Vascular anatomy of archipallium and paleopallium

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Abstract:
The fiber architectonics and the organization of the neurons are different from archipallium, paleopallium and neopallium in the brain. Each pallium has each character of the vascularization. However, there are few report and documentations regarding the point of view in terms of the phylogenetical organization of the central nervous system.
The vascular anatomy of archipallium and paleopallium are reviewed and discussed with the consideration of the angioarchitecture of AVM in these particular area.

1.Introduction
If we could know the phylogenetically aspect of our brain, it is helpful to understand the anatomy of our brain where all our world exists.
The vasculature of our brain is not morphologically homogeneous, but a certain place of the arterial system has a certain character of the shape and function. It is quite helpful to understand the vascularization of the human brain

Emotionality serves a protective function, either to promote survival of the individual (e.g. feeding, and fight or flight) of that of the species (e.g. sexual activity). Moreover, emotion promotes memory. Events, places, and individuals which are emotionally significant are likely to be remembered. Broadly considered, emotion and memory functioning are associated with the olfactory limbic system, the core structures of which include the hypothalamus, amygdala, hippocampus, septal nuclei, cingulate gyrus, and the olfactory bulbs and olfactory cortex. Over the course of evolution much of the limbic system was in fact derived from the olfactory system--cortical structures which conferred upon the evolving limbic lobe those concerns traditionally referred to as the "four Fs:" feeding, fighting, fleeing, and sexual activity.

2. Types of pallium
The allocortex (also known as heterogenetic cortex) is one of the two types of cerebral cortex, the other being the neopallium (isocortex). It is characterized by having just three or four cell layers, in contrast with the six layers of the neocortex, and takes up a much smaller area than the neocortex. There are three subtypes of allocortex: the paleocortex, the archicortex, and the periallocortex – a transitional zone between the neocortex and the allocortex.
(Fig.1)
The specific regions of the brain usually described as belonging to the allocortex are the olfactory system, and the hippocampus.[1–3]

Allocortex is termed heterogenetic cortex, because during development it never has the six-layered architecture of homogenetic neocortex. It differs from heterotypic cortex, a type of cerebral cortex, which during prenatal development, passes through a six-layered stage to have fewer layers, such as in Broadmann area 4 that lacks granule cells. (Fig.2)

3. Structure of the allocortex

The allocortex has just three or four layers of neuronal cell bodies in contrast to the six layers of the neocortex. There are three subtypes of allocortex, the paleocortex, archicortex and periallocortex.

4. What is the archipallium?
Archipallium (archicortex) is a type of cortical tissue that consists of three laminae (layers of neuronal cell bodies). It has fewer layers than both neocortex, which has six, and paleocortex, which has either four or five. Because the number of laminae that compose a type of cortical tissue seems to be directly proportional to both the information-processing capabilities of that tissue and its phylogenetic age, paleopallium is thought

to be an intermediate between neopallium and archipallium in both aspects, and archipallium is thought to be the oldest and most basic type of cortical tissue.
The archipallium is often considered contiguous with the olfactory cortex, but the extent of the archipallium varies among species. In older species, such as fish, the archipallium makes up most of the cerebrum. Amphibians develop an archipallium and paleopallium, whereas reptiles develop an archipallium, paleopallium and a primitive neopallium. (Fig.3,4)

5. What is the paleopallium?
The paleopallium includes the olfactory cortex and the pyriform lobe, which are integral parts of the limbic system. Both the archipallium and paleopallium comprise the allocortex or heterogenetic cortex, consisting of three layers. Most of the cerebral cortex, approximately 90%, constitutes the neopallium (neocortex or isocortex), which is formed by six distinct layers (homogenetic cortex). By the seventh month of intrauterine development, the six layers of the homogenetic cortical regions become distinct.

Paleopallium is present in the parahippocampal gyrus, olfactory bulb, accessory olfactory bulb, olfactory tubercle, piriform cortex, periamygdalar area, anterior olfactory nucleus, anterior perforated substance, and prepyriform area. Paleopallium is a type of thin, primitive cortical tissue that consists of three to five cortical laminae (layers of neuronal cell bodies). In comparison, the neocortex has six layers and the archipallium has three or four layers. [4–6]

6. Vascularization of the archipallium.
The hippocampal arteries arise mainly from the posterior cerebral artery and to a lesser degree from the anterior choroidal artery. The posterior cerebral artery can be divided, during its perimesencephalic path, into two segments: P1 segment, which is located in the intercrural (or interpeduncular) cistern, and P2 segment, which is situated in the crural (along the uncus) and ambient cisterns. In the ambient cistern, the posterior cerebral artery is usually situated along the margin of the parahippocampal gyrus but may cover the subiculum by occasional loops in the wing of the ambient cistern (laterally closed by the choroid fissure). (Fig.5)
In its P2 segment, the posterior cerebral artery gives rise to numerous important branches, which render the surgical approach to the medial temporal lobe particularly difficult (Gaffan and Lim 1991)[7]. These branches are the inferior temporal arteries, which are usually divided into the anterior, middle, and posterior inferior temporal arteries; the posterolateral choroidal artery and the splenial artery.

