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ORIGINAL ARTICLE

Morphology of the lateral fossa of the brain (sylvian valley): anatomo-radiological aspects and surgical application

Racky Wade[1,2] · Odile Plaisant[2] · Alexis Guédon[2] · Abdoulaye Dione Diop[3] · Aïnina Ndiaye[1] · Philippe Manyacka[4] · Magaye Gaye[1] · Sokhna Ba[3] · Abdoulaye Ndiaye[1] · Abdarahmane Dia[1]

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Abstract

Introduction The knowledge acquired on the lateral fossa of the brain (LFB) is heterogeneous and incomplete. Our goal was to provide a morphological description of the LFB and analyze the impact of these descriptions on the surgical approach of the region.

Methods The morphology of LFB was studied on 40 cerebral hemispheres of 20 right-handed subjects aged 18–55 years with an MRI of 1.5 T. The anatomo-radiological identification of the two section levels preceded the description of the shapes of the LFB. From these landmarks, the forms presented by the LFB were identified and described on each of the transverse, sagittal and frontal planes. The comparison of the proportion of shapes made it possible to identify the typical shapes at each section level and on each section plane.

Results The average age of the subjects was 33 years with extremes of 19 and 54 years including 7 women and 13 right-handed men. According to the plane and the level of section, 6 typical morphologies of the LFB have been described, 2 of which were identical. The forms did not vary according to the cerebral hemisphere or the sex of the subject. The set of typical morphologies made it possible to determine a reference subject called NSK which presented the greatest number of typical morphological characteristics.

Conclusion Knowledge of LFB anatomical imaging is of paramount importance in the pre-surgical evaluation of pathologies in this region. The reference subject will be used for our future biometric and three-dimensional manual reconstruction work in this region.

Keywords Lateral fossa of brain · Sylvian valley · Morphology · Surgery · MRI

Introduction

The lateral fossa of the brain (LFB) is a depression located deep in the lateral sulcus (LS) of each cerebral hemisphere. It was formerly named sylvian valley in honor of Franciscus Sylvius (F. De le Boë), anatomist, physiologist and chemist–physicist of Leiden University [2, 9].

Nowadays, this area of the brain is frequently explored in neuroimaging. It has become an important and unavoidable corridor in microsurgery [22]. Various studies on LFB mainly involve hemorrhages due to aneurysms of the middle cerebral artery (MCA), arachnoid cysts of LFB or metastases [27]. Other scientific studies have focused on the various stages concerning the surgical approach, which is much feared by surgeons because of prolific vascular connections [3, 4, 22]. Most complications include cerebral retraction, venous occlusion, edema and ischemic injury [17]. The

✉ Racky Wade
racky.wade@hotmail.com

1 Laboratory of Anatomy and Organogenesis, Faculty of Medicine, Pharmacy and Stomatology, Cheikh Anta Diop University, Post Box 5885, 10700 Dakar, Senegal

2 Research Unit for the Development of Anatomy and Imaging (URDIA) EA 4465, Department of Numerical, Surgical, Radiological and Experimental Anatomy, Paris Descartes-Sorbonne Paris Cité University, Paris, France

3 Diagnostic and Medical Imaging Center, Fann National University Hospital Center, Dakar, Senegal

4 Laboratory of Anatomy and Organogenesis, UFR 2S, Gaston Berger University, Saint-Louis, Senegal

direct transsylvian (TS) approach is often bypassed to prevent these complications. It requires wide opening of the superficial and deep subarachnoid space or deep sylvian cisterns and careful protection of the opercular arteries and their perforators, as well as preservation of the dominant superficial middle cerebral veins. The insula is the medial and deep wall of the LFB. His TS approach requires opercular retraction, which is often limited by the superficial middle cerebral veins bridging the LS [7]. Another way of approach is the transcortical (TC) corridor which has been previously described as one of the main surgical approaches to the insula, a depth structure of the LFB. Cortical and subcortical mapping is critical during the TC approach because a fair amount of cortical areas of the operculum is functional [7]. The facial motor and somatosensory functions and language areas may be involved. There is insufficient evidence to support one approach versus the other. However, Benet et al. [7] concludes in his study that the TC approach to the depth part of the LFB, precisely during the surgical treatment of gliomas of the insula, provided better insula exposure and surgical freedom compared with the TS. Nevertheless, this region remains surgically complex. It is noted that there is no reliable and consensual method for preserving LFB [16].

