Review article

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Neurosurgical anatomy of the insula and Sylvian fissure in gliomas: literature review and personal experience. The second report. Veins

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Insular gliomas account for 25% of all low-grade and 10% of high-grade gliomas. Neurosurgical treatment of insular gliomas involves achieving the maximum possible volume of tumor removal while ensuring high quality of life.

The anatomical proximity of functionally important brain structures and the involvement of important insular arteries and veins limits the possibility of radical removal of tumors.

The key to the effectiveness of surgical intervention in insular gliomas is the selection and implementation of adequate surgical access surgical access. The most commonly used approach to insular gliomas is transsylvian-transinsular. The implementation of this approach is largely determined by individual characteristics of the venous system of the sylvian fissure, since it is characterized by extreme anatomical variability in particular, the type of outflow direction dominance, the number of veins, their size, type of branching, drainage, collateral connections.

The review presents data on the informativeness of modern methods of instrumental research in the assessment of the venous system of the sylvian fissure and insula with the aim of planning surgery for insular gliomas.

Methods of preserving venous collectors of the sylvian fissure and possible complications associated with the exclusion of draining veins from the circulation are described.

Key words: *insular gliomas; anatomy; veins of sylvian fissure and insula; diagnosis, surgery*

Introduction

Optimal anatomical and physiological surgical approach to the insula affected by the tumor is provided by the sylvian fissure dissection. The sylvian fissure dissection is one of the necessary and extremely difficult skills to perform, its performance requires a lot of time and extensive experience of a neurosurgeon [1–3]. Successful completion of this procedure enables the shortest anatomically and physiologically atraumatic way to reach the lesions of the insula.

Surgically, the insula is a complex anatomical structure due to its proximity to critical neural structures, as well as its unique vascular anatomy, particularly its relationship to the middle cerebral artery and middle cerebral veins (MCV). In literature, much attention has been paid to such problems of insular glioma surgery as the necessity of branch dissection at the level of M1 and M2 segments, preservation of perforating arteries arising from M2 segment of the middle cerebral artery and involved in tumor blood supply, importance of avoiding trauma to the lenticulostriate arteries [4, 5]. However, the variable anatomy and physiology of veins of the sylvian fissure and insula are not frequent topics for discussion in scientific periodicals [6–8]. It has been only noted that during transsylvian-transinsular approach to insular gliomas, it may be necessary to exclude certain veins from the blood circulation, which interfere with sylvian fissure dissection and cause additional traumatic traction of the brain matter [6, 7]. This practice was generally accepted for a long time. The method of dissection of sylvian fissure structures, which was performed after transection of venous inflows from the frontal lobe, was even considered "classical" [9].

Later, there were publications noting that unreasonable coagulation and transection of superficial or deep MCV cause seizures, paresis, and aphasia [10], and venous infarction or aggressive cerebral edema caused by venous congestion can lead to a significant deterioration of patient's clinical condition [11].

Surgical anatomy of veins of the sylvian fissure and insula

From the point of view of surgical purpose, the venous system of sylvian fissure and insula can be classified according to the level of drainage, the variant of vein branching and the type of drainage of main venous collectors. The venous system of sylvian fissure and insula is characterized by extreme anatomical variability in terms of the number of main venous collectors, the predominance and the place of their entry into venous sinuses, type of branching, drainage area and the functionality of anastomosis.

Among numerous studies devoted to attempts to classify all the diversity of venous anatomy of sylvian fissure of the convexital surface of the cerebral hemispheres and insula, the studies by K. Kazumata *et al*. (2003) are worthy of special attention [9, 13, 14].

Venous outflow from any anatomical structures of cerebral hemispheres (including the insula) occurs in superficial (cortical) and deep venous system of the brain ***(Fig. 1)***. The main cortical venous collector for the sylvian fissure and insula is the superficial middle cerebral vein (SMCV; code for the anatomical international nomenclature A12.3.06.009). The superficial veins of sylvian fissure are one of the three main venous drainage systems of the convexital surface of the cerebral hemispheres, located on the surface of sylvian fissure and cause a number of difficulties both at the stage of surgical approach to the insula and during the main stage of surgery, preventing brain traction. Usually, SMCV is formed by fronto-orbital, fronto-parietal and fronto-temporal tributary veins [9].

