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Neurosurgical anatomy of the insula and Sylvian fissure: Literature review and personal experience. The third report. Anatomy of sylvian fissure, sylvian cistern, gyri and fissures of the insula

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Despite being a region where numerous pathological processes may develop, the insula remains one of the least studied anatomical structures of the human brain. The clinical course of insular glioma is accompanied by a severe morbidity, caused by the proximity of the central core, important projection and associative pathways, main arteries and large venous collectors. For a long time, surgery of patients with insular gliomas, which would involve the total volume tumor removal while ensuring high quality of post-surgery life, was considered impossible.

Understanding the surgical anatomy of the insula is key to successful transsylvian-transinsular, transopercular approaches to insular gliomas and their radical removal.

The article provides a detailed surgical anatomy of the sylvian fissure, the operculum and the insula.

Key words: *insular gliomas; sylvian fissure; sylvian cistern; operculum; surgical anatomy of the insula*

Introduction

Insular gliomas (IGs) are the most common internal tumors that can arise in this region, accounting for up to 25% of all low-grade gliomas and 10% of all high-grade gliomas [1, 2]. IGs are typically associated with pronounced neurological symptoms, including pharmacoresistant epilepsy, motor and sensory aphasia, and motor deficits [2]. These tumors are aggressive and destructive due to their invasive growth patterns and progressive involvement of deep subcortical structures, as well as critical associative and projection pathways.

Recently, the anatomy and functional significance of the insular region have been thoroughly studied and described, allowing for a reconsideration and refinement of surgical strategies and resection techniques for IGs [3].

The insula is a hidden lobe of the cerebral hemispheres that becomes visible only after dissection of the Sylvian fissure (SF) and retraction of the opercula [4, 5]. The opercula, projection and association white matter tracts, and subcortical nuclei surrounding the insula are functionally significant, particularly in the dominant hemisphere. Additional limitations to the surgical access of IGs are associated with the complex branching patterns of the venous system within the

Sylvian fissure, as well as with the individual topography of the middle cerebral artery (MCA) and the course of its branches deep within the lateral sulcus [6, 7]. All these factors make the surgical management of IGs an extremely challenging task, even in the era of advanced diagnostic and intraoperative technologies.

Surgical anatomy of the Sylvian fissure

The insula (according to anatomical nomenclature A14.1.09.149 [8, 9]) is a triangular protrusion of cerebral tissue located in the depth of the SF. It is bounded by the circular sulcus of the insula. The surface of the insula is divided by sulci into short and long gyri. The portions of the frontal, parietal, and temporal lobes that cover the insula are referred to as the operculum. The Sylvian fissure of the brain is a deep groove on the lateral convex surface of the brain, extending from the crest of the sphenoid bone to the supramarginal gyrus. It separates the lateral cerebral surface into the frontal and parietal lobes above, and the temporal lobe below.

The SF is conventionally divided into anterior and posterior segments (**Fig. 1**). The anterior segment begins at the anterior clinoid process, extends laterally and posteriorly along the lesser wing of the sphenoid bone (sphenoidal segment), and ends at the level of



the pars opercularis of the frontal lobe. In the frontal operculum, the Sylvian fissure gives rise to the anterior horizontal and anterior ascending rami [10]. The anterior horizontal ramus divides the frontal operculum into the pars orbitalis and pars triangularis. The anterior ascending ramus separates the pars triangularis from the pars opercularis. The junction point of the anterior segment of the SF, the anterior horizontal and ascending rami, and the beginning of the posterior segment is termed the "Sylvian point". This is the widest part of the SF and serves as a landmark for initiating SF dissection. From the "Sylvian point", the apex of the insula is located 12.6 mm inferiorly [5]. The posterior segment of the SF extends from the "Sylvian point" to the parietal lobe, where it is surrounded by the supramarginal gyrus. In its posterior portion, the SF reaches a depth of 25 mm from the superior edge of the supramarginal gyrus [5]. Within the opercula of the posterior SF there are several functionally significant brain regions: the cortical area in the inferior portion of the third frontal gyrus of the left hemisphere (Broca's area), the premotor and facial motor zones in the frontal operculum, the primary sensory area of the face in the parietal operculum, the transverse temporal gyri (gyri temporales transversi, Heschl's gyri) involved in auditory processing, and Wernicke's area in the temporal operculum.

Based on meticulous intraoperative observations of the SF and its cistern, M.G. Yasargil described four anatomical variations of the SF [12]. The first type is characterized by a straight and wide SF, the second type by a straight and narrow SF, while the third and fourth types are distinguished by the invagination of the frontal and temporal lobes into the SF, respectively [12]. A widely used practical classification of the SF among radiologists was proposed by H.M. Ngando et al., who, taking into account data from spiral computed tomography, slightly modified M.G. Yasargil's classification (**Fig. 2**) [13].

