig. 2 A-C).

The branches of cerebellar arteries remain on the surface of cerebellum circumvolutions without entering the fissures. They contribute to the formation of an arterial network that occupies the external face of pia mater and will generate nutritive branches for cerebellar cortex (Fig. 2 C).

2. Analysis of the location of lateral aperture (Luschka) and of extra-ventricle part of fourth ventricle choroid plexus

From the macroanatomic analysis of rhombencephalon specimens one can easily state the presence of an extra-ventricle part of fourth ventricle choroid plexus in the neighborhood of flocculus lobule pedicle. Due to this relation, the extra-ventricle part of fourth ventricle choroid plexus was named “choroid plexus of flocculus lobe” (Fig. 1 and 3). After opening the fourth ventricle, we identified the choroid plexus in the lateral recesses and its protrusion into lateral aperture, thus becoming partially extraventricular (Fig. 3 A – H). The external extremity of this choroid plexus has a granular aspect (Fig. 3 E, F).

3. Analysis of location and relations of subarachnoid cisterns

Subarachnoid space is known a space for accumulating fluids (effusion, hemorrhagic, purulent). It drew our attention when examining the sagittal sections through fetus cephalic extremity. When dealing with a hemorrhagic collection, five subarachnoid cisterns become obvious: cerebellomedularis posterior, cisterna magna, cerebellomedularis lateralis, pontocerebellaris and quadrigeminalis (Fig. 6 H).

Analyzing the sagittal sections through the cephalic extremity of a 16 weeks old fetus, we identified a subarachnoid space of rhombic shape in the caudal part of primordial segments of rhombencephalon (Fig. 6 B). The rostral angle of this territory corresponds to splenium corpori callosi, caudal angle to cerebellar vermis and lateral angles to peduncle subarachnoid cisterns. In this space we visualized the posterior cerebral arteries and galien vein (Fig. 6).