Important characteristics of veins of sylvian fissure of the brain and insula are the type of SMCV branching and the area of venous drainage, since they are often the determining factors when choosing a surgical approach to insular gliomas. K. Kazumata *et al.* (2003), identified three main types of branching of SMCV: Type I - SMCV is absent or hypoplastic (observed in 10% of cases), Type II - SPMV is represented by one main trunk (frontal or temporal) (in 46% of cases), Type III - SMCV is represented by two main trunks (frontal and temporal) (in 44% of cases) [9]. Some researchers advise focusing on the dominance of its venous tributaries: frontal, temporal, parietal rather than on the number of SMCV trunks [15, 16].

Yasuhiro Suzuki *et al.* (2000) [13], analyzing the results of three-dimensional computed tomographic angiography performed on 250 patients with various neurosurgical pathologies, proposed a classification of options for priority drainage of SMCV ***(Fig. 2)***:

1. Clinoparietal (sphenoparietal) variant: SMCV drains into the cavernous sinus system after entering the clinoparietal sinus.

2. Cavernous variant: SMCV enters the anterior parts of the cavernous sinus directly.

3. Emissary variant: SMCV runs along the lesser wing of the sphenoid bone, turns down, reaches the bottom of the middle cranial fossa (MCF), connects with the outlet (emissary) vein of the sphenoid bone and provides venous drainage into the pterygopalatine venous plexus system.

4. Superior petrosal variant: SMCV runs along the lesser wing of the sphenoid bone, returns back along the bottom of the MCF between the foramen ovale and the lateral wall of the cavernous sinus and flows into the superior petrosal sinus.

5. Basal variant: SMCV passes behind at the bottom of the MCF, bypasses the foramen ovale laterally and flows into the transverse, superior petrosal or lateral sinus of the cerebellar tentorium.

6. Squamous variant: SMCV does not turn medially, but goes posteriorly along the inner surface of the cranial base to connect with the transverse or lateral sinus of the cerebellar tentorium.

7. Hypoplastic variant: SMCV is absent and venous drainage from the superficial part of sylvian fissure is carried upwards, anteriorly, posteriorly into the superior sagittal or transverse sinuses system. The authors note that the data obtained during 3D computed tomography angiography (CTA) enable to accurately determine the drainage pathways of the SMCV, which should be considered when planning and performing surgical interventions in the area of sylvian fissure in order to minimize surgical approach and risks of intraoperative and postoperative complications.

Deep (parenchymal) drainage of sylvian fissure of the brain and the insula is carried out by the deep middle cerebral vein (DMCV; code according to the international anatomical nomenclature A12.3.06.020) into the system of the basal vein (vein of Rosenthal). The latter is also formed by olfactory, posterior fronto-orbital, anterior

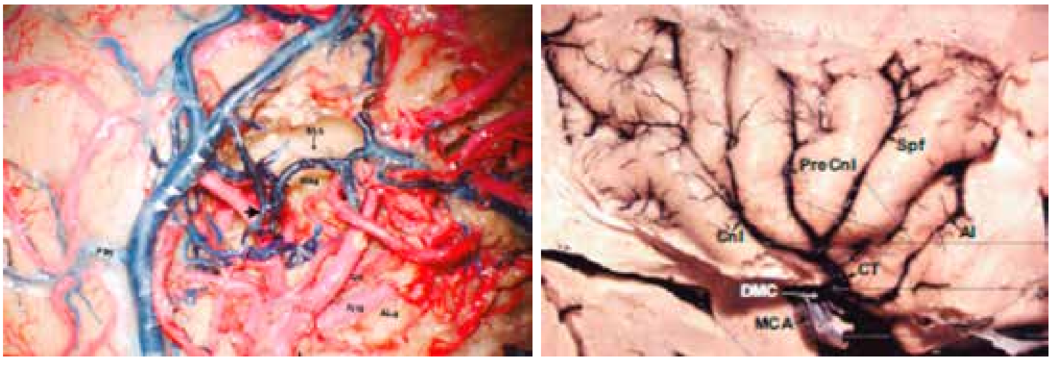

Fig. 1. Structural variant of the venous drainage link of the sylvian fissure and insula: A - the superficial system is represented by the superficial middle cerebral vein; B - the deep system is formed by insular veins, which flow into the basal cerebral vein through the deep middle cerebral vein [9]