The Sylvian fissure contains a large subarachnoid space — the Sylvian fissure cistern (A14.1.01.209), which extends from the carotid cistern at its medial and deepest point to the outer SF membrane at the posterolateral end [11]. The deepest wall of the SF cistern lies in the sphenoidal segment near the anterior clinoid process. At this location, the SF cistern and the carotid cistern are separated by the proximal SF membrane, which is penetrated by the M_1 - segment of the MCA. Above the insular surface, the Sylvian cistern contains three partitions that divide the subarachnoid space into four levels [11]. The deepest level includes the medial Sylvian membrane, which is anchored to the deepest part of the frontoparietal operculum and the insular surface, and also contains the M_2 - segment of the MCA. The M_2 branches continue as M_3 branches, penetrating the medial Sylvian membrane. The M_3 - segment of the MCA, en route to the surface of the Sylvian fissure, passes through another membrane — the intermediate Sylvian membrane. Lateral to this intermediate membrane lies the outer Sylvian membrane, on which the superficial Sylvian veins are located. Branches of the M_3 - segment penetrate the outer Sylvian membrane and continue as the M_4 - segment of the MCA (cortical branches). The

superficial Sylvian veins and M_4 branches traverse the outer Sylvian membrane, which is the most superficial layer, and are covered by the common arachnoid membrane. The outer arachnoid membrane encloses all cortical vessels and has a denser and more robust structure. Thus, the SF contains the M_1 - M_3 segments of the MCA with their perforating and cortical (M_4) branches, as well as the superficial and deep veins (**Fig. 3**) [12].

The SF cistern is unique due to its specific and variable microanatomy of the arachnoid membrane, particularly at different depths [2,14]. This necessitates the use of diverse technical approaches at each stage of SF dissection. A. Tayebi Meybodi et al. have provided a detailed description of the arachnoid membrane's anatomy within the SF and identified six potential types of arachnoid adhesions (septations) between arteries (A), veins (V), and brain tissue (B): (1) A-A, (2) A-B, (3) A-V, (4) B-V, (5) B-B, and (6) V-V [14]. The authors also outlined the typical configurations of these interrelationships in various compartments of SF (superficial opercular, deep opercular, and cisternal), aimed at optimizing surgical maneuvers during sulcus dissection (see **Fig. 3**) [15].

Surgical anatomy of the opercula of the insula

The lobus limbicus consists of structures that form a complex located centrally within the hemisphericum cerebri. This complex is considered to include the medial regions of the frontal, parietal, and temporal lobes, as well as the insula, which lies deep within the fossa lateralis cerebri.

The portion of the cerebral cortex that covers the insula laterally forms the operculum or pars opercularis, and it is composed of adjacent regions of the frontal, temporal, and parietal lobes.

In our view, the anatomical subdivision of the opercular compartments proposed by U. Türe et al. (1999) — into fronto-orbital, fronto-parietal, and temporal — is appropriate and practical.

It is commonly accepted that the gyri and sulci of the insular cortex continue into the corresponding gyri and sulci of the opercular compartments, with the CSI serving as the boundary between them [16]. In their seminal work on the surgical anatomy of the insula, U. Türe et al. (1999) emphasize that the gyri and sulci of the insula do not always form a continuous extension of the opercular structures. However, they note that in most cases, there is a configuration suggestive of such continuity. Continuations of the gyri and sulci have been identified between the anterior insular region and the frontal lobe, as well as between the posterior insular region and the parietal and temporal lobes [16].

Fronto-orbital operculum

The posterior orbital gyrus, the posterior segment of the lateral orbital gyrus, and the orbital portion of the inferior frontal gyrus form the suprainular operculum, which covers the anterior surface of the insula. The anterior limiting CSI marks the boundary

between the fronto-orbital operculum and the insula. The posteromedial orbital region is located at the medial end of the transverse orbital sulcus and consists of the posterior segment of the medial orbital gyrus and the medial portion of the posterior orbital gyrus. This region continues seamlessly into the transverse short insular gyrus. The posterolateral orbital region, located at the lateral end of the transverse orbital sulcus, comprises the lateral segment of the posterior orbital

gyrus and the posterior segment of the lateral orbital gyrus. There is no clearly defined boundary between the lateral orbital gyrus and the orbital part of the inferior frontal gyrus. Two suborbital gyri (superior and inferior), located in the medial portion of the fronto-orbital operculum, overlie the anterior surface of the insula. These gyri are continuous with the accessory insular gyrus and the anterior surface of the anterior short insular gyrus [16].