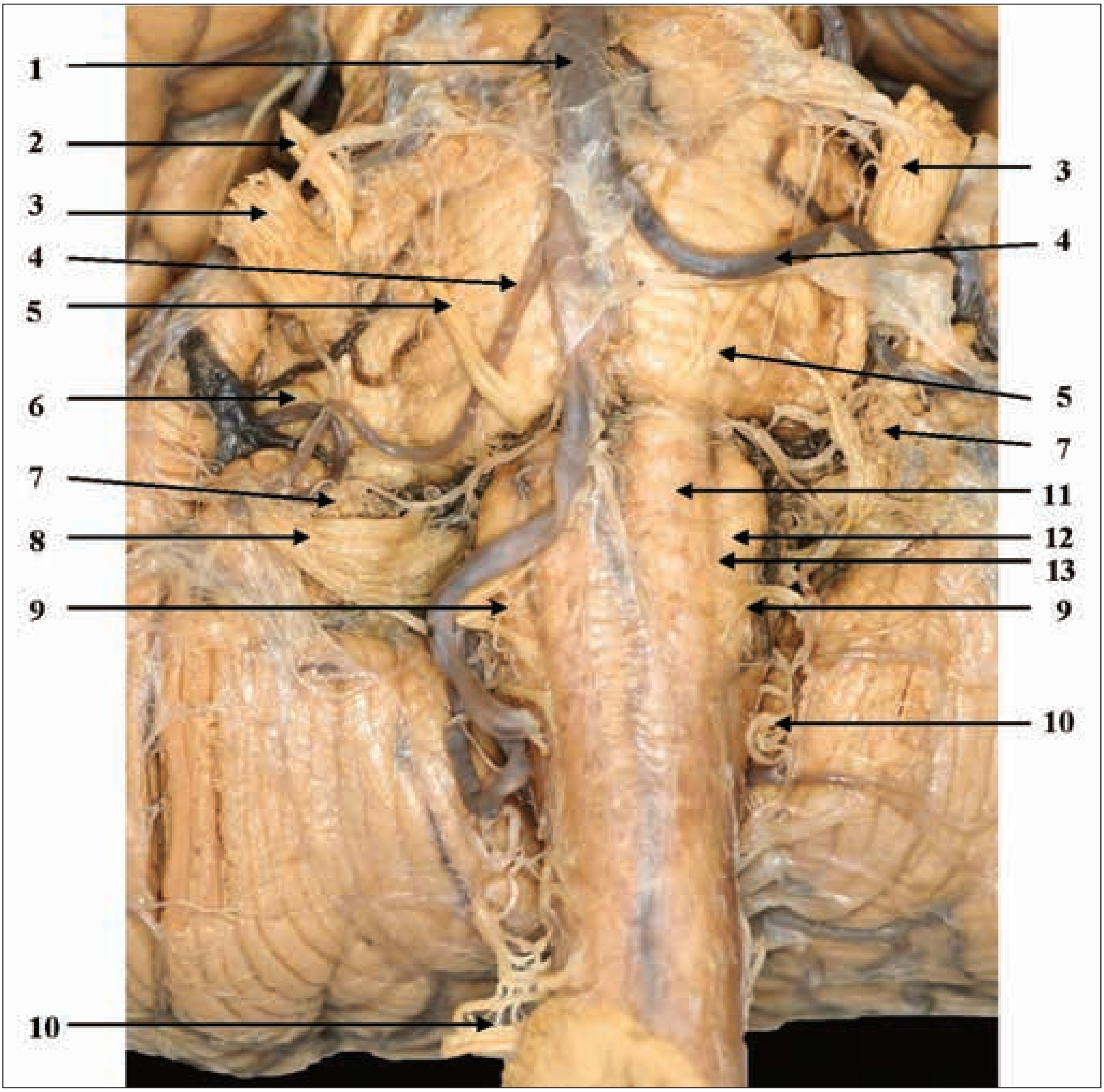

Figure 1. Visualization of rhombencephalon parts, of basilar artery branches and of emergence of cranial nerves on the base of encephalon. 1. Arteria basilaris; 2. Nervus trigeminus – radix sensoria; 3. Nervus trigeminus – radix motoria; 4. Arteria inferior anterior cerebelli; 5. Nervus oculomotorius; 6. Pedunculus cerebellaris medius; 7. Plexus choroideus ventriculi quarti – pars extraventricularis; 8. Nervus vagus; 9. Nervul hipoglossus; 10. Nervus accessories – radix spinalis et cranialis. Macrophotos by Canon EOS Mark II Digital Camera. Macro Ultrasonic lens, EF 100 mm, F/2,8. Imagery from Prof. Dr. G.S. Dragoi's neuroanatomy collection.

Examination of posterior part of rhombencephalon allowed us to identify posterior cerebelomedullaris cistern. It has a 3D shape of a pyramid with the apex oriented ventrally, and with the convex faces formed by the caudal part of vermis – tonsil cerebelli. The base of that pyramid is represented by a large arachnoid tissue that spreads vertically between medulla oblongata and cerebellum hemispheres. In this space we identified arteria inferior posterior cerebelli. Close to the apex of this pyramidal space there is the median opening (Magendie) [3, 4] that allows the communication to fourth ventricle (Fig. 3 G, H).

On adult encephalon, we distinguished a transit canal described by Bichat (Fig. 5E) [15, 16], in the rostral part of transverse fissure (Bichat), between splenium corpori callosi and quadrigeminal tubercles, in the middle of quadrigeminalis cistern. The author considered that arachnoid forms a circular fold similar to Winslow hiatus around Galien vein. He noticed that

