The consequences of the epigenesis of the encephala anastomotic arterial systems. Implications in pathology

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Abstract: The existence of the anastomotic arterial systems as an exceptional way for irrigation of human brain raises problems regarding their genesis and evolution in time and space, the pattern of their anastomotic canals as well as the phenotype variability of their anastomosis. Our study achieved on fetus, new born, mature and old adult individuals by micro and macro anatomic methods draws the attention towards the epigenetic mechanism of encephalon anastomotic arterial systems. The authors consider that based on the ontogenetic criteria of the Willis anastomotic arterial system formation, the posterior cerebral artery is derived from the internal carotid artery and contributes to the genesis of the basilar artery. A particular attention is offered to the leptomeninges anastomotic arterial system, localized under pia mater, by the contribution of anterior, middle and posterior cerebral arteries. The microanatomic study of the internal carotid and basilar arterial wall proved the structural particularities of the muscular layer and a rich nervous supply.

Key Words: arterial anastomosis; anastomotic canals epigenesis; cerebral arteries; Willis arterial circle.

The existence of numerous collateral anastomotic arterial channels in human brain, between the two major arterial systems – internal carotid and vertebral artery – and their branches, raises important problems regarding:

- The absence of genesis and evolution synchronism of the neuronal and vascular structures;
- The angiogenesis for the anastomotic structures;
- The structural anatomy of the vascular wall;
- The value of the anastomosis at the level of leptomeninges;
- The biodynamic of fluids in the brain anastomotic arterial system;
- The variability of anastomosis type in the Willis arterial circle;
- The pattern of posterior cerebral arteries;
- The relative high incidence of aneurism and cerebral stroke;
- The location for the communicating canals in the brain anastomotic system.

The purpose of this paper was imposed by the necessity for the knowledge of variability limits for the topography of the structures forming the brain anastomotic arterial system.

The objectives of the paper appeared during the search for answering the above mentioned problems regarding the descriptive, topographic and structural anatomy, the genesis and evolution of the structures forming the brain anastomotic arterial system.

Materials and methods

The study of the brain anastomotic system was carried out on human biologic material. We used 24 brains harvested from: 6 fetus (aged between 3-8 months); 4 new born; 3 young adults (aged between 20-28); 7 adults (aged between 30-50) and 4 old individuals (aged between 65-80). We fixed and preserved the material in 10% formaldehyde solution buffered at 7.5 pH. The macro anatomic analysis was made by dissection, perivascular sculpturing, sectioning and China ink injection. For the micro anatomic part of the study we harvested fragments of internal carotid and basilar arteries that we included in paraffin.

The serried sections were stained: Hematoxiline Eosine, Van Gieson, PAS Mac Mannus, Gomori and Cajal Nonidez argentic impregnation. For the micronatomic

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examination we used a Nikon research microscope; the macro anatomic imagery was photographed by Canon EOS Mark II digital camera equipped with an Ultrasonic Macro objective EF 100 mm F/2,8.

Results
A. Macro anatomic analysis of the location and relationships of the structures forming the intracranial anastomotic arterial system at the base of encephalon.

The examination of the encephalon basal surface allows the identification of the Willis arterial circle. The area of the circle is compartmented by the presence of optic chiasm and optic tracts, into two sectors: pre chiasm and retro chiasm. In the first sector we observed the internal carotid arteries and the anterior cerebral arteries (Figure 1 A; Figure 2B). The dissection of the anterior cerebral arteries permits the analysis of their anteriorly curved trajectory and their communication by anterior communicating artery (Figure 1 B, D). In the second retro chiasm sector, bounded distally by posterior cerebral arteries, one can notice the presence of the structures belonging to diencephalon, hypophysis rod and mammillary bodies (Figure 1A,D; Figure 2B).

The trajectory of posterior cerebral arteries describes an anteriorly convex curve. The site of anastomosis between posterior cerebral artery and posterior communicating artery, represents the boundary between the two territories (before and after the communication) with particular significations for the epigenesist of this anastomotic canal (Figure 1D).

B. Macro anatomic analysis of the structures forming the anastomotic arterial system of leptomeninges.

Our attention was captured by two leptomeninges structures because of their role played triggering and expansion of leptomeninges hemorrhages: arachnoid granulations and pia mater arterial network. When examining macro anatomically the borders of the superior sagittal fissure, we observed the arachnoid granulations grouped in conglomerated (Figure 3A, B).

On mediosagital sections and after opening the superior sagittal sinus, we saw the arachnoid granulations that protrude inside the venous sinus (Figure3 C-F).

The leptomeninges arterial network is very well visible on the surface of cerebral hemispheres. One can easily notice the relations of the cortical branches of anterior, medium and posterior cerebral arteries with pia mater while descending deep into the cerebrum grooves (Sulci cerebri) (Figure 4). One can equally point out the presence of arachnoid granulations around cerebrum gyruses (Figure 4 C-D).