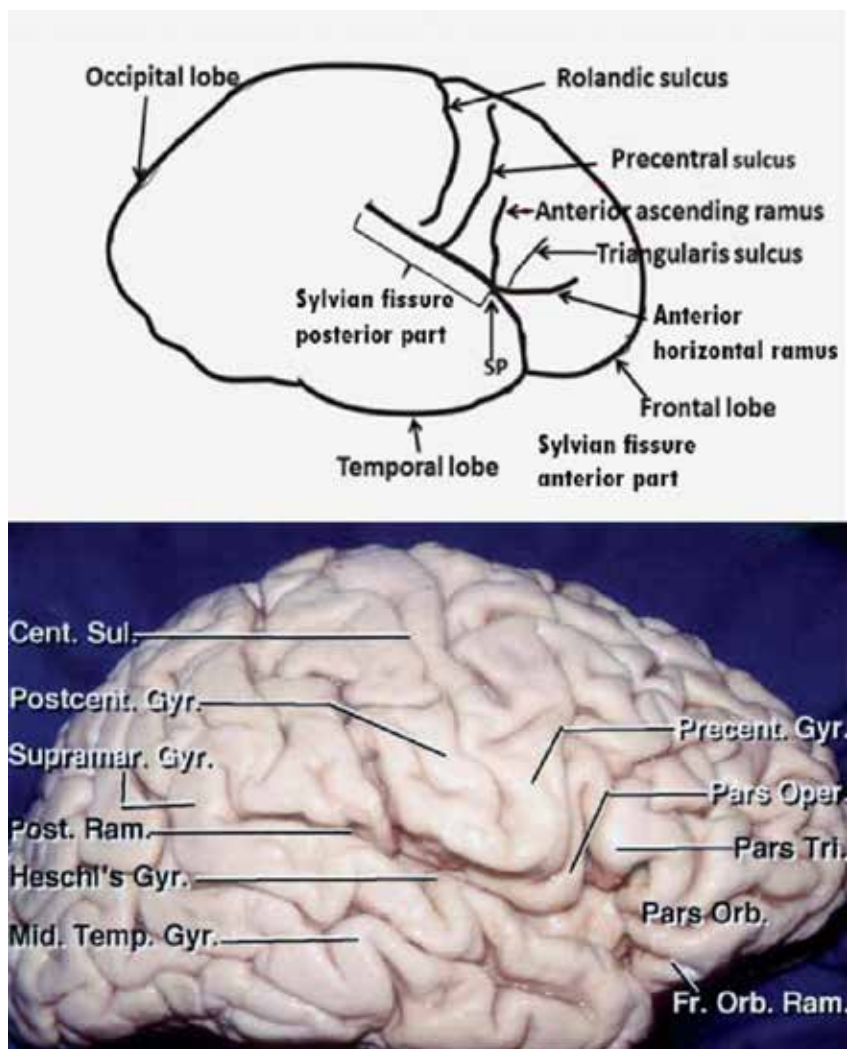


Fig. 1. Topographic anatomy of the SF [5]

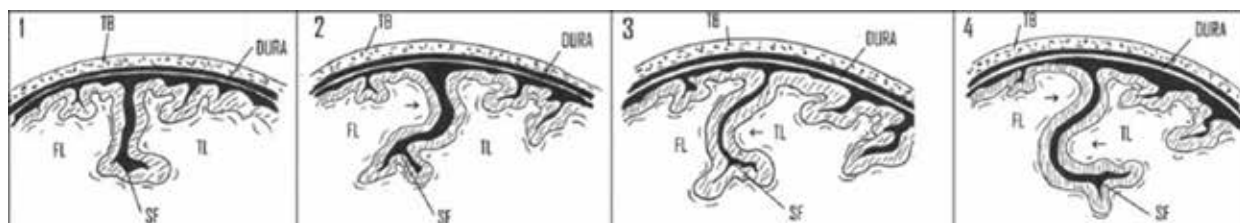


Fig. 2. Types of the SF: Type I SF – straight and wide or narrow fissure; Type II – wide fissure with invagination of the frontal or temporal lobe; Type III – invagination of the frontal or temporal lobe with a narrow SF; Type IV – invagination of both frontal and temporal lobes into the fissure. TB – temporal bone; SF – Sylvian fissure; FL – frontal lobe; TL – temporal lobe; arrow – invagination of the frontal or temporal lobe [13]