Venous Vascularization of the Hippocampus
Venous vascularization of the hippocampus is provided by the intrahippocampal veins, comprising the subependymal intrahippocampal veins and sulcal intrahippo- campal veins, which drain into the superficial hippocampal veins [3].
The superficial hippocampal veins form two venous arches: the venous arch of the fimbriodentate sulcus and the venous arch of the hippocampal sulcus, located in the corresponding sulci. Both venous arches drain into the basal vein anteriorly by the inferior ventricular vein, and posteriorly by the medial atrial vein. The basal vein is a satellite of the posterior cerebral artery on the lateral surface of the mesencephalon in the ambient cistern and drains posteriorly into the vein of Galen.[8]
The venous arch of the fimbriodentate sulcus receives the subependymal intrahippocampal veins, visible at the alveus on the surface of the intraventricular part of the hippocampus. The venous arch of the hippocampal sulcus receives the sulcal intrahippocampal veins that arise from the hippocampus at the junction of the gyrus dentatus and the cornu ammonis. (Fig.4) [3, 7]

7. Vascularization of the paleopallium

Olfactory Tract
In the observation of the primates (Monkey),the arteriole supplying the olfactory tract and bulb came from either the anterior cerebral artery or its anterior communicating branch on each side and then ran anteriorly along the olfactory tract. On its way to the bulb, the arterioles gave rise to many capillaries that ran spirally and supplied the tract. These capillaries anastomosed with each other and communicated with the capillary network of the olfactory bulb at the front border of the olfactory tract. [9]

Olfactory Bulb

The olfactory bulb of the Japanese monkey was a deep and narrow midline structure its width was less than half its height and depth. After the arterioles entered the olfactory bulb, they divided into the cortical and medullary branches.
In the horizontal section of the bulb, the intracortical capillaries formed two layers of different density. The superficial layer appeared like a ladder with sparse parallel capillaries. The olfactory bulb was surrounded by a dense venous network. The upper part of this drained into the external cerebral veins and the lower part went into nasal mucosal venous plexus.

8. Archipallium (limbic) AVM
It is essential to analyze the arteries supplying a nidus compartment of AVMs for either microsurgical extirpation or the planning of embolization.
The goal of successful endovascular treatment of brain AVMs with respect to nidus obliteration and clinical outcome of the patient really depend on the quality of superselective catheterization with microcatheter. Superselective angiography with sophisticated flow directed type of microcatheter is the key to analyze the angioarchitecture of brain AVMs.
Arteriovenous malformation is usually defined by early venous filling on conventional angiography. However, if the malformation presents with hemorrhage, its precise vascular structure is compressed by the hematoma and intranidal vascular resistance increases. Therefore, its venous drainage might be delayed and this type of small AVM may become a so-called angiographically occult AVM that means anatomically present but angiographically invisible. In this situation, superselective angiography is useful to detect and identify the small AV shunt. [10–13] Generally speaking, AVMs supplied either exclusively by dominant feeding arteries or by more dominant than supplementary feeding arteries have a high chance to achieve complete or subtotal obliteration, than AVMs supplied either exclusively by more supplementary than dominant feeding arteries.

In order to analyze the angioarchitecture of AVMs, topographical classification and the location of the AVMs are very useful. (Table 1,2)

Sulcal AVMs are primarily located within a specific sulcus. (Fig.7)
Based on the electron microscopic studies, the pial arteries on the surface of gyri and sulci are located in the subpial space, which forms an intrinsic compartment of the subarachnoid space. Therefore, the nidus of sulcal AVMs occupies the subpial space of the sulcus and, depending on its size, it compresses the adjacent gyri to various degrees. Sulcal AVMs may be confined to a sulcus or may extend into the depths of the sulcus, through underlying cortex into the subcortical white matter and even to the ventricular wall. Depending on their size and extension, sulcal AVMs are therefore further classified into three subtypes: (1) pure sulcal, (2) sulcal with subcortical extension and (3) sulcal with subcortical and ventricular extension. [10, 12, 13]

9. Angioarchitecture of archipallium AVM
Since the archipallium is mainly composed from limbic system, the arterial supply can be anterior and posterior choroidal arteries, pericallosal artery from anterior cerebral artery and posterior pericallosal artery supplied from medial posterior choroidal arteries. These arteries are considered as the limbic arcade. The limbic arterial arch is an arterial arcade that has been described in animals (reptiles, birds) and particularly the opossum. It can be recognized during embryological development of the anterior choroidal artery in man [14]. It usually represents a transient stage during ontogenesis. There are two types of persisting limbic arches:
1. The "true" one links the anterior choroidal artery to the anterior cerebral artery around the limbic structures.
2. In the secondary one the posterior cerebral artery has taken over the anterior choroidal artery role and is linked to the anterior cerebral artery.

The former has been encountered only once; most cases seem to correspond to the secondary limbic arch type. Both types supply the corpus callosum and the cingulum, and multiple connections are present with the choroidal arteries, as in ontogenesis, but also because of the diseases which can make this arch persist. The limbic arch can be encountered in congenital diseases, where it persists either partially or completely. Vein of Galen aneurysmal malformations (VGAM) are particularly frequently associated with a full persistence of the limbic arch.

The dominant draining veins are usually periventricular venous channel (i.e.superior and inferior choroidal veins, medial and lateral atrial veins) and parahippocampal and hippocampal veins.