The arterial injection of a China ink suspensions helps us visualize a luxuriant leptomeninges capillary network on the encephalon surface (Figure 5 A-D) that achieves a vascular "wrap" easily detachable (Figure 5 D). The surface of the subjacent cortex appears smooth without any grooves and gyruses (Figure 5 D). The subarachnoid space becomes a remarkable space for the accumulation and diffusion of meningeal and cerebral hemorrhage in fetus (Figure 5 E, F).

C. Comparative micro anatomic analysis of the basilar and internal carotid arterial wall.
1. Basilar artery

The micro anatomic analysis of the serried sections after paraffin inclusion of basilar artery fragments showed us the sinusoid trajectory of the arterial wall in the internal third (Figure 6 A). On Mac Mannus stained sections we identified circumferential routes of glycosaminoglycans that cross under variable angles (Figure 6 B). On Cajal Nonidez stined sections, the external layer is sprinkled with numerous transversely sectioned nerves (Figure 6 A). The argirofil collagen fibers form a small mesh network in the internal third of the medium layer and a big mesh network in the external two thirds (Figure 6 C). When examining with the 40 objective we observed the argirofil collagen fibers grouped in pairs.
2. Internal carotid artery

The internal layer and the internal third of the medium layer have a sinusoid trajectory (Figure no. 6 D). We identified neurofibers with a circumferential route in the medium layer (Figure 6 G) or with a network-like distribution in the external third of the medium layer (Figure 6 G). The argirofil collagen fibers examined on Gomori stained sections is heterogeneously distributed. In the internal half they are oriented on the direction of the rays of the circle that circumscribes the arterial wall and in the external half they are orientated after the generator of the arterial wall. We equally noticed that the argirofil collagen fibers are grouped in pairs (Figure 6 H). On the Cajal Nonidez stained sections through internal carotid artery we identified "intimal cushions" (Figure 6 E).

Discussions
After analyzing our observations we concluded that there are two particularities regarding the brain anastomotic arterial systems:
1. The integration of the posterior cerebral artery in one of the major brain irrigation systems – carotid and/or vertebral and basilar;
2. The location and the value of cortical leptomeninges anastomosis.

It is known that the brain arterial supply is ensured by two vascular systems: internal carotid system that serves the major part of cerebral hemispheres and diencephalon, and the vertebral system that goes to the posterior fossa and spinal cord. Those systems achieve an anastomotic network at the base of diencephalon (the anastomotic arterial circle of Willis) from whom there go vascular networks in all directions.

The posterior communicating artery and the lateral territory of posterior cerebral artery, ontogenetically speaking, come from the distal trunk of internal carotid artery. The medial part of posterior cerebral artery originates from the vertebral basilar system that is recently appeared in onto and filo genesis.

This last segment was named as "fetal type" of posterior cerebral artery.