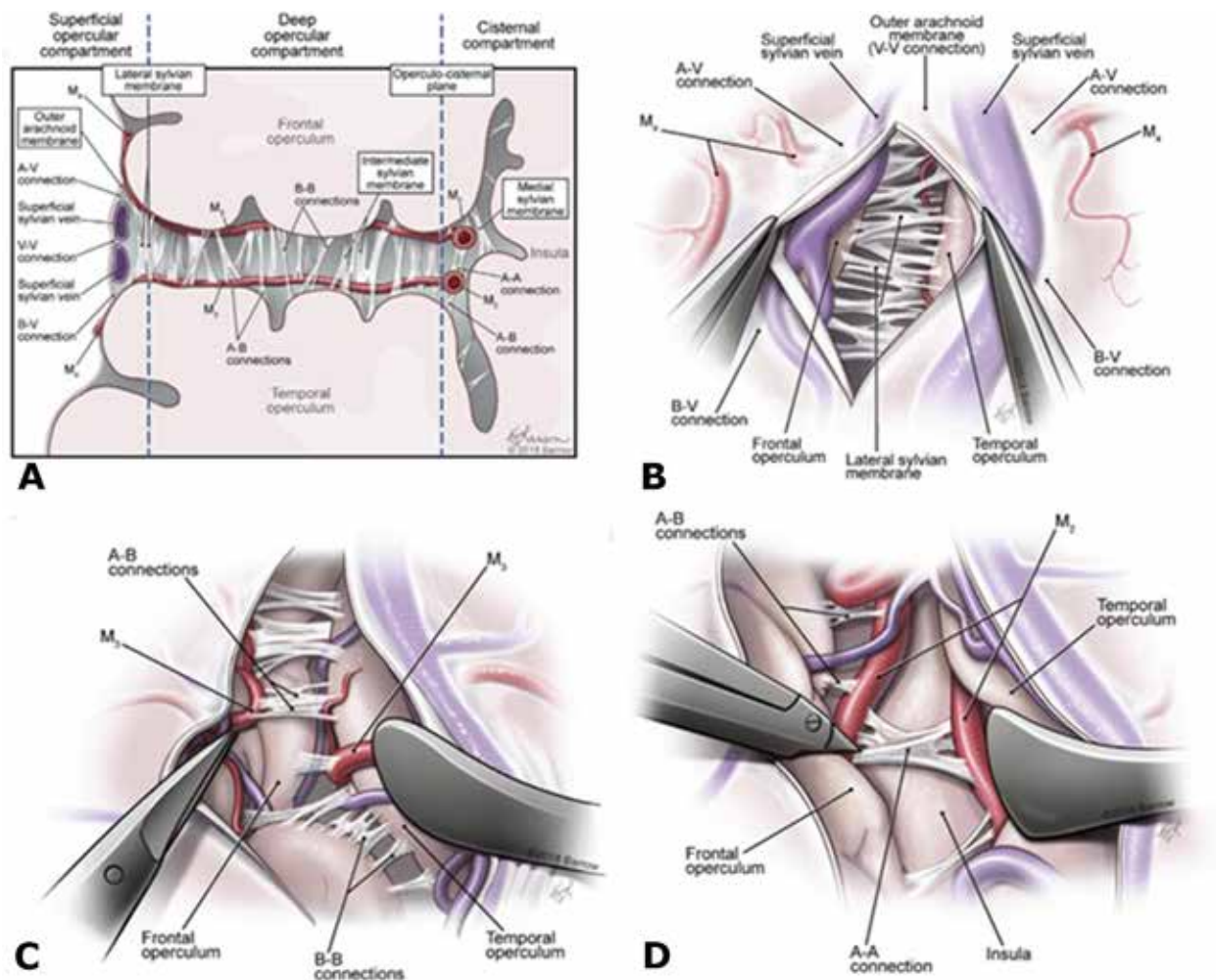


Fig. 3. A – Visualization of the superficial opercular, deep opercular, and cisternal compartments of the SF; B – Dissection of the outer arachnoid membrane provides access to the superficial opercular compartment. The paired superficial Sylvian veins are shown with a dissection plane created between them (V–V membranes opened). An alternative dissection of the outer arachnoid membrane on the temporal side of the superficial Sylvian vein (B–V membranes) may be selected depending on the patient's individual anatomy. The outer membrane of the SF is shown at the depth of the superficial opercular compartment, serving as the boundary between the superficial and deep opercular compartments; C – The deep opercular compartment with M3 branches running along their respective opercula. The main arachnoid membranes in this compartment are represented by A–C (between the M3 branches and the opposite operculum) and C–C membranes between opposite/adjacent opercula; D – Exposure of the cisternal compartment with M2 branches. A–A membranes between M2 branches are predominant among arachnoid adhesions in this compartment. Dissection of the A–C membranes between the M2 branches and their corresponding opercula may be required to expand the dissection toward the circular sulcus of the insula (CSI) [15]

Fronto-parietal operculum

The triangular and opercular parts of the inferior frontal gyrus, along with the inferior segments of the precentral and postcentral gyri and the superior portion of the supramarginal gyrus, form the fronto-parietal operculum, which overlies the superior surface of the insula. The posterior portion of this operculum also includes the temporal operculum, with the two regions separated by the "retroinsular sulcus" located in the deep posterior segment of the SF.