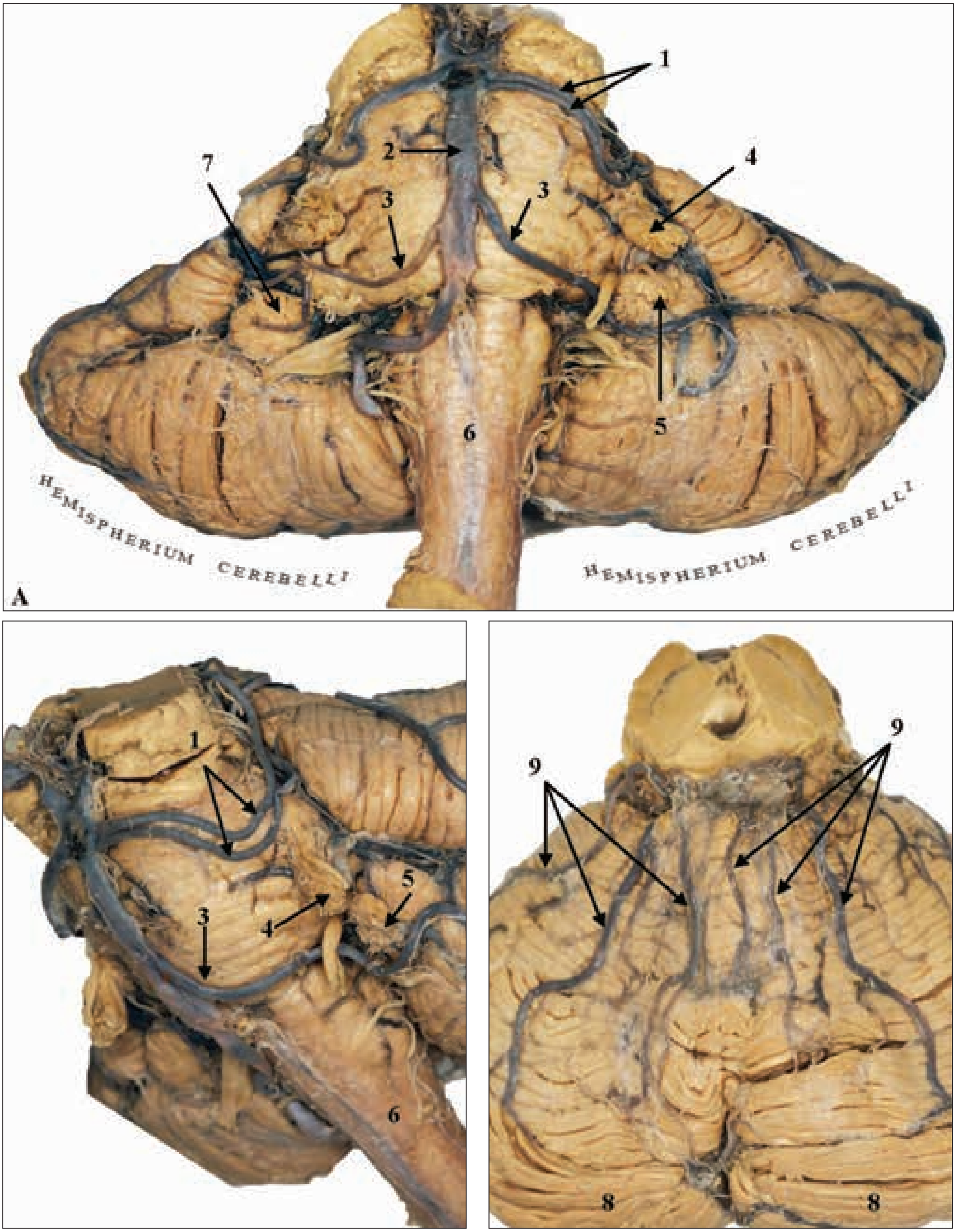

Figure 2. Space distribution of basilar artery branches visualized on ventral (A), lateral (B) and dorsal (C) faces of rhombencephalon. 1. Arteria superior cerebelli; 2. Arteria basillaris; 3. Arteria inferior anterior cerebelli; 4. Nervus trigeminus – radix motoria; 5. Plexus choroideus ventriculi quarti – pars extraventricularis; 6. Medulla oblongata; 7. Lobus flocculonodularis; 8. Hemispherium cerebelli; 9. Branches of arteria superior cerebelli. Macrophotos by Canon EOS Mark II Digital Camera. Macro Ultrasonic lens, EF 100 mm, F/2,8. Imagery from Prof. Dr. G.S. Dragoi's neuroanatomy collection.