During the embryo and fetal stages of ontogenesis the internal carotid system is the only vascular source for the encephalon. Each internal carotid artery divides at
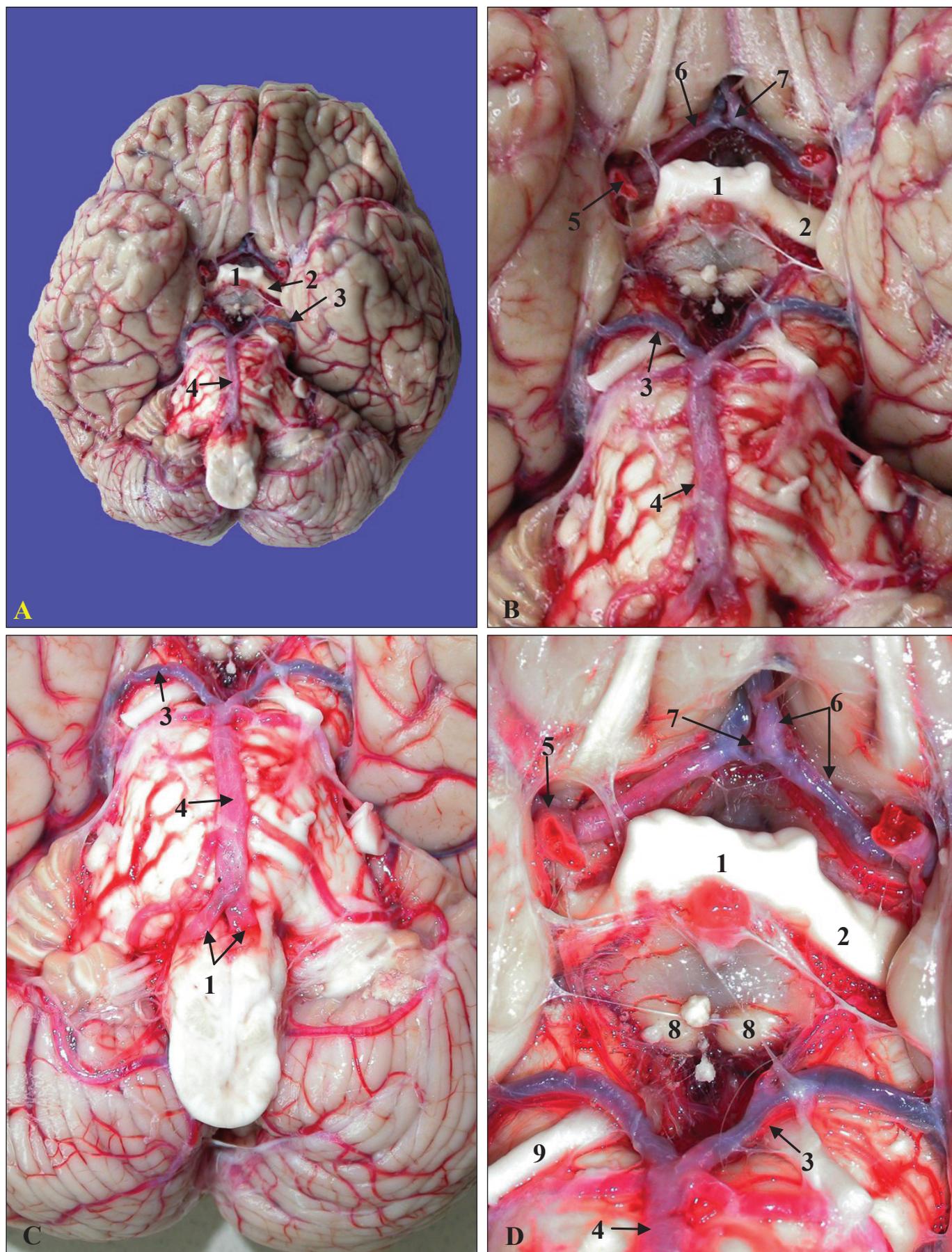
Figure 1. **The location, content, relations and compartments of the circulus arteriorsus cerebri area on a human brain fixed in alcohol immediately after harvesting**. *1. Chiasma opticum; 2. Tractus opticus; 3. Arteria cerebri posterior; 4. Arteria basilaris; 5. Arteria carotis interna; 6. Arteria cerebri anterior; 7. Arteria comunicans anterior; 8. Corpus mammilare; 9. Nervus oculomotorius; 10. Arteria vertebralis.