10. Clinical manifestation and outcome of post embolization of the archipallium AVMs
The clinical manifestation of the archipallium AVMs depends on the size and magnitude of hemorrhage. In general, the initial clinical manifestation with hemorrhage causes the disturbance of cognitive function and memory disorders. However, over the time course, these neurological deficits frequently recover well. After the absorption of the hematoma, the entire angioarchitecture of the nidus can be clarified. Therefore, the endovascular treatment can be indicated safely in most of the cases.[10, 12, 15] (Fig.8-12)

11. Summary
There are several differences of vascular system among the archipallium, paleopalliuim and neopallium. The knowledge and analysis of these characters may provide us more accurate indication and strategy in the management of the vascular malformations.

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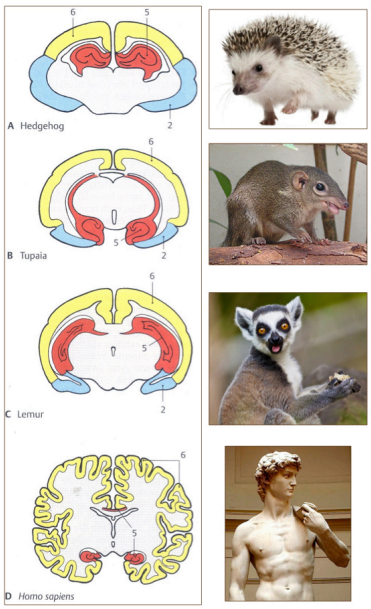
Disclosure Statement
The author declares no conflicts of interest.

Legend:



Phylogenesis of the cerebral cortex

During the phylogenesis of mammals the proortion of the paleopallium and the archipallium decreased,while the neopallium became dominant occupying almost the whole surface of the brain.

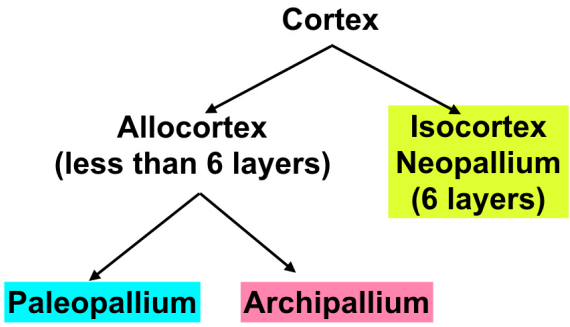


Fig.1

Fig.1. Phylogenesis of the cerebral cortex

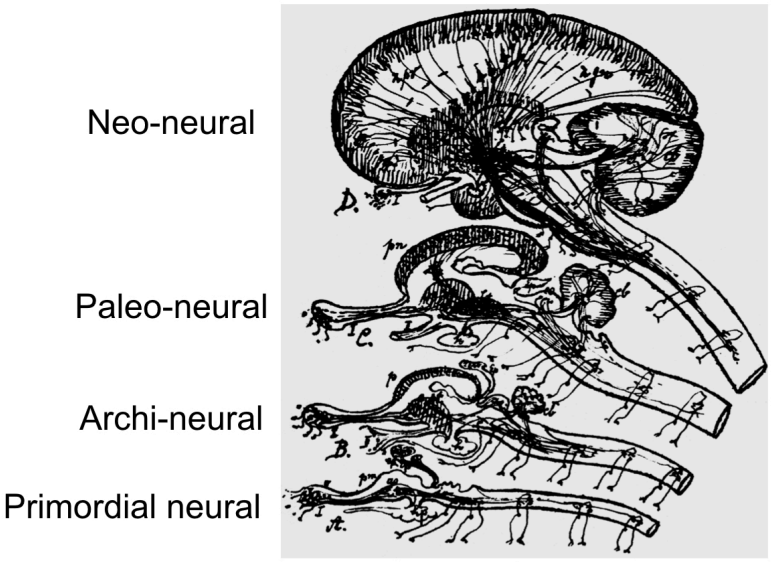
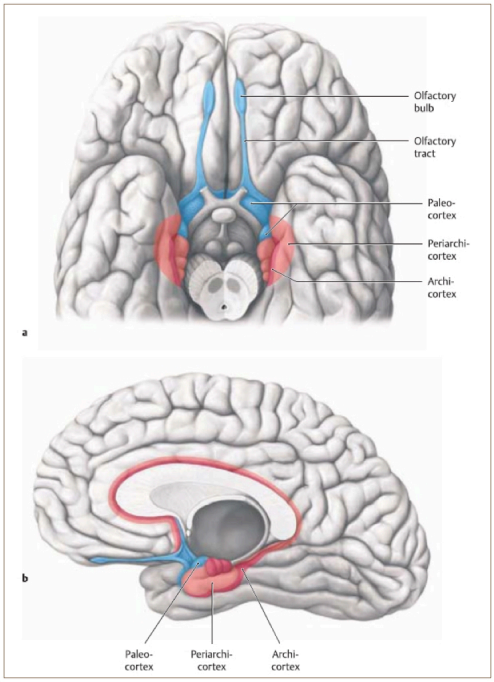


Fig.2

Jakob, C. (1945) (Folia Neurobiológica Argentina, Tomo IV). Buenos Aires: Aniceto López.

Fig.2. Schematic drawing of primordial neural (A), archineural (B), paleoneural (C) and neoneural (D) systems.