This article contains some figures that are displayed in color online but in black and white in the print edition

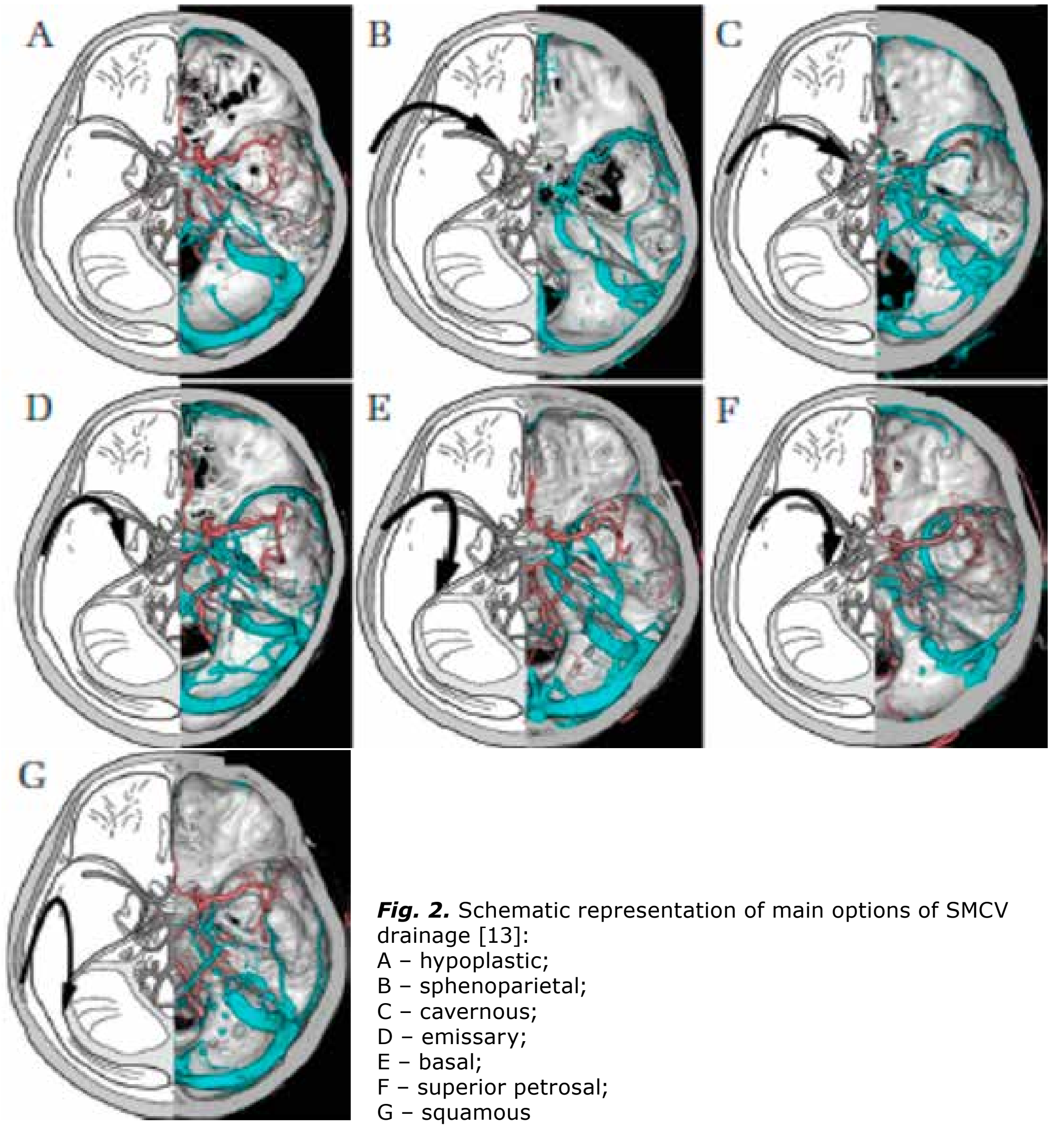

Fig. 2. Schematic representation of main options of SMCV drainage [13]:
A – hypoplastic;
B – sphenoparietal;
C – cavernous;
D – emissary;
E – basal;
F – superior petrosal;
G – squamous

cerebral and chiasmatic tributary veins [9]. K. Kazumata *et al.* [9] pay attention to veins of the insula and separate the deep venous system of sylvian fissure of the brain and the insula into a separate (intermediate) group. These veins are usually represented by veins of anterior limiting sulcus, precentral sulcus, central sulcus, and inferior limiting sulcus [13].