* **Macrophotos by Canon EOS Mark II Digital Camera; Macro Ultrasonic Lens EF 100mm, F / 2.8**
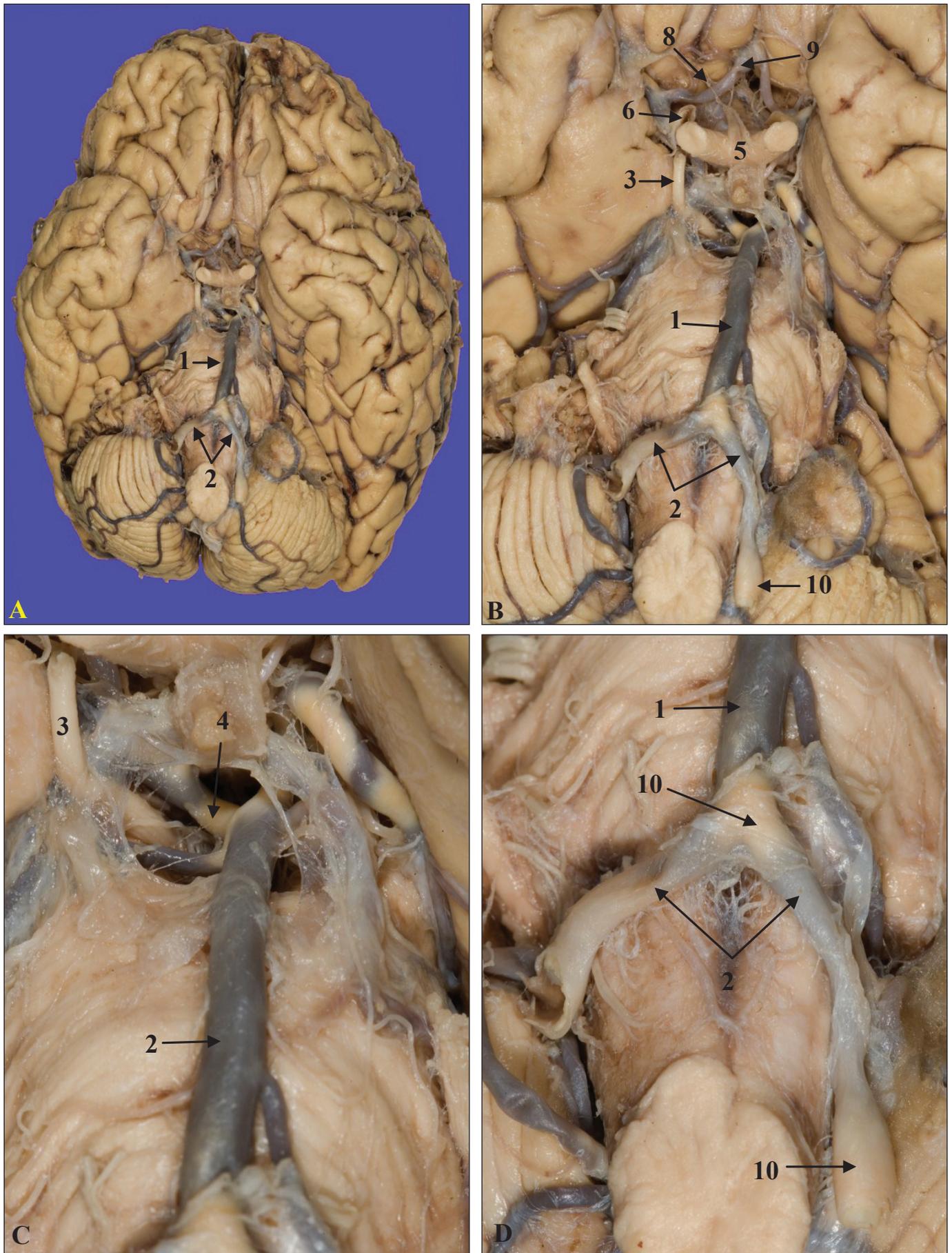
Figure 2. Phenotype changes in arterial wall of due to the presence of atherom plaques in vertebral arteries and at their junctions with basilar artery. *1. Arteria basilaris; 2. Arteria vertebralis; 3. Nervus oculomotorius; 4. Arteria cerebri posterior; 5. Chiasma opticum; 6. Arteria carotis interna; 7. Nervus opticus; 8. Arteria cerebri anterior; 9. Arteria communicans anterior; 10. Atherom plaques*. ***Macrophotos by Canon EOS Mark II Digital Camera; Macro Ultrasonic Lens EF 100mm, F / 2.8***