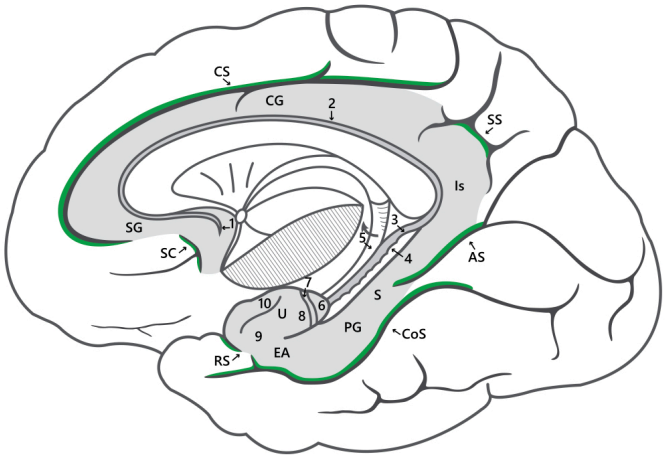
Paleocortex: the oldest cortical area of the telencephalon which contains 3 to 5 layers of neuronal cell bodies. Paleocortex includes the olfactory bulb, olfactory tubercle (approx. at the anterior perforated area) and the piriform cortex (approx. the uncus and the anterior part of the parahippocampal gyrus). All those cortical and non-cortical areas which are related to the sense of smell are summarized as the rhinencephalon or olfactory brain.

Archicortex: Constituted by 3 to 4 layers of neurons and includes the hippocampus and related structures (dentate and fasciolar gyri, indusium griseum).

Neocortex: occupies approx. 90% of the total cerebral hemispherial surface. 6 layers of neuronal cell bodies are present.

Fig.3

Fig.3. Topographical organization of paleocortex, archicortex and neocortex.



Archipallium: The limbic lobe (gray) is delimited by the limbic fissure, which is formed by the subcallosal sulcus (SC), the cingulate sulcus (CS), the subparietal sul- cus (SS), the anterior calcarine sulcus (AS), the collateral sulcus (CoS), and the rhinal sulcus (RS). Tatu et al. 2014. “Structure and Vascularization of the Human Hippocampus.” In The Hippocampus in Clinical Neuroscience, 34:18–25.

Fig.4

Fig.4. Inferomedial view of the right hemisphere.
Archipallium: The limbic lobe (gray) is delimited by the limbic fissure, which is formed by the subcallosal sulcus (SC), the cingulate sulcus (CS), the subparietal sul- cus (SS), the anterior calcarine sulcus (AS), the collateral sulcus (CoS), and the rhinal sulcus (RS).
Tatu et al. 2014.

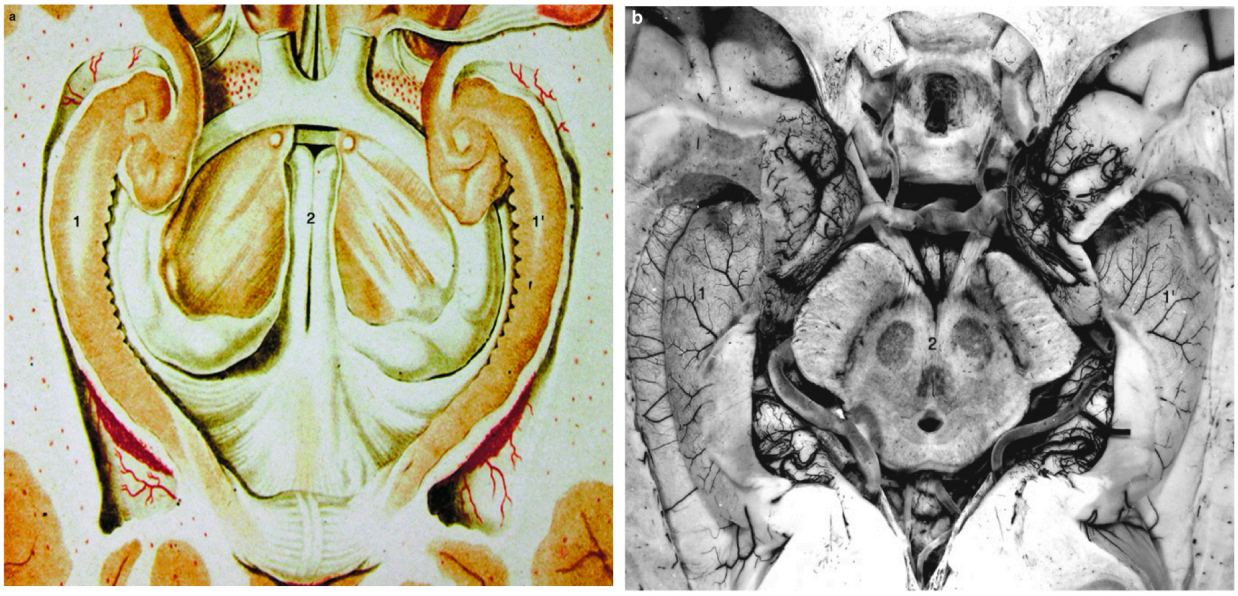
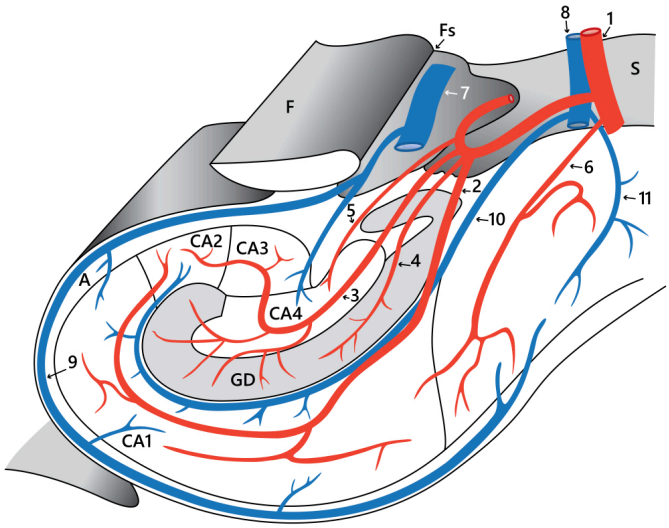