A fundamental study devoted to the topographic anatomy of the insula, which examines the peculiarities of its venous drainage, is the study of G.G. Varnavas *et al*. (1999) [14]. The authors distinguish three anatomical zones of the insula according to features of venous drainage: threshold, anterior and posterior lobes. A significant part of the anterior lobe is drained mainly into the SMCV system, the posterior lobe is mainly into the DMCV ***(Fig. 3)***. According to researchers, the area of threshold of the insula contains veins that are drained only in the DMCV (in 94% of cases). Analysis of a series of studies of sectional material showed that DMCV was present in all (52) anatomical block preparations. In 86% of cases, it was represented by a single trunk, in the rest it was represented by a double trunk: with tributaries from the cortex of the insula and the cortex of the lateral parts of the perforated substance. In all cases, the DMCV flowed into the basal vein of the brain.

According to the literature, drainage of the common trunk of the insular vein can be classified into two types: the classic variant with the common trunk flowing into the basal vein, and the alternative variant with the common trunk flowing into the sphenoparietal sinus [14].

Veins of the insula are characterized by a variety of not only the number and types of drainage, but also types of anastomoses. There are superficial anastomoses between cortical veins of the insula and deep anastomoses between veins of the insula and subependymal deep veins. From a surgical point of view, anastomoses between SMCV and DMCV are functionally important. According to J. Lang [17], the anastomotic vein from the surface of the insula passes from the bottom up and flows into the SMCV in the middle parts of the sylvian fissure of the brain. F. Galligioni *et al*. (1969) and T. Frigeri *et al*. (2005) describe multiple anastomoses between SMCV and DMCV [18, 19]. G. G. Varnavas *et al*. (1999) [14] indicate 4-11 (average 6) anostomotic veins between SMCV and DMCV in 81% of the studied anatomical block preparations of cerebral hemispheres.

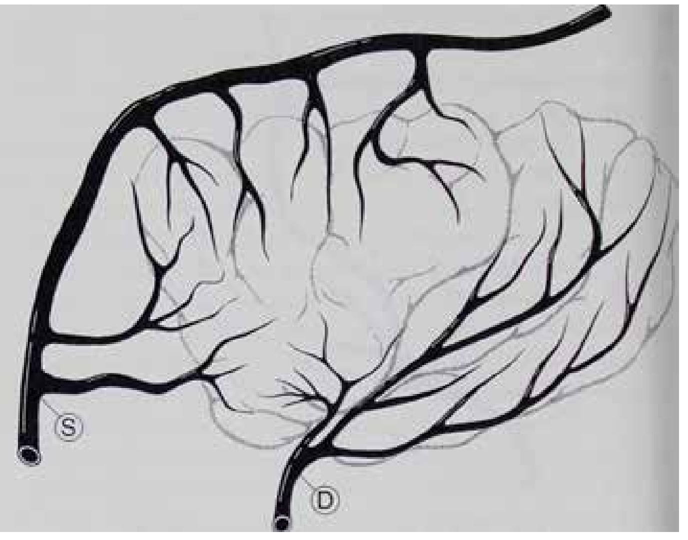

Fig. 3. Schematic representation of the most common branching variant of the insular veins: D – deep middle cerebral vein; S – superficial middle cerebral vein [14]

According to K. Kazumata *et al*. (2003) [9], insular veins form anastomoses with SMCV in 51 % of cases. The absence of anastomotic veins between the superficial and deep parts of the venous system of the sylvian fissure of the brain in the operating field indicates that the common trunk of insular veins is probably drained into the basal vein.