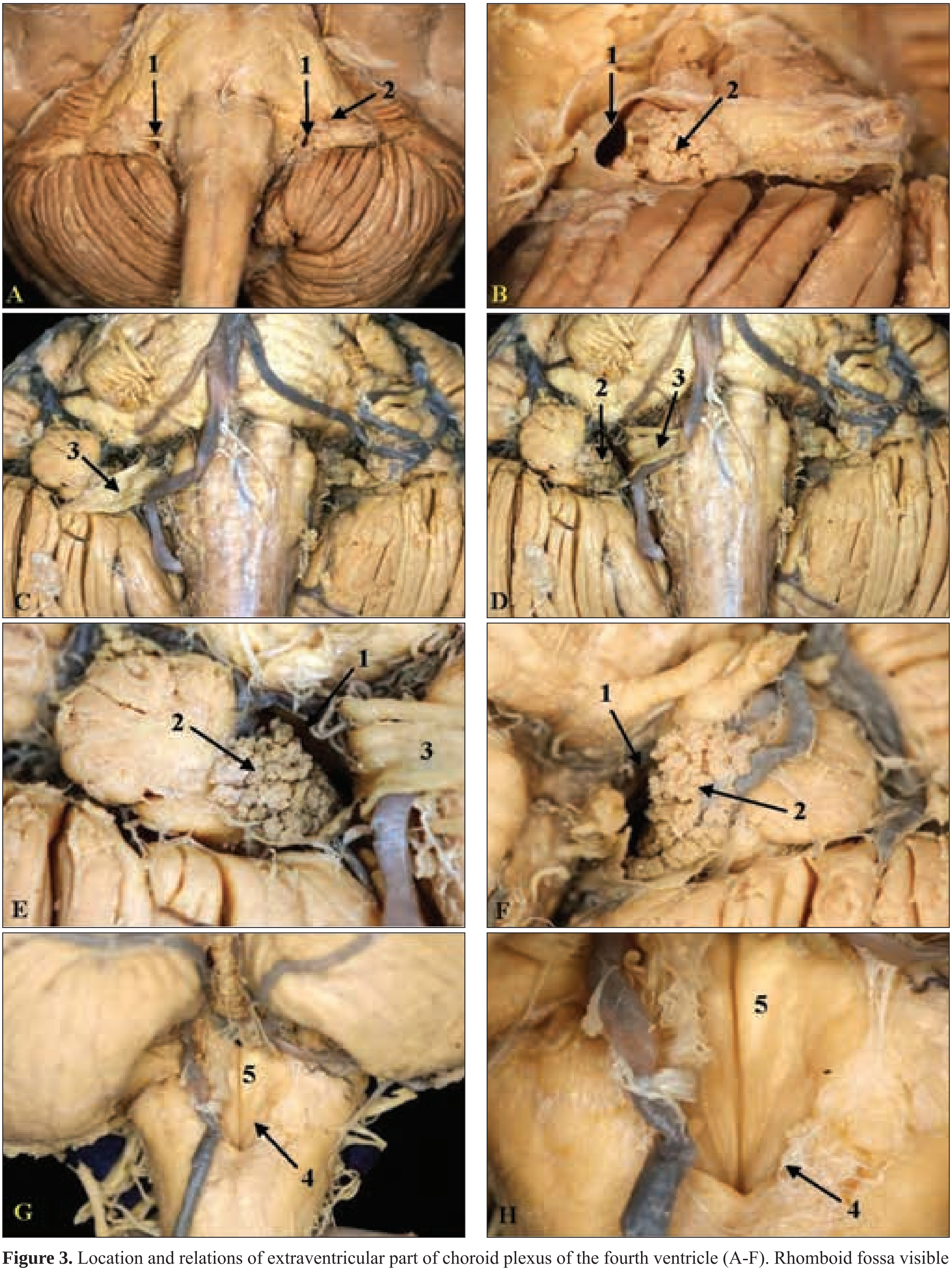

Figure 3. Location and relations of extraventricular part of choroid plexus of the fourth ventricle (A-F). Rhomboid fossa visible after sectioning of tegmen ventriculi quarti (G, H). 1. Apertura lateralis (ventriculus quartus); 2. Plexus choroideus ventriculi quarti – pars extraventricularis; 3. Nervus vagus; 4. Apertura mediana ventriculi quarti; 5. Fossa rhomboidea. Macrophotos by Canon EOS Mark II Digital Camera. Macro Ultrasonic lens, EF 100 mm, F/2,8. Imagery from Prof. Dr. G.S. Dragoi's neuroanatomy collection.

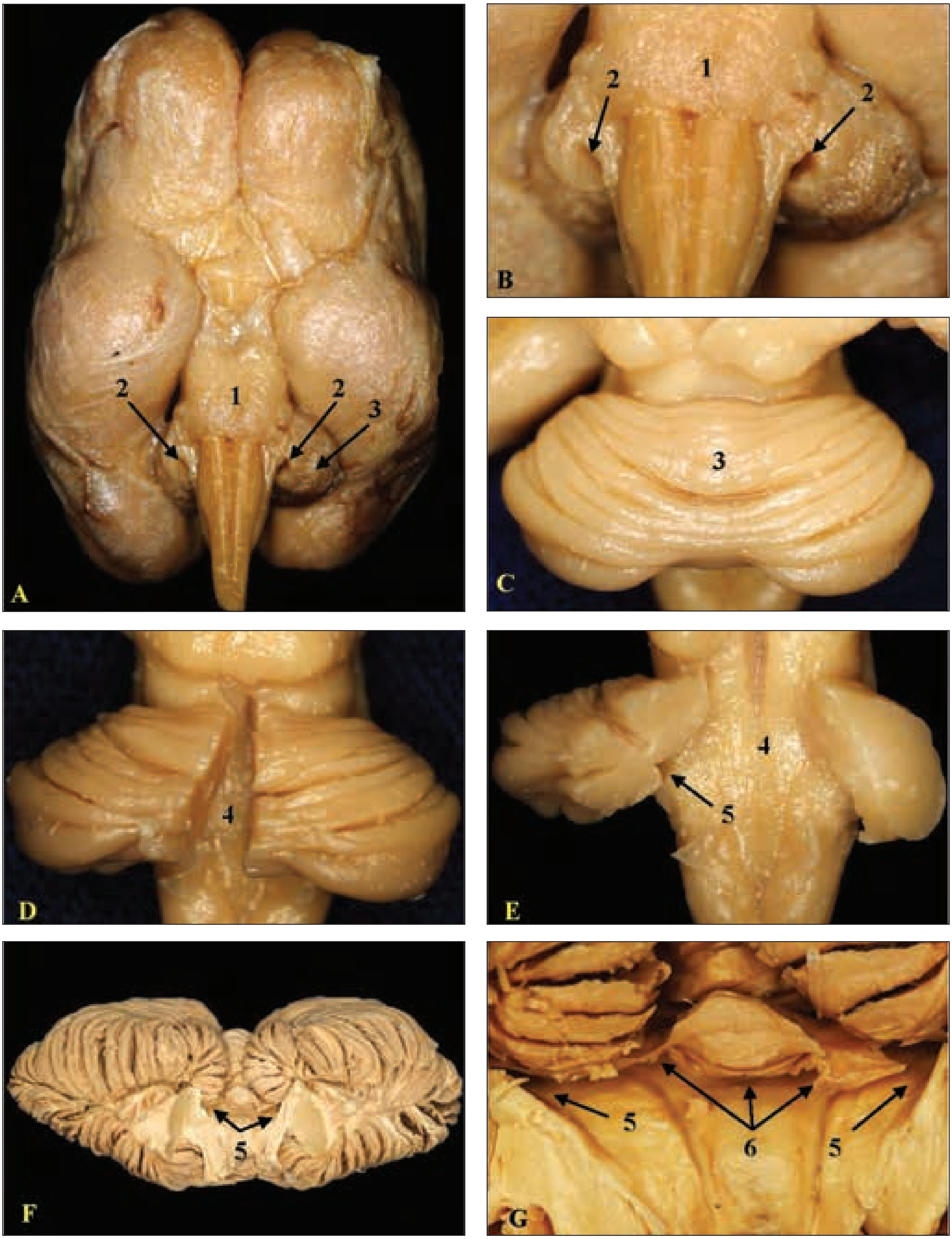

Figure 4. Identification of Luschka's aqueduct trajectory and opening inside the fourth ventricle on a 20 weeks old fetus rhombencephalon. 1. Pons; 2. Apertura lateralis (Luschka); 3. Cerebellum; 4. Fossa rhomboidea visualized after sectioning of cerebellum; 5. Recessus lateralis – ventriculi quarti; 6. Velum medulare inferius. Macrophotos by Canon EOS Mark II Digital Camera. Macro Ultrasonic lens, EF 100 mm, F/2,8. Imagery from Prof. Dr. G.S. Dragoi's neuroanatomy collection.