Fig.5

Fig.5. Drawing of the hippocampus by Vicq d’Azyr (1786). The right and left hippocampi (1) encircle (embracing) the median structures (2).
(b) Dissection (endoventricular view) of the right and left hippocampi (1, 1’); 2. mesencephalon. (c) MRI view; 1 hippocampus, 2 mesencephalon

Intrahippocampal vascularization.
A = Alveus; F = fimbria; Fs = fimbriodentate sulcus; S = su- biculum; GD = gyrus dentatus; 1 = superficial hippocampal artery; 2 = large ventral hippocampal artery; 3 = large dorsal hippocampal artery; 4 = small ventral hippocampal artery; 5 = small dorsal hippocampal artery; 6 = subiculum arteries; 7 = venous arch of the fimbriodentate sulcus; 8 = venous arch of the hippocampal sulcus; 9 = subependymal intrahippocampal veins; 10 = sulcal intrahippo- campal veins; 11 = subiculum veins.



Tatu et al. 2014. “Structure and Vascularization of the Human Hippocampus.” In The Hippocampus in Clinical Neuroscience, 34:18–25.

Fig.6

Fig.6. Intrahippocampal vascularization. A = Alveus; F = fimbria; Fs = fimbriodentate sulcus; S = su- biculum; GD = gyrus dentatus; 1 = superficial hippocampal artery; 2 = large ventral hippocampal artery; 3 = large dorsal hippocampal artery; 4 = small ventral hippocampal artery; 5 = small dorsal hippocampal artery; 6 = subiculum arteries; 7 = venous arch of the fimbriodentate sulcus; 8 = venous arch of the hippocampal sulcus; 9 = subependymal intrahippocampal veins; 10 = sulcal intrahippo- campal veins; 11 = subiculum veins.
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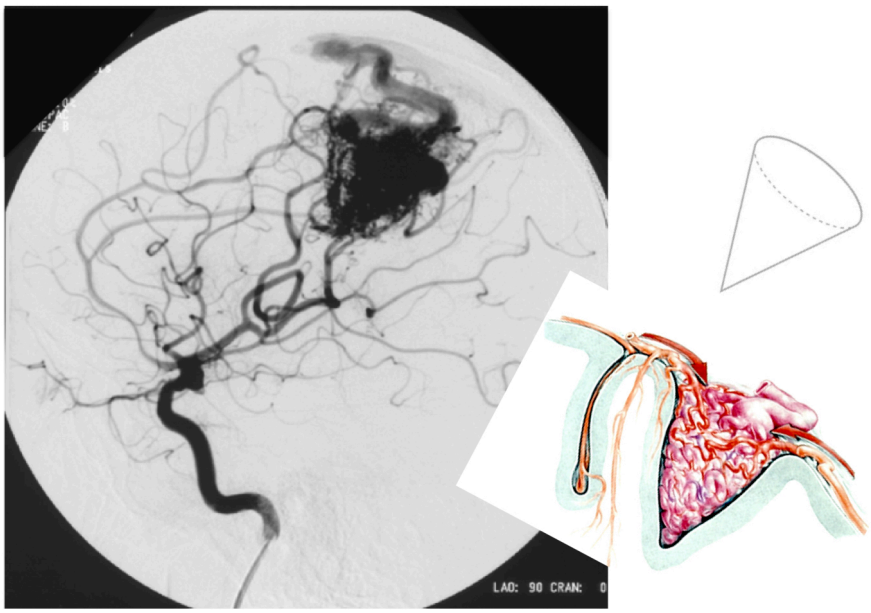
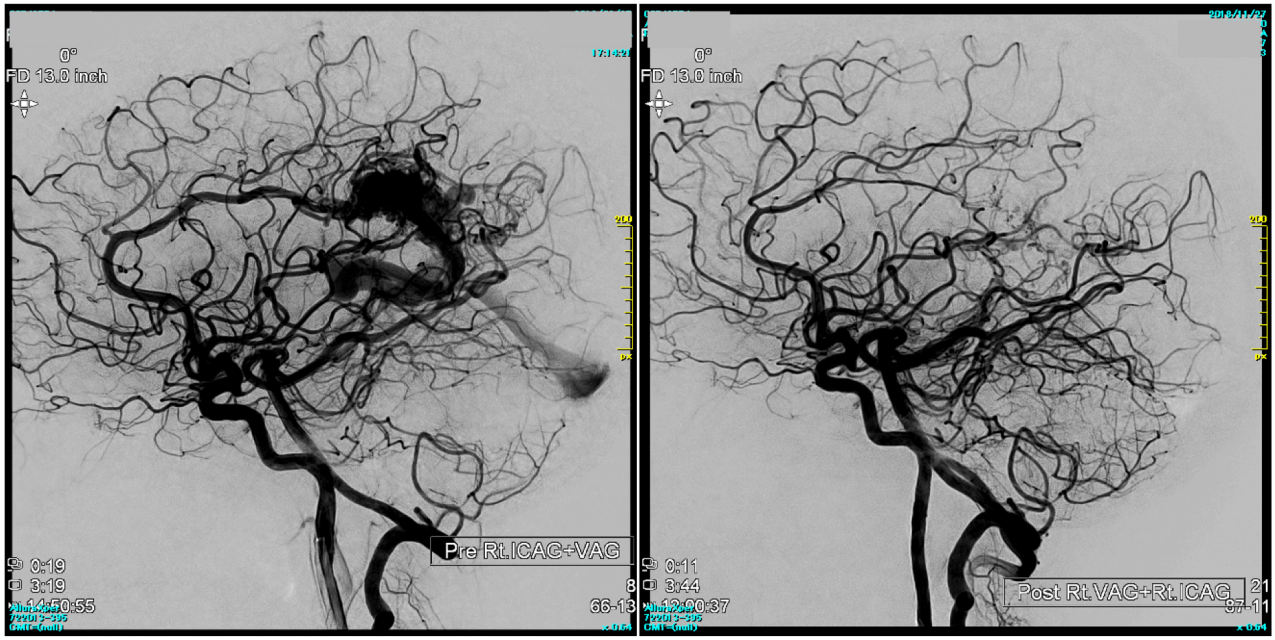