Consequences of surgical exclusion of veins of the sylvian fissure and insula from the circulation

Since superficial veins of sylvian fissure of the brain pass along the inferior frontal lobe, where Broca's kinetic-language area is located in the dominant hemisphere, venous occlusion causes speech disorders that significantly reduce the patient's quality of life. Disturbance of venous outflow from the sylvian fissure, not even in the dominant hemisphere, provokes a neurological deficit, in particular paresis and convulsions [10]. In addition, damage to the veins makes the brain tissue more "sensitive" to traction, which leads to an increased risk of intraoperative contusion [11, 12].

Y. Kageyama *et al.* (1992) [20] were among the first to pay attention to venous complications of transsylvian approach. They noted that in 15% of cases, transsylvian approach is accompanied by the appearance of cerebral edema and hemorrhagic imbibition, due to the exclusion of the venous tributaries of SMCV. Localization of these complications is mainly in the inferior frontal lobe [20].

B.L. Dean *et al.* (2005) [21] studied postoperative angiographic changes of superficial veins of sylvian fissure of the brain and cerebral edema after clipping of middle cerebral artery aneurysms. 31% of patients were described to have SMCV injuries of various severity (from partial to complete occlusion according to postoperative venography data). Cerebral edema, according to computed tomography (CT), occurred in 47% of cases. According to the data of angiographic and tomographic comparisons, cerebral edema was detected in 77% of cases with damaged SMCV and in 33% - with intact SMCV. The average area of the cerebral edema zone, according to postoperative CT scan, ranged from 4.05 to 5.22 cm^2. In case of exclusion of SMCV from the circulation, postoperative CT revealed cerebral edema with an average area of 10.8 cm^2. The authors established a correlation between the severity of angiographic changes of SMCV and the area of postoperative cerebral edema. Results of the study demonstrate consequences of impaired venous outflow and indicate the importance of preserving veins of sylvian fissure of the brain. The authors did not indicate whether they deliberately crossed the SMCV in necessary situations. Clinical results of such cases are not described.

There is little literature on the frequency of clinical complications of exclusion of venous collectors. This explains the often erroneous decision of the surgeon to "sacrifice" the superficial veins of sylvian fissure of the brain to ensure a wide exposure of surface of the insula and increase the degree of surgical freedom in the operating field. There are practically no published data on the consequences of exclusion of the sylvian fissure and insula from the blood flow of deep veins. Only J. Browder *et al*. (1974) [22] reported that intraoperative exclusion of DMCV can entail a distinct hemorrhagic extravasal reaction.

Modern possibilities of neuroimaging methods in the study of veins of the sylvian fissure and insula

Modern, highly informative level of neuroimaging methods makes it possible to assess the state of the venous system of sylvian fissure of the brain and insula even at the preoperative stage, gives an idea of the topographic anatomy of this area and allows planning both surgical approach and stages of removal of insular gliomas.

In the 1990s, a number of studies demonstrated high levels of sensitivity, informativeness, and specificity of noninvasive methods of neuroimaging of veins of the sylvian fissure and insula, which were not significantly inferior to those of digital selective angiography [23]. Thus, S. Wetzel *et al*. (1999) [24] in the study of 426 cases of evaluation of venous structures of the brain (sylvian fissure and insula) using CT venography revealed 95% sensitivity and 91% specificity of the method.

3D-CTA allows a clear assessment of details and features of sylvian fissure veins location and their anatomical variants [25,26]. Cerebral veins may also be stereoscopically related to surrounding arteries and bony structures. In addition, 3D-CTA examination of anastomotic connections of deep veins of sylvian fissure of the brain and insula helps to assess the risk of potential exclusion from the blood flow of certain venous collectors. 3D-CTA data are informative in justifying the optimal surgical tactics for insular gliomas, namely, when choosing a surgical approach (transinsular or transcortical) based on the risk assessment of possible exclusion or damage of main or anastomotic veins. 3D-CTA enables visualization of cerebral arteries and veins simultaneously, which provides stereoscopic correlation of cerebral veins with corresponding arteries and bony structures. Some authors note that simultaneous enhancement sometimes complicates the differentiation of veins and arteries [27,28]. In our opinion, this issue can be resolved by rotating the reconstructed image and by comparing 3D-CTA images and digital subtraction angiography. Research by Y. Suzuki *et al*. (1999) showed that 3D-CTA enables clear visualization of deep veins of sylvian fissure and insula and demonstrated complete correspondence between tomographic data and intraoperative findings, making 3D-CTA a valuable technique when planning surgical interventions [13].