Other relevant questions involving this anatomical region of the brain remain unresolved. First, its terminology is related to that of the LS of the brain formerly called lateral fissure or sylvian fissure [5, 9, 17]. Paradoxically, the LFB is also studied in many articles under the same term of sylvian fissure [13, 20, 31]. Hence, the importance of revising the terminology of this region is essential. Morphologically, only Maslehaty, Cornelius [17] and Ngando [18] studied the shape of a subset of the region, in this case the anterior or sphenoid compartment (Table 1). They showed a positive correlation between the shape of the region and the occurrence of postoperative complications in the treatment of MCA aneurysms. However, there is a lack of more descriptive studies in the literature involving the morphology of LFB as a whole. Thus, the precise knowledge of all possible forms of this region becomes necessary to further support the link established by these authors. There is also a paucity of descriptive data on LFB as a well-defined topographic anatomical entity. Indeed, the authors report separately the constituent elements of the LFB while it is a region with limits and a specific content. However, it has been described as a specific entity by Dejerine [10] and Rouvière and Delmas [23] but at an embryonic and fetal stage.

Thus, the objective of our study was to provide a morphological description and a systematic characterization of the LFB, then to analyze the impact of these descriptions on the surgical approach of the region.

Methods

Subjects

The study sample consisted of 40 cerebral hemispheres of 20 right-handed adults. They were recruited consecutively through a register that included all those who were scheduled daily to perform a brain MRI exam at the Fann Diagnostic and Medical Imaging Center. The selection criteria included: (1) age between 18 and 55 years; (2) lack of history of neurosurgical treatment. We also excluded after image interpretation of the standard protocol sequences of brain MRI: (1) subjects with early cortico-subcortical atrophy; (2) those with brain lesions with or without mass effect on the LFB.

Table 1 Morphological studies of the LFB by Yasargil (cited by Ngando and Maslehaty) [17, 18]

Authors	Method	Description FLC	Year
Yasargil et al. cited by Ngando and Maslehaty [17, 18]	Intra operative observations	Type 1: Straight wide *Sylvian fissure* Type 2: Straight narrow Type 3: Includes a partially herniated frontal Type 4: Includes a partially herniated temporal	1984
Ngando et al. [17]	Computed tomography	Type 1: Straight wide or narrow *Sylvian fissure* Type 2: Wide *Sylvian fissure* with herniation of the frontal or temporal lobe Type 3: Narrow *Sylvian fissure* with herniation of the frontal and temporal lobe Type 4: Herniation of temporal and frontal lobe	2013
Maslehaty et al. [16]	MRI	Type 1: Wide straight *Sylvian fissure* Type 2: Narrow straight *Sylvian fissure* Type 3: Wide *Sylvian fissure* with herniation of the frontal or temporal lobe Type 4: Narrow *Sylvian fissure* with herniation of the frontal or temporal Type 5: Herniation of temporal and frontal lobe	2017

MRI

We used a Philips brand MRI from the Achieva range at 1.5 T. The Philips DICOM Viewer R1.2 and MILLENSYS Viewer 10.6 software were used for image acquisition, reconstruction, visualization and post-processing.