Fig.7

Fig.7. Left pre central sulcal type of AVM
Internal carotid angiography lateral view showing the typical morphological appearance of sulcal type of AVM. Note there are several terminal feeders supplying to this AVM but, there is only the single draining vein



Pre Post Fig.8

Fig.8. Case of left cingulate (so called limbic) AVM.
Pre and post angiography of lateral view. These were opacified with the simultaneous injection of ipsilateral internal carotid artery and vertebral artery.
Note the significant decreasing in the caliber of distal pericallosal artery in post angiography.

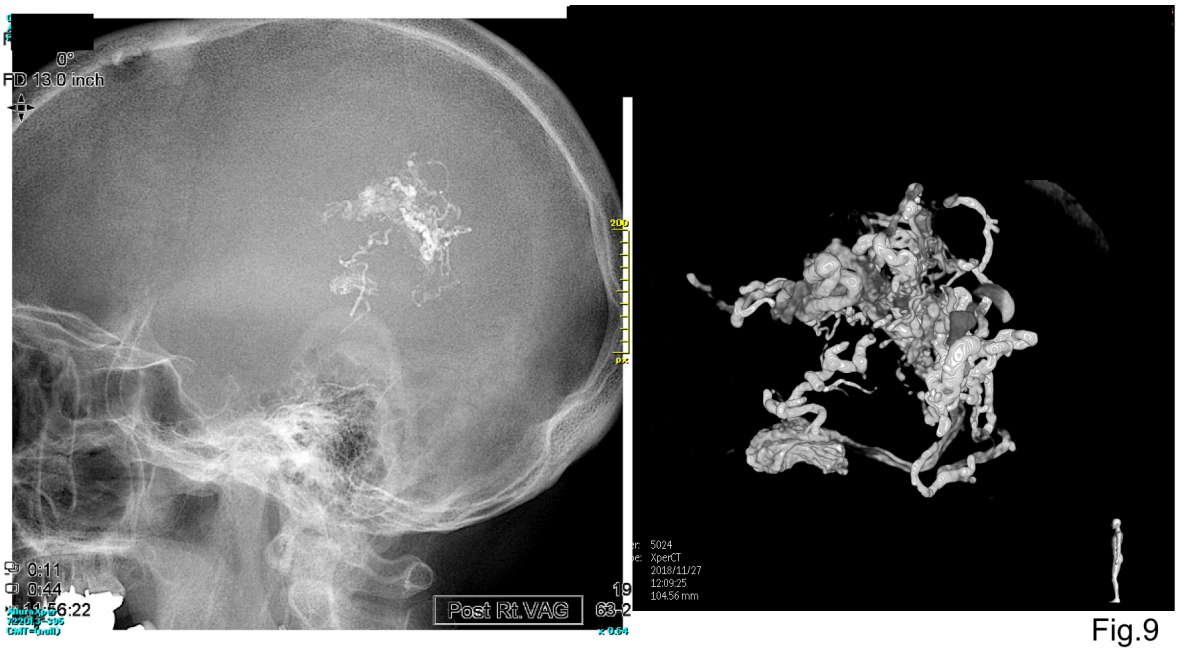


Fig.9

Fig.9. The cast of glue (NBCA with lipiodol) shows the angioarchitecture of cingulate AVM