The superior CSI demarcates the boundary between the fronto-parietal operculum and the insula. The triangular part lies between the horizontal and ascending rami of the SF. The horizontal ramus of the SF is a continuation of the superior CSI, while

the ascending ramus continues the anterior CSI. The intersection of these sulci is identified as the "anterior insular point". The medial aspect of the triangular part is referred to as the "subtriangular gyrus", which covers the anterior short insular gyrus and transitions into it. The orbital and subopercular gyri encircle the anterior short insular gyrus anteriorly and posteriorly, respectively. The opercular part of the inferior frontal gyrus lies between the ascending ramus of the SF and the inferior precentral sulcus, overlapping with Broca's area (Brodmann area 44). The medial surface of this part is called the subopercular gyrus, which covers the short insular sulcus, the middle short insular gyrus, and the posterior portion of the anterior short insular gyrus. The subprecentral gyrus is located medially to the

opercular part and the inferior precentral gyrus, covering the middle short insular gyrus and the precentral insular sulcus [16].

In 82% of hemispheres, the inferior end of the Rolandic (central) sulcus does not reach the SF. The subcentral gyrus occupies the medial region of both the inferior precentral and postcentral gyri and is delimited by the anterior, posterior, or subcentral sulci. This gyrus overlies the central insular sulcus [16].

The inferior postcentral gyrus and the superior part of the supramarginal gyrus constitute the remaining portion of the fronto-parietal operculum. The anterior, middle, and posterior transverse parietal gyri are located on the medial side of the operculum. The anterior transverse parietal gyrus covers the postcentral insular sulcus as well as the superior part of both the anterior and posterior long insular gyri, which are adjacent to Heschl's anterior gyrus of the temporal operculum. The junction between the anterior transverse parietal gyrus and Heschl's anterior gyrus is identified as the "posterior insular point". The middle transverse parietal gyrus overlies the transverse temporal sulcus of the temporal operculum. The posterior transverse parietal gyrus and the temporal planum overlap and form the medial wall of the supramarginal gyrus [17].

Temporal operculum

The superior temporal gyrus, together with the temporal pole and the inferior portion of the supramarginal gyrus, forms the temporal operculum, which covers the inferior surface of the insula and the anterior perforated substance. The polar plane, anterior and posterior Heschl's gyri, as well as the temporal plane, constitute the medial surface of the temporal operculum (see **Fig. 3**). The lateral olfactory stria courses lateral to the limen insulae, projects medially towards the surface of the hippocampal uncus, and continues medially into the semilunar gyrus, and more laterally into the gyrus ambiens [18]. The entorhinal sulcus separates the uncus of the hippocampus from the temporal operculum and the anterior perforated substance [19].

The first lateral branch of the main trunk of the SF is referred to as the "temporal notch," which separates the piriform cortex from the temporal pole. The polar plane covers the margin and inferior surface of the insula and borders the inferior CSI, covering two-thirds of its length. The gyri of the polar plane are known as the "Schwalbe gyri" [20]. The anterior Heschl's gyrus is adjacent to the posterior part of the inferior CSI. The transverse temporal sulcus separates the anterior and posterior Heschl's gyri. The temporal plane forms the posterior part of the internal surface of the temporal operculum [17] (**Fig. 4**).

Surgical anatomy of the insular surface

The insular cortex forms the medial wall of the Sylvian cistern. The insula is shaped like a pyramid with a triangular base and a small apex (**Fig. 5, A–D**). Its base is oriented medially toward the deep subcortical structures of the cerebral hemisphere. One of the base angles is directed inferiorly and corresponds to the insular pole. The apex, located posterior and lateral to the pole, represents the highest point of the lateral surface of the insular cortex. It is positioned laterally,

anteriorly, and inferiorly, resulting in an eccentric orientation relative to the base. The apex points toward the exit of the Sylvian cistern but does not reach the fissure itself. During a transsylvian approach to the insula, the apex can be visualized directly through the anterior Sylvian point — the region of the lateral sulcus where the triangular part of the inferior frontal gyrus lies opposite the superior temporal gyrus. At this point, the Sylvian cistern widens and gives rise to its anterior ascending, horizontal, and posterior branches [5].

Anatomically, the insula has three distinct surfaces: anteroinferior, posteroinferior, and lateral. The anteroinferior surface is the smallest and is concealed by the fronto-orbital operculum, which consists of the posterior portion of the posterior orbital gyrus and the orbital part of the inferior frontal gyrus. On the anteroinferior surface of the insula — an area traversed by the middle cerebral artery — a transverse gyrus (Eberstaller's gyrus) can be identified. This gyrus connects the apex of the insula with the orbital part of the inferior surface of the frontal lobe. It extends to the posteromedial regions of the frontal lobe, which include the posterior segment of the medial orbital gyrus and the medial part of the posterior orbital gyrus that courses laterally toward the lateral olfactory stria [21].