B. Gogia *et al.* (2018) demonstrated the informative value of MR venography and possibilities of preoperative planning of surgical interventions using this method of non-invasive diagnosis of the venous system of sylvian fissure of the brain using the material of 20 observations of patients with insular gliomas [29]. In addition to the list of difficulties of neuroimaging of the venous link, the authors found in all observations the main veins from a surgical point of view (SMCV, DMCV, veins of periinsular sulcus and the actual surface of the insula).

Targeted, systematic studies devoted to the features of neuroimaging assessment of the venous link of sylvian fissure in insular gliomas have not been conducted. Their relevance is determined by the need for the neurosurgeon to form a complete topographic-anatomical picture of this pathology in order to plan optimal approach to the insular glioma, stages of removal, and predict the likely radicality of the surgical intervention.

Peculiarities of surgical manipulations in insular gliomas and reasonable necessity to preserve venous circulation

Evaluation of anatomical features and understanding the physiology of the venous system of sylvian fissure and insula is essential for successful surgical intervention for insular gliomas. Individual features of the superficial venous system of this area significantly affect the choice of surgical approach and the method of sylvian fissure dissection. The work of H. Maekawa and H. Hadeishi in 2015 [30] describes in detail the methods of sylvian fissure dissection with the maximum possible preservation of SMCV venous collectors for various topographic and anatomical options. Researchers develop the concept of sylvian fissure dissection, according to which blood supply and venous drainage of the frontal and temporal lobes are always performed by separate branches, and vice versa - one vessel is not involved in the supply (artery) or drainage (vein) of the frontal and temporal lobes simultaneously. Thus, a neurosurgeon should always try to isolate and separate the frontal and temporal vessels: neither vein nor artery can be transferred from the frontal to the temporal lobe in the operating field. Researchers state that since a particular SMCV surface receives blood from either the frontal or the temporal side of sylvian fissure, the surgical approach through the sylvian fissure should be formed between the frontal and temporal veins ***(Fig. 4)***, otherwise within neurosurgeon's sight there will be a vein that will cross the surgical corridor between the frontal and temporal lobes, and will interfere with further sylvian fissure dissection. If this vein is transected, there will be a risk of venous infarction ***(Fig. 4 C and F)***. Therefore, before proceeding with the dissection, the course of SMCV and its inflow should be carefully evaluated to determine the plane of dissection of sylvian fissure ***(Fig. 4 A, B, D and E)***. The correct plane of dissection is between the frontal and temporal superficial veins of sylvian fissure ***(Fig. 4 B, E)***. The authors also note that in many cases superficial veins of sylvian fissure are not located in the center of the sulcus, but lie on the temporal lobe. If frontal inflows of the superficial vein of sylvian fissure pass through the temporal lobe, the dissection should be performed between frontal veins and the temporal lobe ***(Fig. 4 A, D)***.

When dissecting the sylvian fissure, the neurosurgeon often encounters the fact that the vein, even after all the necessary manipulations are performed, limits the exposure of the insula and interferes with further actions in the operating field. In this case, a decision should be made whether this vein can be transected without consequences. Unfortunately, there is very little data in the literature that would help determine surgical tactics in such a situation. Given the fact that consequences of transecting the tributaries of veins of sylvian fissure can be unpredictable and even threatening, the optimal tactic is to try to preserve these veins. However, the problem becomes more acute when preservation of such veins necessarily promotes excessive brain traction or reduces the possibility of radical tumor resection due to limited exposure of the insula due to the attempt to preserve the veins.

Based on personal experience, we provide general recommendations that in no case are intended to reduce the importance of a thorough surgical evaluation of the situation in each case. If the sylvian fissure dissection cannot be continued without transecting certain veins, then a reasonable decision would be to exclude the smallest vein in caliber and the least number of veins necessary to obtain adequate exposure of the insula. The caliber of the vein is an indirect indicator of the size of a drained area, i.e., the larger the caliber of the vein, the higher the chance of deficiency if the vein is excluded. If necessary, it is allowed to exclude a drained vein represented by a single tributary, in contrast to excluding a drained vein formed by the ends of several veins. However, if it is necessary to exclude a capacious vein with multiple tributaries, it should be transected close to the drainage sinus to allow blood to flow freely between branches in order to increase the likelihood of retrograde drainage through collaterals. In addition,