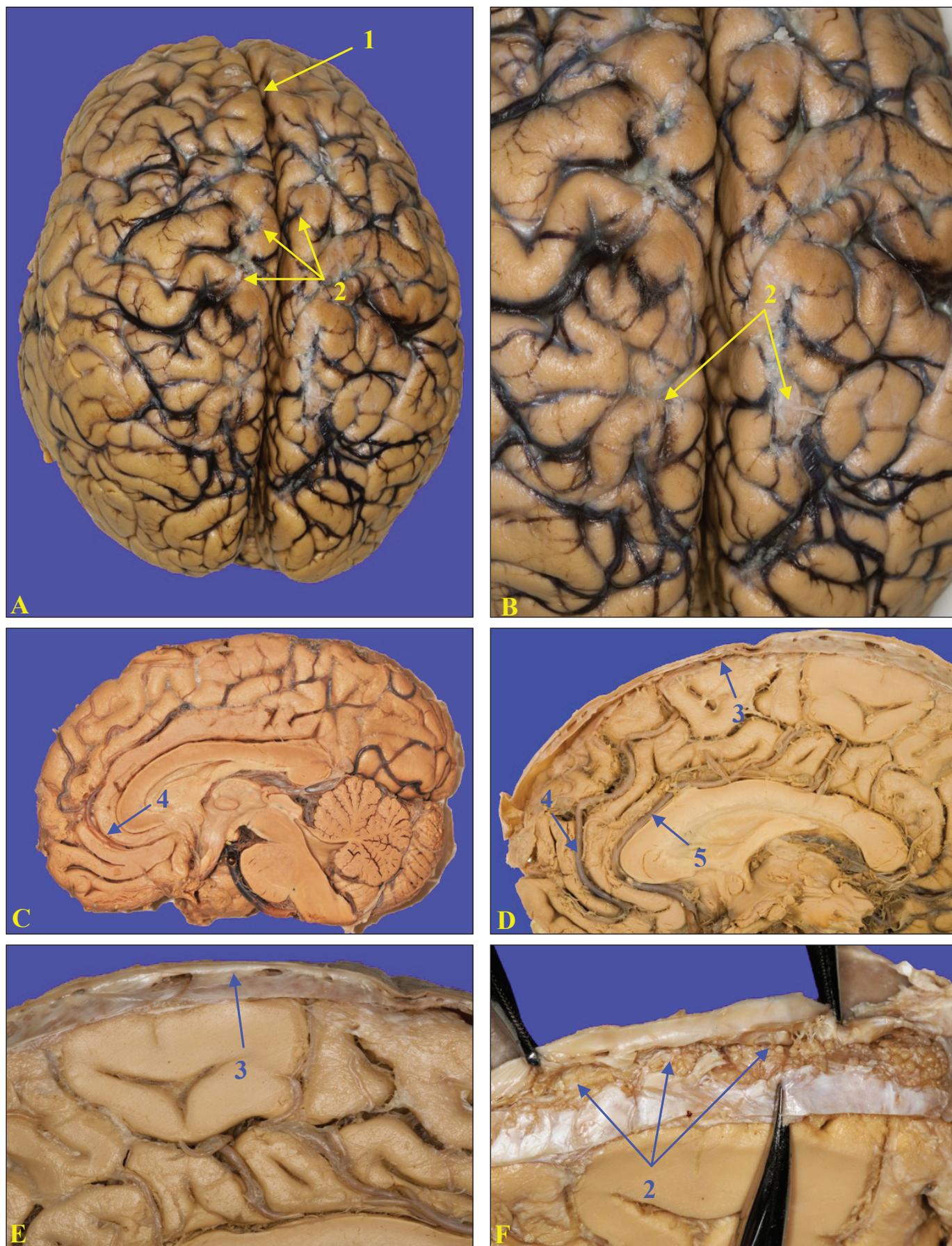
Figure 3. Location and relations of arachnoid granulations visible on the surface of encephalon near the longitudinal fissure, but also on the medium sagital sections and after opening the superior longitudinal sinus. *1. Fissura longitudinalis cerebri; 2. Granulationes arachnoideae; 3. Sinus sagittalis superior; 4. Arteria callosomarginalis; 5. Arteria pericallosa.* **Macrophotos by Canon EOS Mark II Digital Camera; Macro Ultrasonic Lens EF 100mm, F / 2.8**
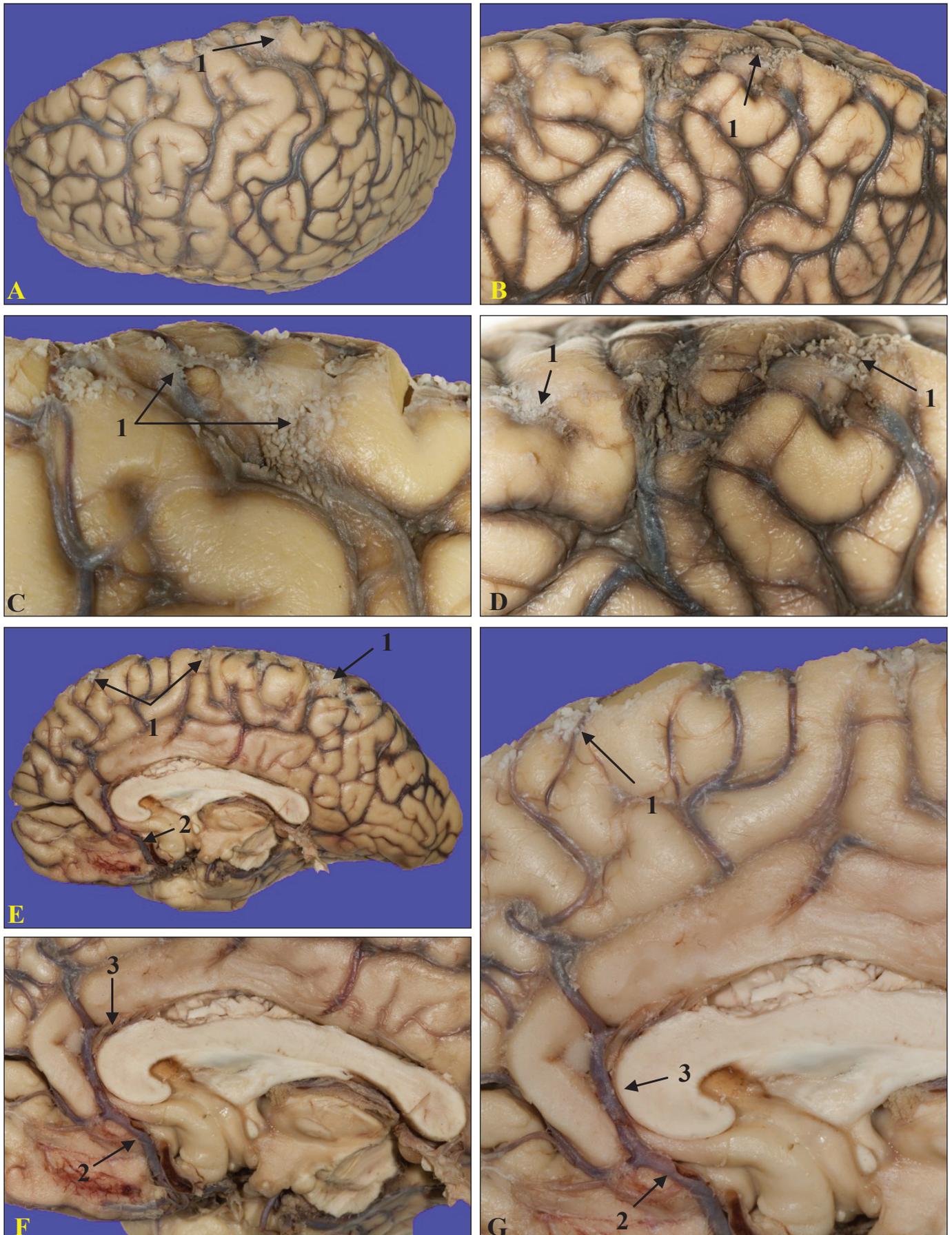