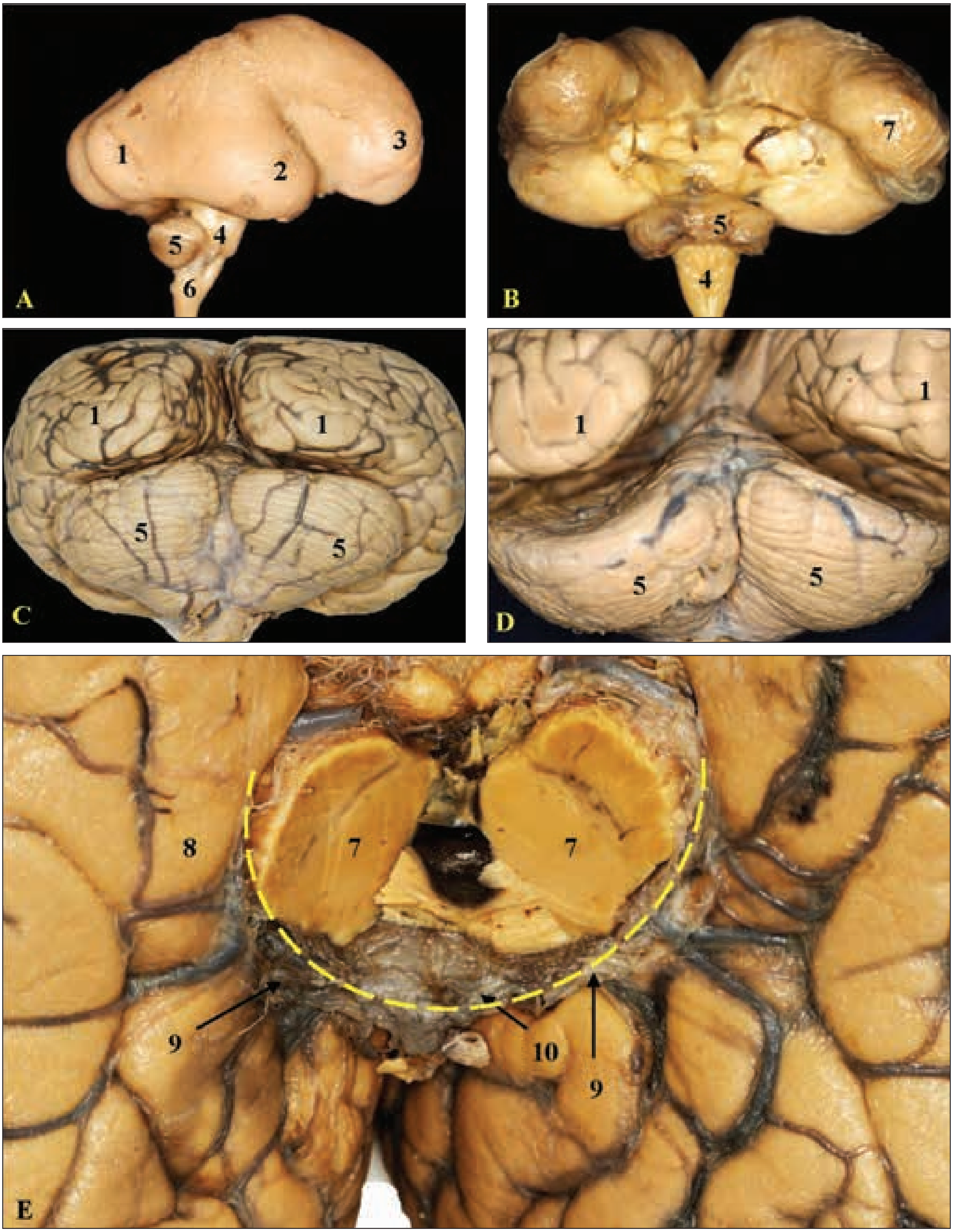

Figure 5. Fissura transversa cerebri – location, visualization and relations in a 24 weeks old fetus (A,B) and adult individual (C-E). 1. Lobus occipitalis; 2. Lobus temporalis; 3. Lobus frontalis; 4. Pons; 5. Cerebellum; 6. Medulla oblongata; 7. Pedunculus cerebri; 8. Gyrus parahipocampalis; 9. Fissura transversa cerebri; 10. Circumferential trajectory of fissure transversa cerebri. Macrophotos by Canon EOS Mark II Digital Camera. Macro Ultrasonic lens, EF 100 mm, F/2,8. Imagery from Prof. Dr. G.S. Dragoi's neuroanatomy collection.