Occasionally, an accessory insular gyrus may be visualized above the transverse insular gyrus, immediately posterior to the inferior portion of the anterior limiting sulcus. If this accessory gyrus is absent, the transverse gyrus extends up to the anterior limiting sulcus (see **Fig. 5**).

The lateral surface of the insula is the largest and most anatomically complex, containing numerous sulci and gyri. Its upper portion is hidden beneath the frontoparietal operculum (composed of the triangular and opercular parts of the inferior frontal gyrus, the precentral gyrus, and the anterior basal portion of the supramarginal gyrus), while the inferior parts are covered by the superior temporal gyrus.

The lateral and posteroinferior surfaces of the insula are surrounded and separated from the frontal, parietal, and temporal opercula by the CSI [22]. This sulcus is often referred to as the "limiting sulcus" as it demarcates the insula along its periphery. Due to the pyramidal shape of the insula, the sulcus has a triangular rather than circular configuration. It consists of three segments: anterior, superior, and inferior. The anterior segment (anterior CSI) runs obliquely upward and forward into the pars orbitalis of the frontal operculum. The superior segment of the limiting sulcus (superior CSI) runs horizontally beneath the frontoparietal operculum, extending from the superior end of the anterior segment along the anterosuperior border of the insula to the posterior end of the inferior segment. The inferior segment lies beneath the temporal operculum along the inferior border of the insula. Of the three segments, the superior one is the longest, and the anterior one is the shortest (see **Fig. 5**).

The cortex of the lateral surface of the insula is represented by three short gyri located anteriorly, and the superior portions of the anterior long and posterior sulci, situated posterior to the short gyri. The short and long sulci are separated by the central insular sulcus. The two anterior sulci divide the three short gyri, while

a single long sulcus separates the two long gyri (see **Fig. 3**). The central insular sulcus, being the deepest among all insular sulci, runs from the limen insulae in a posterior and superior direction, reaching the superior CSI. Additionally, the central insular sulcus courses almost parallel to the central sulcus (Rolandic sulcus) of the cerebral hemispheres. N. Tanriover et al. (2004)

note that the central sulcus frequently curves around the frontoparietal opercular lip and continues into the central insular sulcus [5]. Overall, the sulci and gyri of the insula form a radial pattern extending posteriorly and superiorly from the limen of the insula.