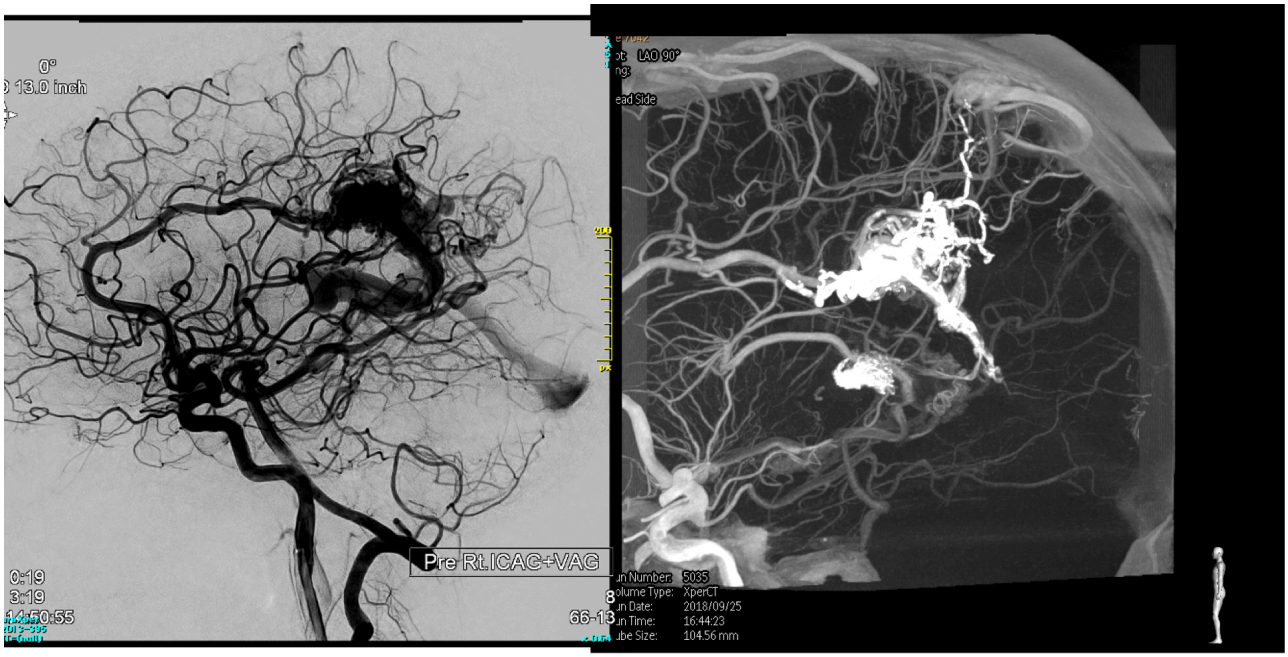


Fig.10

Fig.10. High resolution cone beam CT showed the cast of glue in the nidus. A small amount of glue was migrated into the lateral atrial vein where corresponding to the dominant drainer of this limbic AVM.

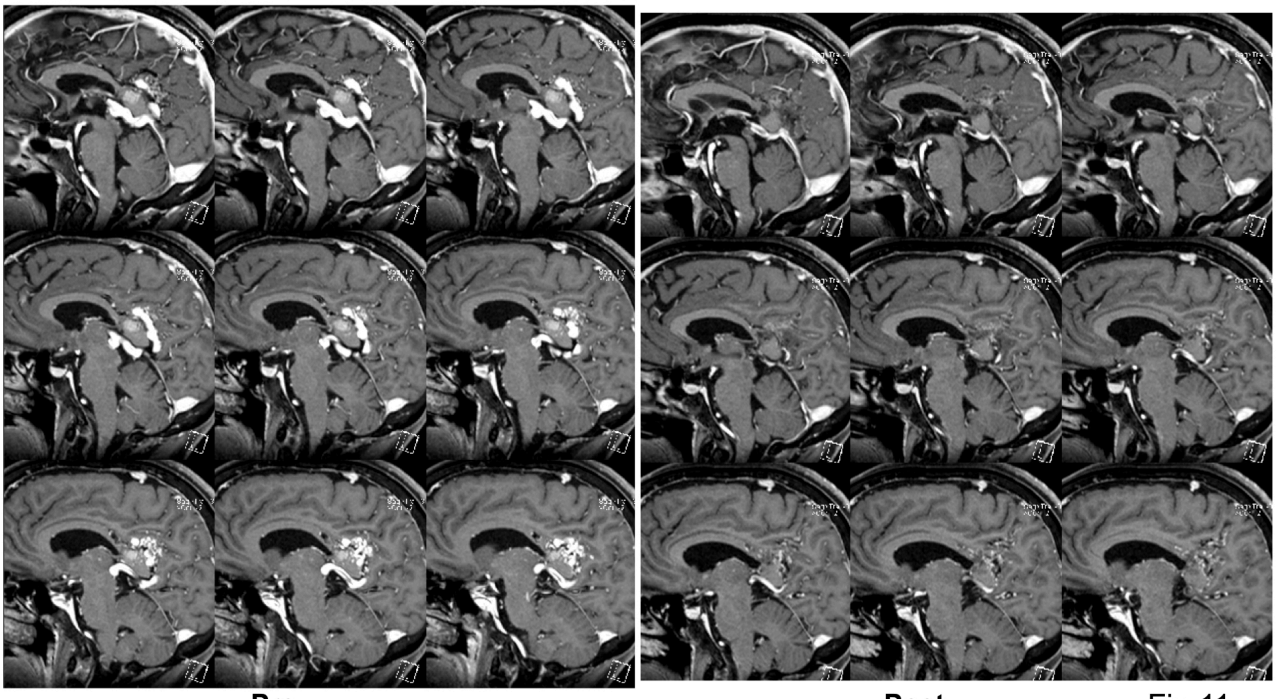
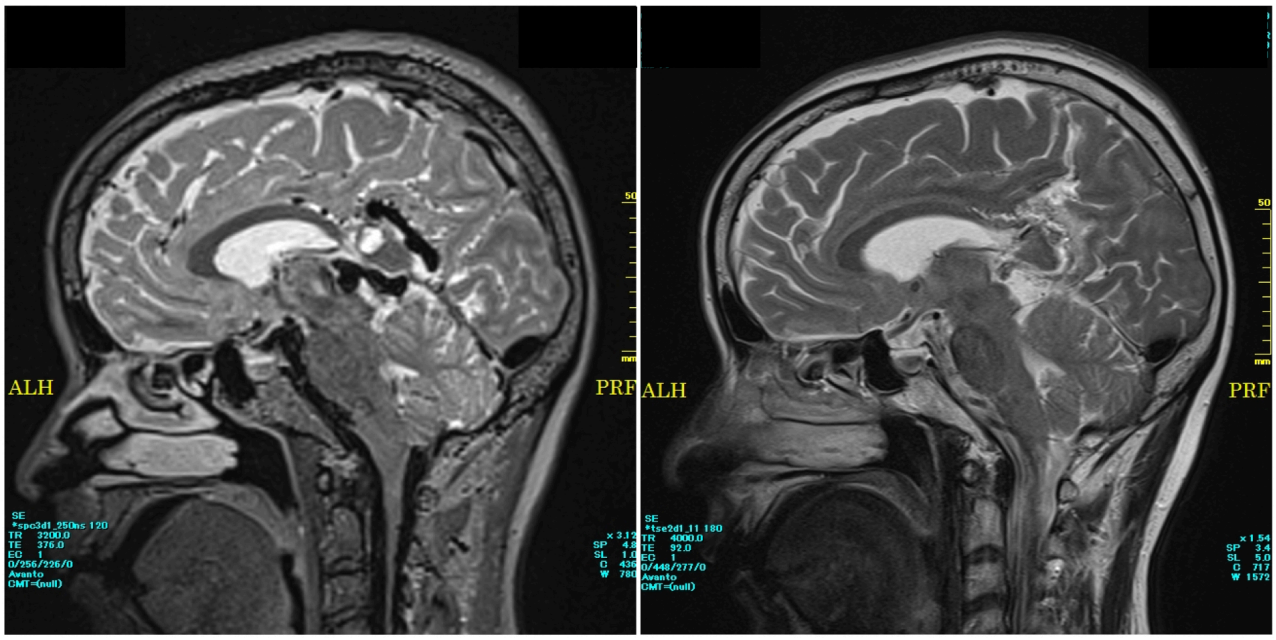