In a first step, we studied the morphology of the LFB of each cerebral hemisphere using a routine brain MRI protocol with common sequences (T1-weighted spin echo, T2-weighted spin echo and TOF echo sequence):

- The T1-weighted spin echo (T1-SE) sequence with a repetition time (RT) is equal to 400 ms and an echo time (ET) is equal to 15 ms. The flip angle was 90° and the slices were sagittal with a thickness of 5 mm;
- The T2-weighted spin echo (T2-SE) sequence with anRT equal to 5950 ms and an ET equal to 110 ms. The flip angle was 90° and the slices were frontal with a thickness of 5 mm;
- The flight time (TOF) angiography gradient echo sequence, with an RT equal to 23 ms and an ET equal to 6.9 ms. The flip angle was 23° and the slices were transverse with a thickness of 1.6 mm.

The LFB is a large, irregular and irregular anfractuosity, hence the need to study its morphological variations with multiplanar (sagittal, frontal and transversal) sections. The sagittal and frontal slices were orthogonal to the transverse plan passing through the Talairach "anterior white commissure—posterior white commissure or AC-PC" line.

Landmarks

Two landmarks were used for the anatomo-radiological description of the LFB (Fig. 1), the summit of the insula (SI) and the middle of the central sulcus of the insula (CSI) defined as:

- Morphologically, the insula in adults presents, after separation of the LS, as an irregularly conical projection whose base forms a triangle [10, 21, 23, 30] or trapezoid [3] and whose summit or pole of the insula of Broca is oriented anteriorly and inferiorly [10, 21, 23]. This summit is considered as an important point of the insula [28] and corresponds to the pole of the anterior insula described recently by Afif and Mertens [3]. It is smooth and is the center from which radiates the short insular gyri. It includes the most protruding part of the insula laterally on the insula convexity. It has the same cytoarchitecture as the short gyri of the anterior insula [19].
- The CSI is the narrowest and deepest insular sulcus dividing the insula into two anterior and posterior portions [14] with an oblique antero-inferior axis [3, 28, 29]. It extends from the falciform fold (*limen insulae*) below to the upper part of the circular sulcus of the insula [3]. It is globally uninterrupted throughout its length.

As recommended by Afif and Mertens [3], we first used sagittal section planes of an LFB-focused MRI to target the CSI middle. The same section plane also clearly exposed SI. In a second step, the identified landmark was projected

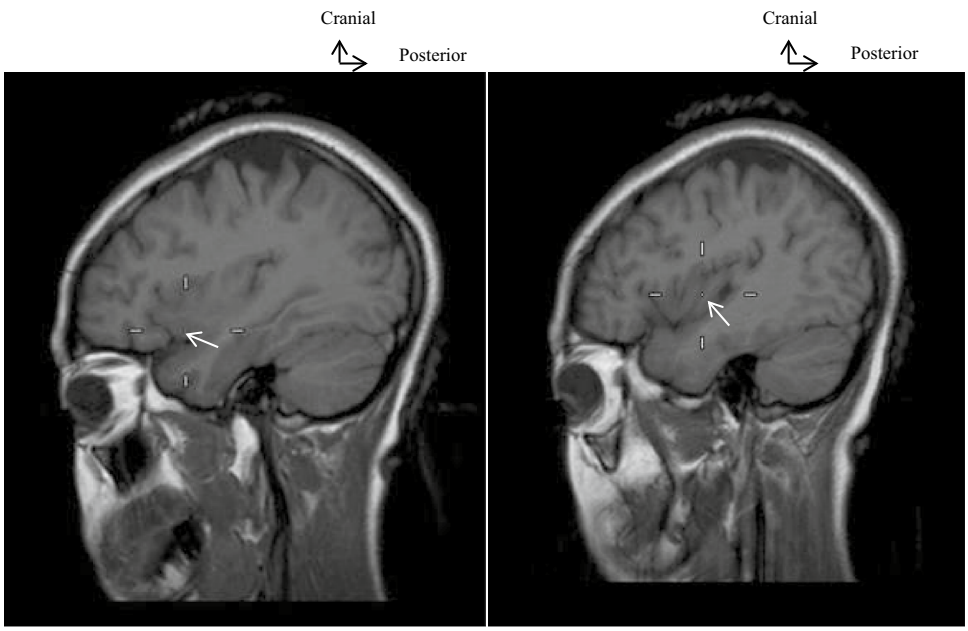


Fig. 1 Locating the SI and the middle of the CSI on a sagittal section (T1-SE sequence) of the brain showing the LFB

simultaneously on the two other orthogonal planes using the "link point" function of the Phillips Viewer software.