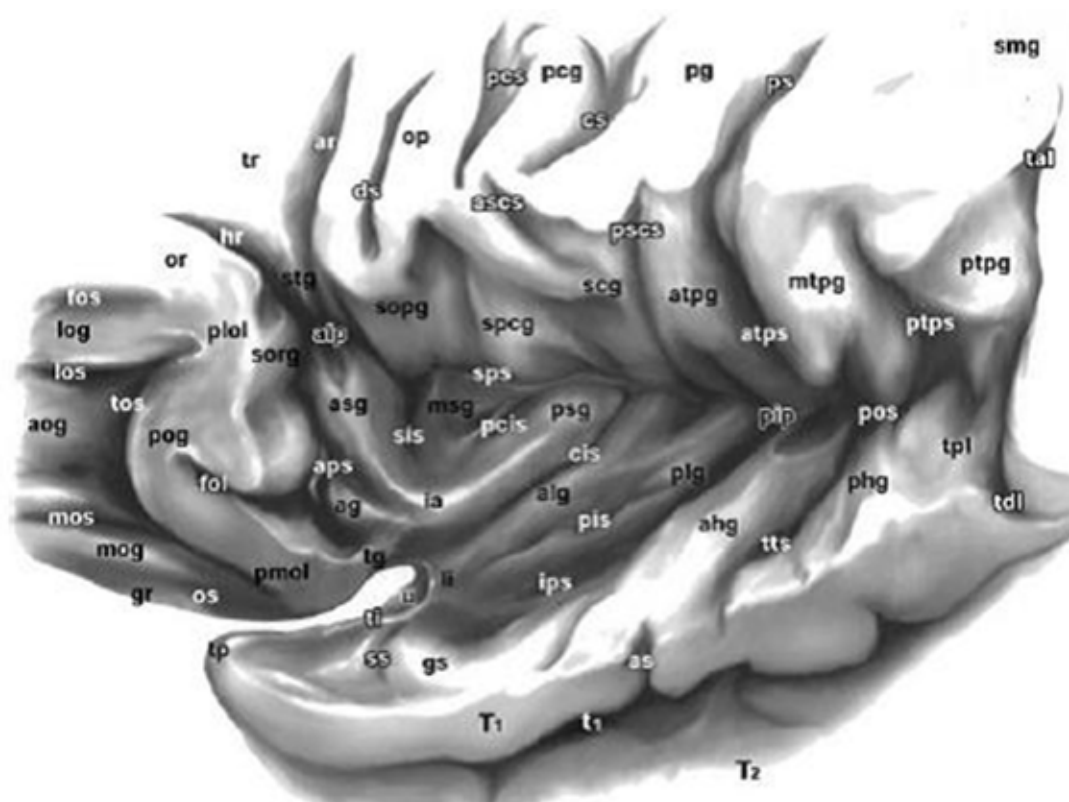


Fig. 4. Image of the left insulo-opercular region with detailed nomenclature [16]. White letters indicate sulci. Abbreviations: ag – accessory insular gyrus; ahg – anterior Heschl's gyrus; aip – anterior insular point; alg – anterior long insular gyrus; aog – anterior orbital gyrus; aps – anterior CSI; ar – ascending ramus of the Sylvian fissure; as – acoustic sulcus; ascs – anterior subcentral sulcus; asg – anterior short insular gyrus; atpg – anterior transverse parietal gyrus; atps – anterior transverse parietal sulcus; cis – central insular sulcus; cs – central sulcus of Rolando; ds – diagonal sulcus; fol – fronto-orbital lateral branch; fos – fronto-orbital sulcus; gr – gyrus rectus; gs – Schwalbe's gyrus; hr – horizontal ramus of the inferior frontal sulcus; ia – insular apex; ips – inferior CSI; li – insular limen; log – lateral orbital gyrus; los – lateral orbital sulcus; mog – medial orbital gyrus; mos – medial orbital sulcus; msg – middle short insular gyrus; mtpg – middle transverse parietal gyrus; op – opercular part; os – olfactory sulcus; pcg – precentral gyrus; pcis – precentral insular sulcus; pcs – precentral sulcus; pg – postcentral gyrus; phg – posterior Heschl's gyrus; pip – posterior insular point; pis – postcentral insular sulcus; plg – posterior long insular gyrus; plol – posterolateral orbital lobule; pmol – posteromedial orbital lobule; pog – posterior orbital gyrus; pos – postinsular sulcus; ps – postcentral sulcus; pscs – posterior subcentral sulcus; psg – posterior short insular gyrus; ptpg – posterior transverse parietal gyrus; ptps – posterior transverse parietal sulcus; scg – subcentral gyrus; sis – short insular sulcus; smg – supramarginal gyrus; sopg – subopercular gyrus; sorg – suborbital gyrus; spcg – subprecentral gyrus; sps – superior CSI; ss – Schwalbe's sulci in the polar plane; stg – subtriangular gyrus; tal – terminal ascending part of the SF; tdl – terminal descending part of the SF; tg – transverse insular gyrus; ti – temporal incisure; tos – transverse orbital sulcus; tp – temporal pole; tpl – temporal plane; tr – triangular part; tts – transverse temporal sulcus; T1 – superior temporal gyrus; T2 – middle temporal gyrus; t1 – superior temporal sulcus