Figure 4. Relations of cortical branches in the junction area between anterior, medium and posterior cerebral arteries. One can notice the location of cortical branches inside encephalon grooves and the contiguity relations to pia mater. *1.Granulationes arachnoideae; 2. Arteria cerebri anterior. 3. Arteria pericallosa.* **Macrophotos by Canon EOS Mark II Digital Camera; Macro Ultrasonic Lens EF 100mm, F / 2.8**
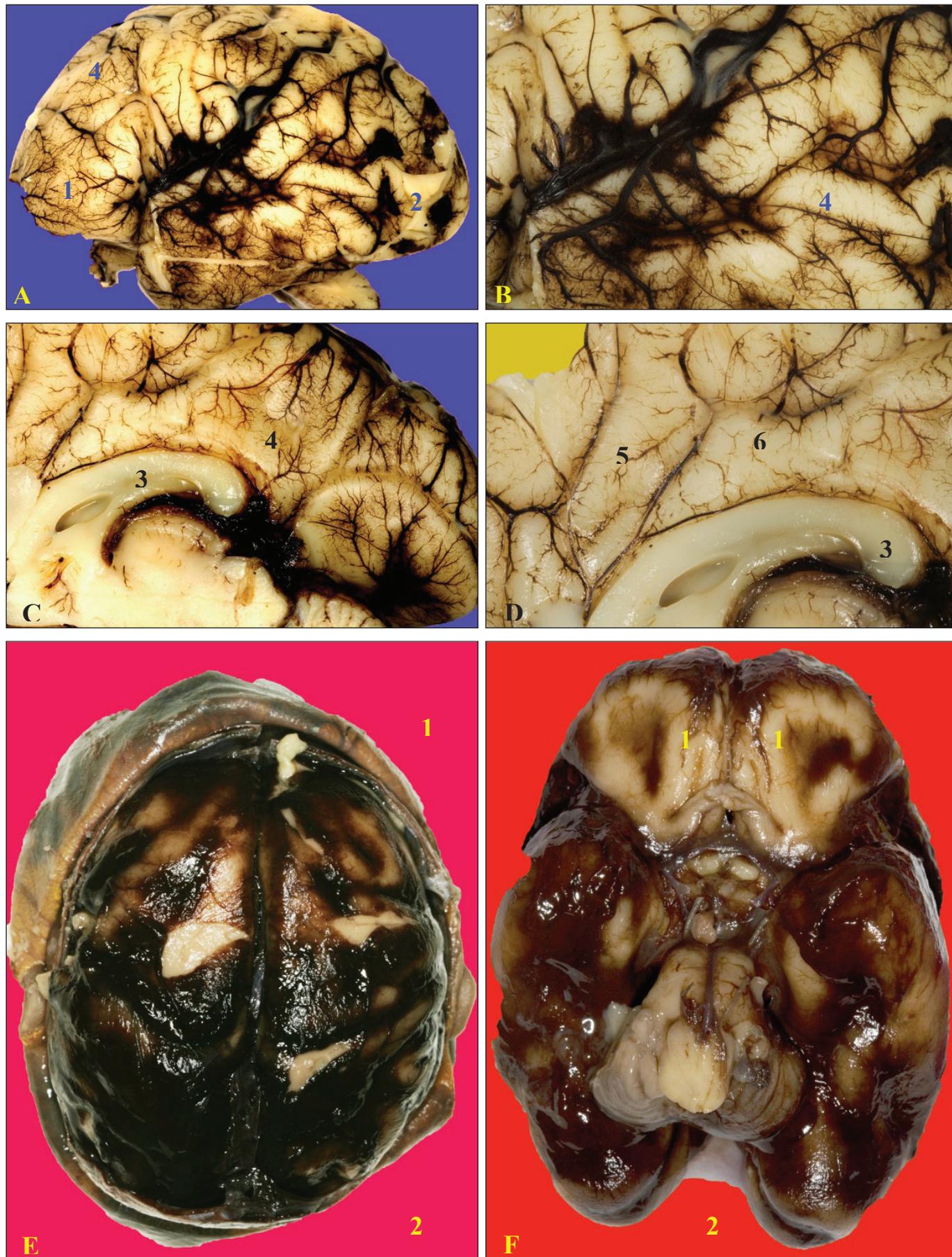
Figure 5. A-D: Leptomeninges anastomotic network visualized after China ink injection in a fetus encephalon; E-F: Meningeal and cerebral hemorrhage due to