The level of section in SI allowed to expose the anterior compartment (sphénoïdal) of the LFB. The level of section in the middle of the CSI made it possible to expose the posterior compartment (insulo-opercular) well.

FLB morphology

After making an image capture of the Dicom Viewer interface, we used the Microsoft Windows version 1511 Paint pencil tool to delineate the LFB with three different colors according to the section plane (Fig. 2). The delimitation consisted of outlining the perimeter of the cortical ribbon of walls bordering the LFB. In the case of frontal and transverse sections, the walls of the LFB consisted of the insular cortex within, and the frontal, parietal and temporal portions of the operculum of the LFB outside. When the section was sagittal, the delineation of the LFB followed only the perimeter of the cortical ribbon of the frontal, parietal and temporal parts of the operculum.

Thus, we noted and described the different morphologies presented by the LFB on the transverse, sagittal and frontal sections appearing at the levels of SI and the middle of CSI. The name of the shape was validated by consensus by an anatomist, a radio-anatomist and a radiologist.

In a second step, we subdivided the LFB into four compartments using two planes: a plane parallel to the LS and a second plane perpendicular to it, passing through the middle of the CSI (Fig. 9).

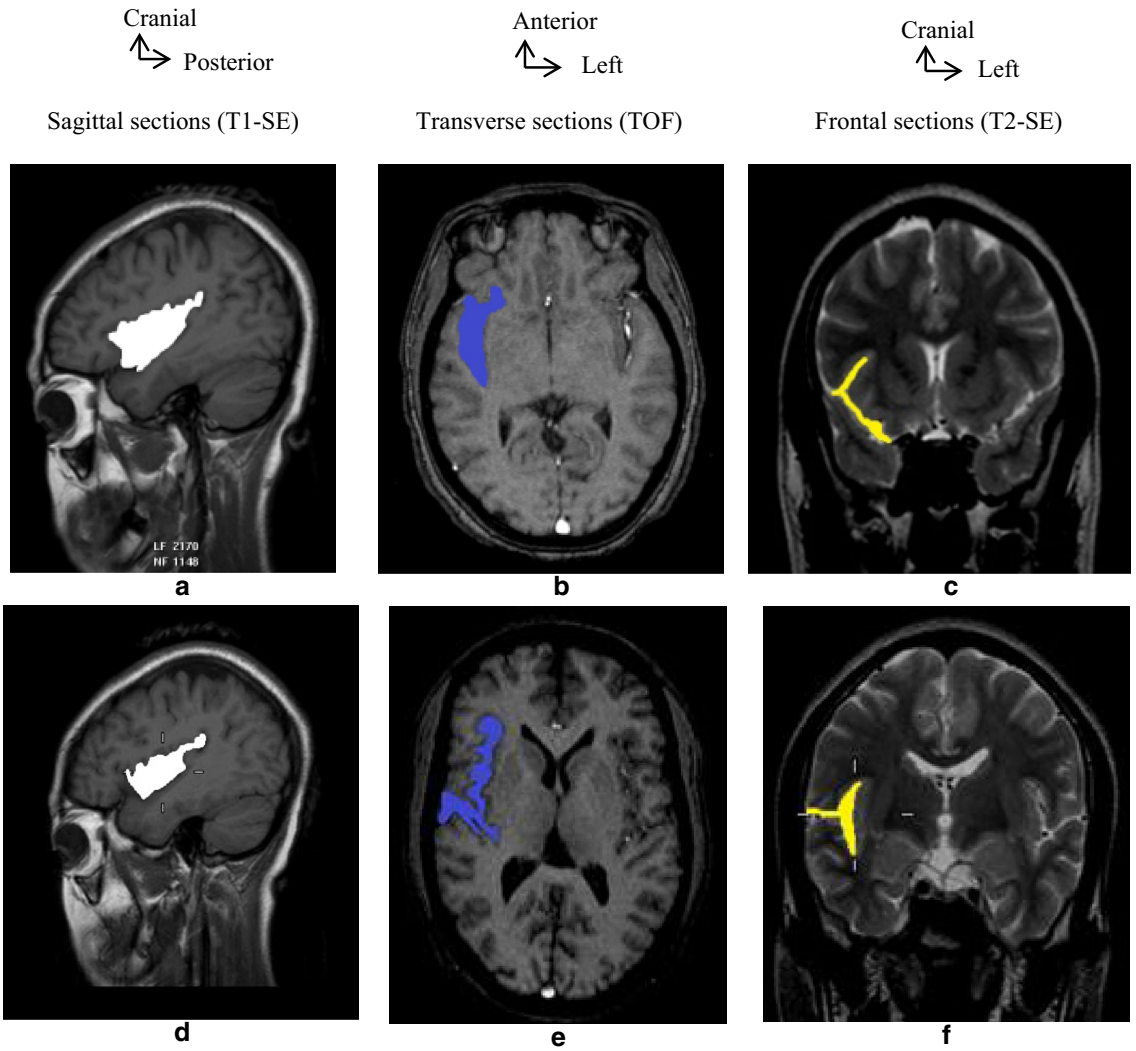


Fig. 2 Determination of LFB shapes on sagittal, transverse and frontal sections of the brain at the SI (**a**–**c**) and the middle CSI (**d**–**f**) levels To properly highlight the LFB in this figure, the bounded space is filled with a color according to the section plane

Statistical analysis