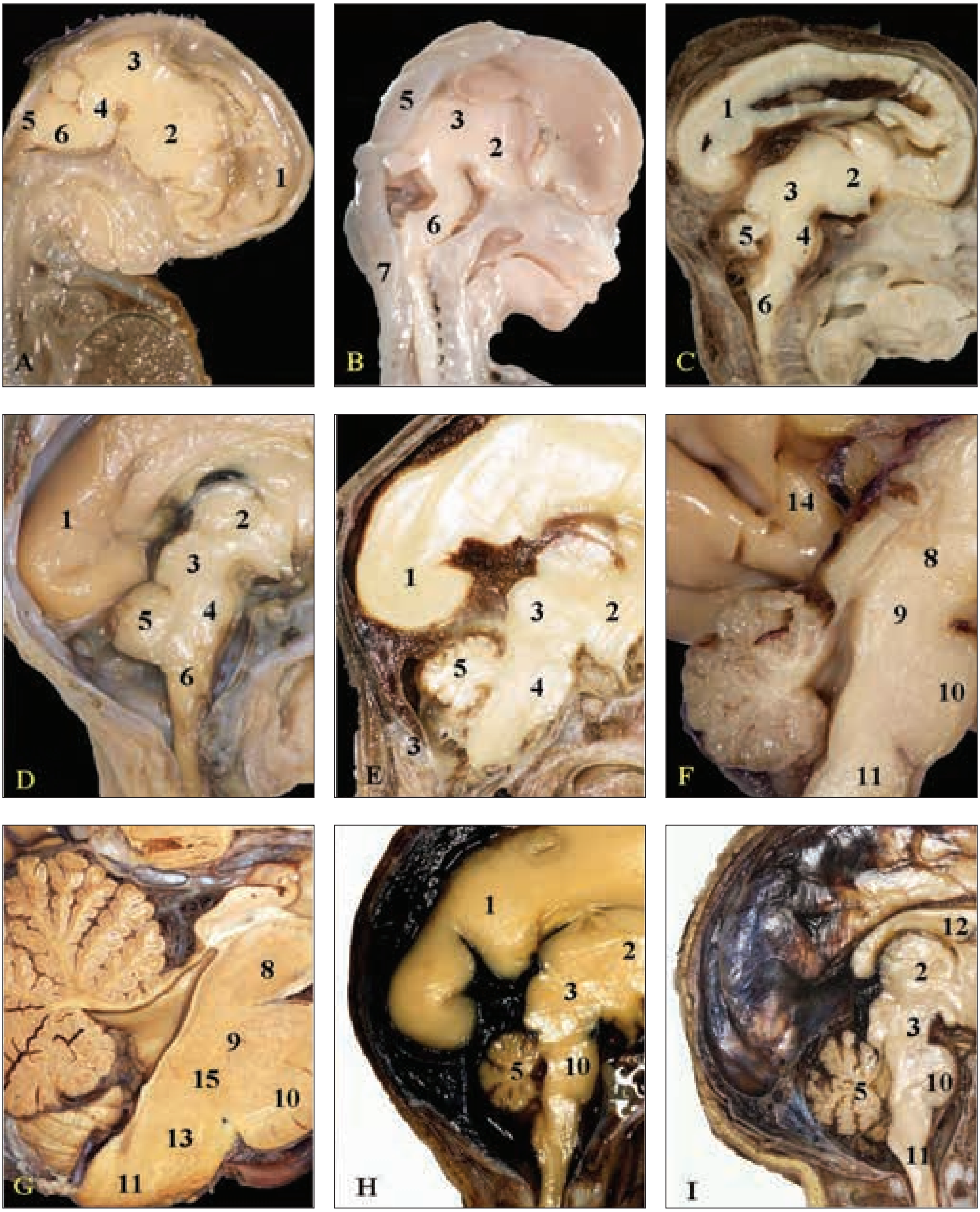

Figure 6. Evolution during ontogenesis dynamics of relations between telencephalon, mesencephalon and rhombencephalon: 8 weeks old embryo (A), 16 weeks old fetus (B), 20 weeks old fetus (C), 24 weeks old fetus (D, E), 28 weeks old fetus (H), new born (F, I) and adult (G). 1. Telencephalon; 2. Diencephalon; 3. Mesencephalon; 4. Metencephalon; 5. Cerebellum; 6. Myelencephalon; 7. Ventriculus quarti; 8. Lamina quadrigemina; 9. Velum medullaris superius; 10. Pons; 11. Medulla oblongata; 12. Corpus callosum; 13. Apertura mediana ventriculi quarti. 14.Bichat's canal. Macrophotos by Canon EOS Mark II Digital Camera. Macro Ultrasonic lens, EF 100 mm, F/2,8. Imagery from Prof. Dr. G.S. Dragoi's neuroanatomy collection.

Xavier Bichat (1771 - 1802)

this external orifice of the arachnoid canal, usually of oval shape, can be reduced to a simple slot. The anatomic specimens that we prepared offered us the possibility to visualize the internal orifice of Bichat's canal that is located in the inferior part of choroid plexus underneath and in front of pineal gland. One can easily prove that this canal opens inside the third ventricle allowing it to communicate to subarachnoid space. The diffusion of hemorrhage collections from the third ventricle to subarachnoid space is a pathology fact that pleads for the existence of such a canal (Fig. 6 F - H).