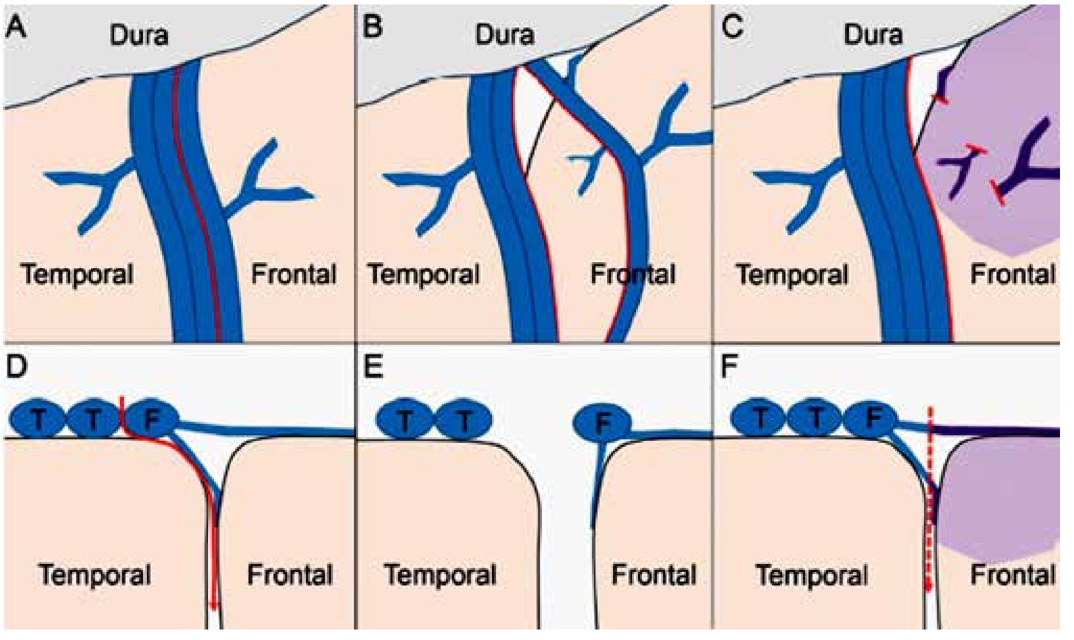

Fig. 4. Features of sylvian fissure dissection with preservation of venous collectors [30]:
A-D – dissection of sylvian fissure between the frontal and temporal SMCV, wherein the frontal branch of SMCV with its tributaries transects the space of sylvian fissure to the temporal lobe;
B-E – dissection of veins of sylvian fissure with preservation of tributaries from the frontal lobe. The frontal branch of SMCV is located on the frontal lobe;
C-F – dissection of veins of sylvian fissure without preserving the tributaries. This option leads to the development of postoperative neurological deficit

before excluding a vein to ensure adequate approach, the surgeon should carefully isolate the vein microsurgically to ensure that sufficient space can be obtained for exclusion. In some cases, another method of preserving venous trunks can be used - a small volume of resection of the "silent" area of the cerebral cortex can provide sufficient exposure without having to transect the vein.

In general, exclusion of any of the superficial or deep veins of the sylvian fissure, while they are located directly in the sulcus, should be done with great care and only when they are of small caliber and wide anastomoses. However, as noted above, the interruption of the ends of the veins of the sylvian fissure after they leave the sulcus and enter the sphenoparietal, sphenobasal, or cavernous sinus can be performed safely. In fact, we often transect the veins at this location without consequences in insular gliomas with significant temporal extension to perform a temporal pole approach. Usually, in such situations, there are enough cortical collateral vessels that facilitate rapid redistribution of blood flow without undesirable clinical consequences.