the involvement of pia mater anastomotic networks. *1. Lobus frontaluis; 2. Lobus occipitalis; 3. Corpus callosum; 4. Pia mater vascular network; 5. Arteria Callosomarginalis; 6. Arteria Pericallosa. Macrophotos by Canon EOS Mark II Digital Camera; Macro Ultrasonic Lens EF 100mm, F / 2.8*
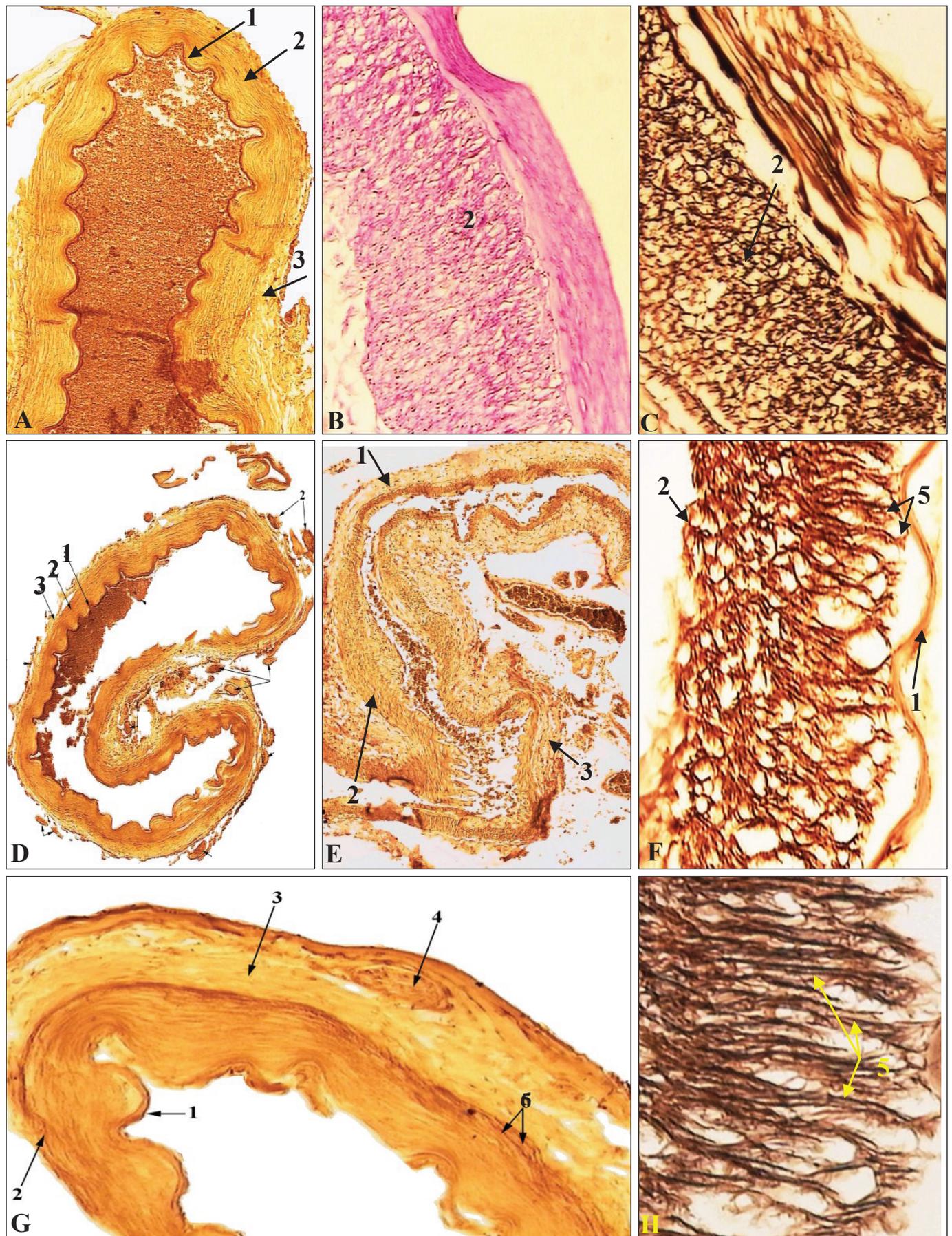
Figure 6. Microanatomy of the basilar (A-C) and internal carotid (D; F-H adult; E - fetus) arterial wall. *1. Internal layer; 2. Medium layer; 3. External layer; 4. Nerves in external layer; 5. Collagen fibers after argentic impregnation; 6. Neurofibers inside medium layer.*