4. Analysis of phenotype changes involving rhombencephalon structures in ontogenesis

Analysis of relations in time and space between rhombencephalon structures was carried out on sagittal sections through cephalic extremity of embryo and fetus (Fig. 6). On mediosagittal sections through a 8 weeks old embryo (Fig. 6A) and a 16, 24 and 28 weeks old fetus (Fig.6A), we underlined the thickening of dorsal areas of neural tube that will generate cerebellum primordial. This continues rostral and caudal with mesencephalon isthmus and with the membrane covering the fourth ventricle. Anterior lamina forms anterior medullary velum that will generate "Vieussens's valve" and lingual.

The rostral part of membrane (Area membranacea, pars rostralis) form anterior medullary velum known in international terminology as "velum medullare superius". The caudal part of membrane (Area membranacea, pars caudalis) form posterior medullary velum, known in international anatomic terminology as "velum medullare inferius". Area membranacea, pars rostralis, is uneven and single layer while pars caudalis is double and double layer. As soon as pons curvature reaches it maximum bending point, cerebellum gets closer to medulla oblongata (Fig. 6 B). The layer that covers it (tela choroidea) forms a choroid semilunar fold. Later, we noticed that caudal face of cerebellum sticks to choroid semilunar fold. In the same time, cerebellum, that borders by its entire caudal face, the cavity of the fourth ventricle, becomes from intraventricular – extraventricular (Fig. 6 C-E). In the area corresponding to medulla oblongata, the rhomboid lip form villosities that move away from the ventricle and locate above rhomboid fossa. The internal groove of rhomboid lip persists in the area of maximum width of rhomboid fossa and forms the lateral recess of the fourth ventricle (Recessus lateralis) (Fig. 4E). The wall of neural tube that was discharged by choroid expansions becomes thin and reduces to a single layer, simple epithelium. Thus a structural complex is formed; it is made of connective tissue, blood vessels and this epithelial layer and it is called caudal choroid layer and choroid plexus of the fourth ventricle.

The analysis of space relations between cerebellum and adjacent structures was carried out on sagittal and frontal sections. Analyzing the middle sagittal sections through embryo and fetus cephalic extremity, we easily identified the succession of the following structures: rostral, Vieussens valve and lingual, then cerebellum expands ventrally by a prominence – uvula – that continues to a nodule, then membrane of fourth ventricle with choroid layer. On paramedian sagittal sections, we noticed from rostral to caudal: Vieussens valve and cerebellum that continues with an expansions, represented by flocculus that continues to Tarin valve giving the insertion for obturator membrane of fourth ventricle. When examined from anterior, the fourth ventricle is closed by this membrane that is framed and bound to the ventricle floor by neuronal structures of variable thickness: on the ventral (inferior) borders of rhomb and on the inferior angle, there is lingual that corresponds to the inferior angle named obex; on the dorsal (superior) borders, there is also lingual; close to superior angle – Tarin valve.

The examination of sagittal sections during rhombencephalon ontogenesis dynamics (Fig. 6) reveals that in embryo cerebellum forms the ceiling of this region, and pons, its floor. At first, cerebellum appears like a structured originating from a thick caudal lamella, like a fold on the wall of neural tube. Rostral (anterior) lamella of neural tube determines the formation of mesencephalon and its tip belongs to mesencephalon isthmus. In this way primordial of cerebellum becomes dominant and appears on mediosagittal section like a prominent transverse crest outside the primordial rhomboid region. Later, this crest thickens and forms a bilobular mass centered by vermis and will generate cerebellar hemispheres. The surface of vermis and of cerebellar hemispheres folds and creates the fissures and circumvolutions of cerebellum.

During ontogenesis dynamics the relations between telencephalon and rhombencephalon are determined by the caudal expansions of telencephalon that covers diencephalon, mesencephalon and cerebellum (Fig. 6 C-E). A great excavation is formed caudally from optic chiasm, between telencephalon (dorsal) and rhombencephalon (inferior), named "fissure transversa cerebri" (Bichat's slot) (Fig. 5E). It appears as a horse shoe shape, uneven, symmetrical structures, whose concavity is oriented ventrally (inferiorly) and rostral (anterior).

It is admitted that this space has two lateral and a median part. Each lateral part expands from anterior to posterior along the inferior and medial margin of cerebral hemisphere from anterior perforated space (where it seems to continue to lateral fissure Sylvius) to the external border of splenium corpori callosi. It has a superior lip represented by optic tract and cerebral peduncle and an inferior lip made by the arcuate free margin of parahippocampalis gyrus. The median part of the fissure has a horizontal direction between splenium corpori callosi that forms its superior lip, and quadrigeminal tubercles that form its inferior lip. It continues to the lateral parts.