Before excluding a particular vein from the circulation, it is useful to assess the adequacy of venous collaterals by temporarily occluding the vein for several minutes with microclamps. The absence of local venous stasis during temporary occlusion indicates the functionality of alternative anastomotic venous pathways. R. Ferroli *et al.* (2011) [31] published the results of using fluorescence microscopy to assess the development of venous collateral blood flow. They used videoangiography during 153 neurosurgical interventions for various intracranial pathologies and analyzed the features of venous drainage. The authors discovered three patterns of venous flow dynamics: 1) arterialized veins, 2) rapidly draining veins with uniform filling, 3) slow draining veins with nonuniform filling. R. Ferroli *et al*. developed a test to predict the presence of venous collateral circulation and applied it in 8 cases where selective vein exclusion was assumed (3 cases of rapidly draining veins with uniform filling and 5 cases with slow draining veins with nonuniform filling). The test consisted in comparing the fluorescence data before and after the temporary veins occlusion. In addition, semiquantitative analysis of blood flow dynamics was performed in 6 of these patients. Bradyhemarrhea, which was observed in 3 cases with a rapid drainage pattern, was considered a sign of insufficient collateral circulation, and none of these veins were transected. Return blood circulation in 5 cases with slow drainage pattern was interpreted as a sign of adequate venous collaterals. All these patients underwent veins occlusion. Early postoperative T2-weighted magnetic resonance imaging showed no evidence of venous stasis in patients undergoing selective vein exclusion [31].

The study of A. Benet *et al.* - is noteworthy (2015) [6] in which the authors using sectional material, compared the size of insular exposure and the degree of "surgical freedom" in transinsular, transcortical-transinsular approaches to the insula with preservation of the sylvian fissure veins. The Berger–Sanai classification [32] was used to assess the topographic anatomy of the region of insula. The researchers state that the trancortical approach provided better exposure of the insula than the transsylvian one in almost all areas of the insula on sectional material, but, according to the literature, is accompanied by postoperative neurological complications in 30% of patients. A common cause of this is the transection of the superficial veins of the sylvian fissure. In addition, the authors note that a wide and adequate exposure of the insula in zones II and III requires resection of the precentral and superior temporal gyrus. That is why cortical and subcortical mapping is extremely important before and during transcortical approach to the posterior parts of the insula (zones II and III according to Berger–Sanai), since motor and somatosensory projection pathways (zone II) and speech bundles (zone III) are concentrated there. A. Benet et al. emphasize the importance of preoperative evaluation of the venous system of the sylvian fissure of the brain and electrophysiological monitoring for planning and performing surgical interventions for insular gliomas. This study has demonstrated that transcortical approach has certain advantages over transsylvian approach with preservation of venous tributaries for insular gliomas that extend beyond the periinsular sulci. Transsylvian approach and transsylvian approach with preservation of venous tributaries are most appropriate for small and medium-sized tumors located within the insula. Choosing a surgical approach that provides the greatest exposure of the insula, according to researchers, significantly reduces the risk of postoperative neurological deficit. A significant limitation of the clinical application of study results is the experimental nature of the work, since it is difficult to plan in advance the amount of insular exposure and the degree of surgical freedom for certain approach in a real clinical situation on living brain tissue, especially in conditions of pathological changes with a distortion of anatomy (for example, in the case of insular glioma). The importance of vein preservation has been proven and a technical solution to this problem has been proposed.

Conclusions

The importance of obtaining information about individual characteristics of the venous system of sylvian fissure of the brain is primarily due to the need to perform adequate transsylvian approach to the gliomas of the insula, which should ensure sufficient exposure of the surface of the insula and minimal trauma to surrounding anatomical structures of the brain due to its possible subsequent traction. This approach is difficult, painstaking, requires a certain time for its implementation, as well as extraordinary skills and experience of the surgeon. Significant individual variability of the course and branching of SMCV should not lead to unreasonable exclusion of venous tributaries from the blood flow. Clinical consequences of transection venous tributaries of SMCV can be unpredictable and even threatening, so surgical tactics and instrumental surgical manipulations during surgery for insular gliomas should be planned and performed with preservation of these venous structures.

Thus, a thorough study of the normal and pathological anatomy and physiology of veins of the sylvian fissure of the brain and the insula, improvement and optimization and reasonable application of their preoperative visualization techniques, development of preoperative planning techniques and stages of surgical interventions for insular gliomas with preservation of venous collectors of sylvian fissure of the brain are an actual problem of neurosurgery, which requires further detailed analysis and systematic study.

Disclosure

Conflict of interest

The authors declare no conflict of interest.

Ethical approval

This article is a literature review, therefore no ethics committee approval was required.

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