All statistical analyses were performed using Excel and Epi info software (CDC, 7.1.5). We determined the proportion of each distinct shape found across all 40 cerebral hemispheres. The comparison of these proportions made it possible to identify the modal or predominant shapes of LFB on each plane and section level specified.

Ethical statement

The study was approval by the Research Ethics Committee (CER) of the University Cheikh Anta Diop (UCAD) of Dakar. The subjects consented to the study after reading the information sheet validated by the committee.

Results

Regional topography

The LFB is described in this work as a well-defined area that has a boundary and contents. On frontal section at SI, its boundary consists of the following five cortical walls (Fig. 3):

- The insular medial wall;
- The opercular superior-lateral wall (medial face of the fronto-parietal part of the operculum of the LFB);
- The opercular infero-lateral wall (medial side of the temporal part of the operculum of the LFB);
- The inferior wall of the LS and
- The superior wall of the LS.

The first three walls circumscribe the deep subarachnoid space (SAS) of the LFB (sylvian cistern by Yasargil et al. [32] or deep cistern) and the last two walls delimit the LS. All these walls are covered with pia. Thus, the contents of the LFB will include that of the deep SAS and that of the LS.

The deep SAS or deep cistern of the LFB is an enlargement of the SAS of the brain located between the inner leaflet of the arachnoid membrane and the pial surface. It is filled with cerebrospinal fluid (CSF) and is crossed by an arachnoid trabecula which is a fine fibrous extension connecting the inner leaflet of the arachnoid membrane and the outer surface of the pia. It also contains the MCA; the deep middle cerebral vein, the fronto-orbital veins and the collateral branches of the basal (or Rosenthal) vein [32].

The LS gives passage to the M3 segment of the main trunk of the MCA and the collateral branches of the M2 segment.