Fig.11

Fig.11. MRI sagittal view T1 weighted images with Gd contrast. The nidus compartment located in the posterior cingulate sulcus and isthmus of gyrus cinguli.



Pre **Post@3months** Fig.12

Fig.12. MRI T2 weighted image of pre and post embolization.
Although the isthmus part of the cingulate gyrus was damaged because of the initial hemorrhage, the cognitive function of the patient improved significantly.

Table 1. Topographical Classification of brain AVMs

A. Telencephalic AVMs (so called cortical AVMs, neopallium AVMs)
- (1) Sulcal type of AVMs (28%)
  - (a) pure sulcal,
  - (b) sulcal- subcortical,
  - (c) sulcal-subcortical with extension to the ventricle system
- (2) Gyral AVMs (12%)
  - (a) pure gyral,
  - (b) gyral-subcortical
  - (c) gyral-subcortical with extension to ventricle system
- (3) Mixed sulco-gyral AVMs (29%)
  - (a) sulco-gyral,
  - (b)sulco-gyral-subcortical,
  - (c) sulco-gyral-subcortical with extension to ventricle system
- (4) Diffuse AVMs (=proliferative angiopathy) (3%)

B. Subcortical AVMs (2%)

C. Deep or central AVMs (=subpallium AVMs)
- (1)Subarachnoid (fissural, cisternal) (12%)
- (2) Parenchymal (intrinsic) (7%)
- (3) Plexal (intraventricular) (1%)
- (4)Mixed (6%)

Table 1

Table 2. Location of AVMs

A. Supratentorial arteriovenous malformations (86%)

1. Neopallial arteriovenous malformations (47%)
   (frontal,temporal, parietal,occipital and central lobes)
   a) sulcal (pure sulcal, with subgyral, with para- ventricular extension)
   b) gyral (pure gyral, with subgyral, with para- ventricular extension)
   c) mixed sulcal-gyral (with subgyral,with para- ventricular extension)

2. **Archi- and paleopallial arteriovenous malformations** (9%)
   (i.e.limbic and paralimbic system arteriovenous malformations: cingulum, amygdalo-hippo-parahippocampal, septal, insular arteriovenous malformations).
   a) sulcal, fissural
   b) gyral, parenchymal
   c) mixed
   d) ventricular (temporal horn)

3. Deep central arteriovenous malformations (subpallium), (27%) (strio-capsulo-thalamic, diencephalic, mesencephalic and intraventricular-plexal)
   a) fissural, cisternal
   b) parenchymal
   c) mixed
   d) plexal-intraventricular (lateral and/or IIIrd ventricle)

4. Vein of Galen aneurysmal malformations (3%)

Table 2

B. Infratentorial arteriovenous malformations (14%)

1. Neocerebellar arteriovenous malformations (11%)
   a) sulcal, fissural
   b) folial c) mixed

2. Paleo-Archicerebellar arteriovenous malformations (1%)
   a) sulcal, fissural
   b) folial
   c) mixed

3. Deep-central arteriovenous malformations (2%)
(cerebellar-nuclear, brain-stem, intraventricular arteriovenous malformations)
   a) fissural, cisternal
   b) parenchymal
   c) intraventricular (IVth ventricle and/or aqueduct)

Table 3

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