Domenico Cotugno (1736-1822)

In order to see this part, the encephalon is laid with its basal face oriented superiorly and then cerebellum is lifted towards anterior. In the deepness of this space that separates cerebrum from cerebellum, and under splenium, one can notice a compartment with a pia mater fold and pineal body. Pia mater fold expands inside the third ventricle. Thus Bichat's slot is closed by pia mater and not by an epithelial layer. In the dorsal region of mesencephalon, there is quadrigeminal subarachnoid cistern (sin. Cisterna venae magnae cerebri; Bichat's duct; superior cistern). By minute dissection, we visualized all the anatomic structures hosted in this cistern: magna vein, posterior pericallosal arteries; third part of superior cerebellar artery; perforated branches of posterior cerebral artery and of superior cerebellar artery as well as the third part of posterior cerebral artery.

DISCUSSIONS

The presence of cerebrospinal fluid was sensed by Haller [1], proved on cadaver by Cotugno (1764) [2] and proved on living animals by Magendie (1825) [3, 4].

The source, location and circulation of cerebrospinal fluid drew the researchers' attention and generated many controversies. In 1899 Charpy [5] said that he did not precisely the origin of cerebrospinal fluid. It was considered that it originated from the vessels of choroid plexuses and that subarachnoid fluid came from the blood vessels of pia mater and of nervous centers. The circulation of cerebrospinal fluid was far from being explained.

Monro [6] and Sylvius [7, 8] had great contributions to the knowledge of cerebrospinal fluid circulation inside encephalon ventricle system, between lateral ventricles and the third ventricle (Monro) and between the third ventricle and the fourth one (Sylvius).

For a long time it was believed that the fluid inside cerebral ventricles flows into pituitary gland through the infundibulum of the third ventricle. Haller [1] and Cotugno [2] sensed the existence of communications between the intra and extra-ventricle fluids. Magendie

[3] discovered in the posterior angle of the fourth ventricle, a communication orifice between this ventricle and subarachnoid space. Hess (1885) [9] confirmed the existence of this communication in all anatomic specimens. Bochdalek (1849) [10] was the first anatomist to observe that the lateral choroid plexus of the fourth ventricle exits from the ventricle through the lateral recess described by Reychert [11].

Luschka [12, 13] described in detail those orifices of the fourth ventricle and Hess confirmed his research. It is considered that Luschka's orifice appears later during ontogenesis that Magendie's. In the fifth month of antepartum life, the choroid plexuses do not reach the lateral angle of the fourth ventricle.

Sutton (1887) [14] observed that the agenesis of Luschka's orifice or its obliteration in fetus leads to the formation of a ventricle meningocele that projects in occipital region. In pathology, tumors of choroid plexus form lateral cysts of the fourth ventricle.

There are numerous ways of communication between ventricular and extra-ventricular spaces. They can be grouped in two categories: the first one is located around mesencephalon (right and left lateral parts of Bichat's slot, Bichat's duct in its transverse part) and the second one around cerebellum (Magendie and Luschka orifices). It is considered that there are direct (orifices of the fourth ventricle) and indirect (Bichat's slot and duct) communications between cerebral ventricles and subarachnoid space.

Two anatomic structures situated at the limit between telencephalon and mesencephalon, although unanimously recognized as location and relations, generated many discussions about their role as communication spaces between ventricular and extra-ventricular systems. These are – the lateral part of fissure transversa cerebri and its transverse part.

In the middle part of cerebrum transverse fissure Bichat [15, 16] described a duct. He considered that arachnoid forms around galien vein a circular fold analogous to Winslow's hiatus. This is the external orifice of "arachnoid canal" made by arachnoid that lies like a sheath around galien vein. The internal orifice is located in the inferior part of choroid layer ventral and rostral from pineal gland. Thus the communication to the third ventricle is achieved. Charpy (1899) [5] considered that Galien vein is surrounded by a subarachnoid tissue and not by arachnoid, representing the adventitia of the vein; the cerebrospinal fluid is located exactly inside subarachnoid space that forms the sheath for the vein. Nevertheless, Charpy [5] also considered that this communication only exists in few individuals. In our opinion, Bichat's duct is an anatomic reality that opens widely in case of subependimary hemorrhages (Dragoi, 2007) [17]; thus hemorrhagic fluids flow from the third ventricle to cerebellum-medullary cisterns (Figure no. 6).

CONCLUSIONS

1. Difficulties in visualization of aqueducts for cerebrospinal fluid transit from ventricle to subarachnoid space are due to the complexity of phenotype changes undergone by the wall and cavities of neural tube in ontogenesis dynamics.

2. The intraventricular genesis of cerebellum primordial and its evolution in extraventricular space determines the formation of compartment subarachnoid spaces known as subarachnoid cysterns in the territory of rhombencephalon and mesencephalon.

3. The presence of the extraventricular part of choroid plexus of the fourth ventricle in the lateral recess Luschka is an important marker for the permeability of lateral aqueducts Luschka inside rhombencephalon.

4. The hemorrhagic fluids from the third ventricle that reach quadrigeminal subarachnoid cistern, confirm the presence of a transit canal between the third ventricle and subarachnoid space, demonstrated by Bichat but contested by some anatomists because of the difficulties in visualization using macro and/or mesoscopic dissection.

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