Paraffin sections. Cajal-Nonidez argentic impregnation (A-B; D-E; G). Gomori argentic impregnation (C, F, H). PAS Mac Mannus stain (B). X28 (A, D, E); x70 (G); x280 (B, C, F, H).

the base of embryo diencephalon into two trunks: rostral trunk that gives laterally the future medium cerebral artery, and a caudal trunk that will become the posterior cerebral artery.

It should be underlined that the remaining segment from the rostral trunk will form the anterior cerebral artery and the remaining segment from the caudal trunk will unite with the contralateral homologous to form the basilar artery. The anterior communicating artery forms as an anastomotic bridge between the two anterior cerebral arteries. The segment that ties the internal carotid to posterior cerebral artery will form the posterior communicating artery.

Later, its progressive atrophy will lead to the development of the vertebral system. The vascular source of the vertebral system is initially formed by the two vertebral arteries originating from the subclavian artery. They go into the posterior fossa and they join the basilar artery forming a trifurcation together with the anterior spinal artery. The anastomotic arterial circle (Willis) is the source of "short central arteries" and "long cortical arteries". The first group perforates the inferior surface of cerebrum to reach the profound structures and the second ones reach the hemisphere grooves by anterior, medium and posterior cerebral arteries.

There is a large variability of anastomosis between cortical arteries. Some anastomosis are between large caliber vessels such as anterior, medium or posterior cerebral arteries at the level of the superior parietal occipital groove, or between anterior and posterior cerebral arteries by pericalos arch, or between medium and posterior cerebral arteries by posterior communicating artery.

Other anastomosis achieve between the distal parts of two or three terminal branches as 2-3 opposite chandeliers visible in the superior frontal and sub parietal grooves. A special place is occupied by the "network anastomosis" between the arteries from the profound pia mater layer covering the cerebral hemispheres. From this network arise numerous small arteries that branches in the adjacent nervous tissue and in the "central oval".

They are terminal arteries and consequently the adjacent nervous tissue is frequently the site for senile decrepitude or disintegration lacuna.

The relations between the vessels of pia mater and arachnoid were intensely studied (Dahl et al, 1965; Samaringhe, 1965). The anatomic variations of the encephalon anastomotic arterial systems influence the ischemic disorders: hypoplasia or reduced caliber of posterior communicating artery and its direct origin from internal carotid artery. Pascu et al (1982) described in 32.4% of vascular ischemic strokes, anomalies of Willis anastomotic circle and of vertebral arteries.

The functional value of the vertebral basilar system is tightly related to the carotid one by multiple bounds: aortic arch, Willis circle and cortical anastomosis. The obstruction of one vertebral artery induces a change in blood flow both inside basilar artery and the other large cerebrum arteries (Cinca, 1982).

The prevalence of primary thrombotic mechanism inside the vertebral basilar system compared to carotid one, is explained by the anatomic and pathology particularities of the vertebral basilar tree (Cinca, 1982). Abnormal or sustained position of head and neck especially when they are associated with cervical arthritis and/or atherosclerosis can be a certain factor for ischemia (Cinca, 1982). Traumatic agents appear equally in the genesis of ischemic vertebral basilar strokes: spine trauma (fractures, dislocations), strong manipulation of cervical spine (Cinca et al, 1982) or in obstetric trauma of the new born .

Conclusions

1. The brain arterial anastomotic systems are epigenetically determined.
2. Although from an anatomic point of view, the internal carotid and vertebral arterial systems form a personalize anastomotic entity largely accepted in ortology and pathology, their genesis and evolution impose for rigorous criteria of location and relations of anastomotic canals.
3. The basilar artery trunk appear during ontogenesis as a derivate of the carotid arterial system after the convergence of fetal segments of posterior cerebral arteries.
4. The posterior cerebral artery is part of carotid arterial system due to the phenotype change of its primary caudal trunk into posterior communicating artery and into the two segments (before and after communication) of posterior cerebral artery.
5. The small arterial and capillary anastomosis between the anterior, middle and posterior cerebral arteries under pia mater, represents a new anastomotic model named as "pial leptomeninges anastomotic arterial system" implemented in general and forensic pathology.
6. The fluid kinematics inside Willis arterial circle is ensured by neuromuscular units inside the internal carotid and basilar arterial walls.

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