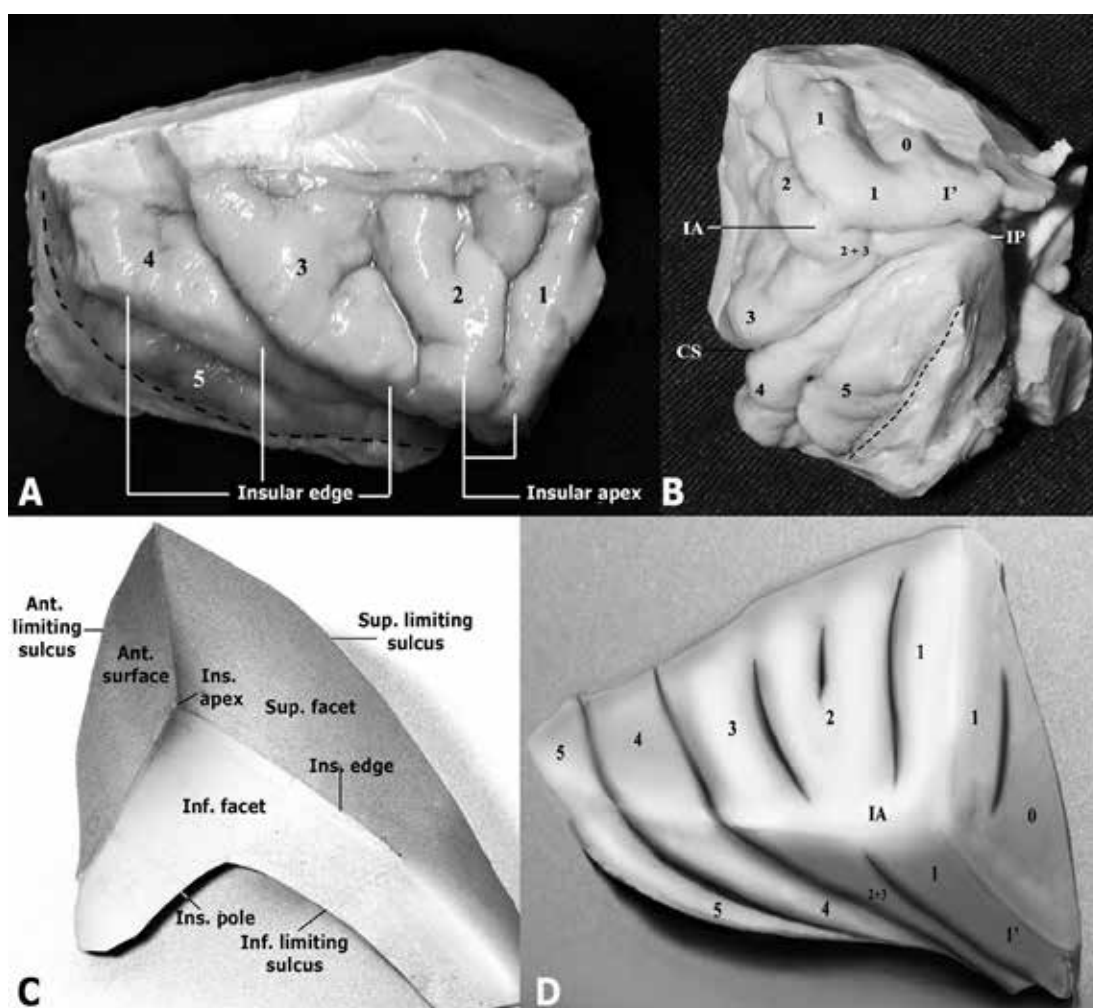


Fig. 5. Macroscopic anatomy of the insula (A, B) and schematic geometry (C, D) [24]: 0 – accessory gyrus; 1 – anterior short gyrus; 2 – middle short gyrus; 3 – posterior short gyrus; 4 – anterior long gyrus; 5 – posterior long gyrus; 6 – transverse gyrus; AI – apex of the insula; PI – pole of the insula; LI – limen insula; MI – margin of the insula; ACSI – anterior CSI; SCSi – superior CSI; ICSi – inferior CSI; red dot – anterior insular point; green dot – posterior insular point

Thus, the central insular sulcus divides the insula into a larger anterior portion, formed by the short gyri, and a smaller posterior portion, composed of the long gyri. The short gyri of the insula are separated by two sulci: the short insular sulcus separates the anterior and middle short gyri, while the precentral insular sulcus divides the middle and posterior short gyri (see **Fig. 5**).

The long gyri are located on the posteroinferior surface of the insula, posterior to the central insular sulcus. Most commonly, they originate below the insular apex near the limen as a single gyrus, which then bifurcates posteriorly into the anterior and posterior long gyri, separated by the long insular sulcus (see **Fig. 5**). The anterior long gyrus is typically broader.

Significant anatomical structures on the lateral surface of the insula include the pole, apex, limen, and margin of the insula. The insular pole is located at the anteroinferior edge of the insula, where the short gyri converge, forming a rounded area lateral to the limen (see **Fig. 5**). The apex of the insula, its highest point on

the lateral surface, is situated above and posterior to the pole, typically on the middle short gyrus (see **Fig. 5**). The limen insulae is a slightly protruding arcuate ridge located at the junction of the limen of the Sylvian fissure and the operculo-insular transition. It extends from the temporal pole to the orbital surface of the frontal lobe. The long gyri of the insula terminate here [23]. The limen is composed of a thin layer of gray matter covering the uncinate fasciculus. The anterior perforated substance lies medially to the limen and serves as an important surgical landmark. The entry point of the most lateral lenticulostriate artery (LSA) is considered the lateral boundary of the anterior perforated substance. The distance from the entry point of the extreme lateral LSA into the anterior perforated substance to the medial boundary of the limen insulae averages 15.3 mm [5]. The margin of the insula represents the edge of the triangular pyramid-shaped insula, extending from its apex to the posterior insular point and protruding onto the lateral surface (see **Fig. 5**).

Conclusions

Insular gliomas are associated with profound neurological deficits due to the proximity of functionally critical brain regions, major projection and association pathways, as well as large arterial trunks and venous collectors.

In cases of insular involvement or extension of gliomas from other lobes into the insular region, spatial anatomy undergoes significant individual pathological alterations. These changes, along with the degree of involvement or displacement of eloquent cortical areas, must be carefully considered during surgical planning.

Understanding the microsurgical anatomy of the Sylvian fissure, the Sylvian cistern, and the insular surface is a crucial prerequisite for the successful execution of transinsular and transcortical approaches to insular gliomas.

Disclosure

Conflict of interest

The authors declare no conflict of interest.

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