Anatomo-radiological forms of the LFB

At the SI level

In transverse section

1. "Atypical fork" shape: 72.5%

This form is composed laterally of a handle limited anteriorly by the posterior extension of the frontal portion of the operculum and posteriorly by the anterior extension of the temporal portion of the operculum. This lateral handle is short and its medial end is divided into two divergent branches with tapered ends of unequal size. One branch lies anteriorly and the other posteriorly. The anterior branch is short and very narrow and limited medially

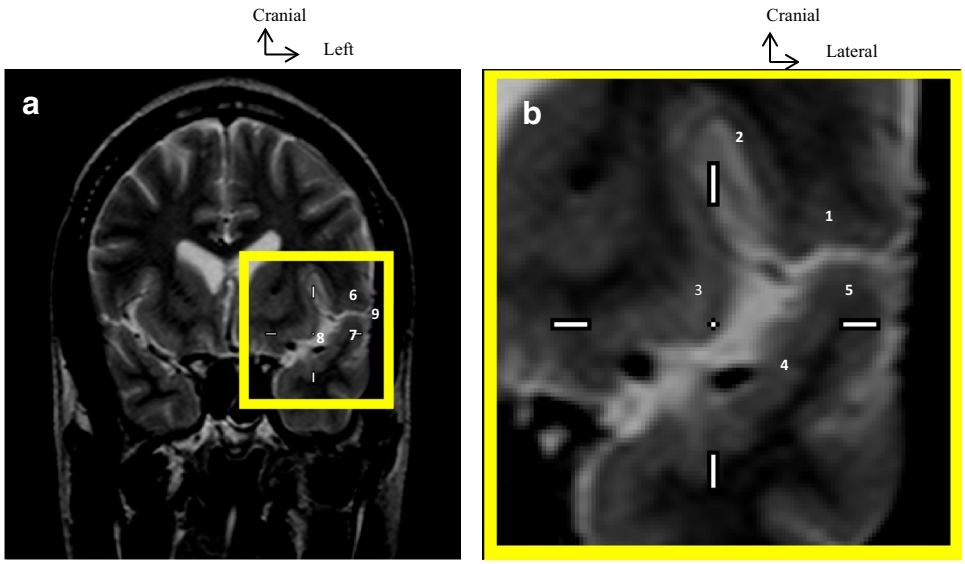


Fig. 3 Frontal section (T2-SE sequence) of the brain showing the left LFB with targeting of the SI (**a**) followed by a window showing the 5 walls of the left LFB (**b**) 1: superior wall of the LS; 2: opercular superior-lateral wall; 3: Insular medial wall (Insula); 4: opercular inferior-lateral wall; 5: inferior wall of the LS; 6: fronto-parietal part of the operculum of the LFB; 7: Temporal part of the operculum of the LFB; 8: deep SAS of the LFB (*sylvian cistern* or *deep cistern*); 9: LS: window: left LFB with targeting of the SI

by the insular cortex and laterally by the medial side of the frontal part of the operculum. The posterior branch is wide at its origin near the lateral handle and narrows towards the rear. This branch is long and its widening is linked to the presence of the M2 segment of the main trunk of the MCA. It is limited medially by the insular cortex and laterally by the medial side of the temporal part of the operculum.

2. "Single fork" or "Y" shape: 7%

This form also has a lateral handle limited anteriorly by the posterior extension of the frontal part of the operculum and posteriorly by the anterior extension of the temporal portion of the operculum. The lateral handle is short and its medial end is divided into two divergent anterior and posterior branches. These are symmetrical, unlike the "fork atypical" form, but their boundary walls are identical. The two divergent branches are wide at their ends near the handle and taper slightly, one towards the front and the other towards the rear. The arterial network of the M2 segment of the MCA is more visible in the SAS of the posterior branch.

3. "Indeterminate" shape: 12.5%

This includes all the forms whose proposed names were ambiguous after their description.

4. "Recessed" shape: 5%

This form is a cul-de-sac. The walls in this form of the LFB are essentially constituted outside by the medial side of the temporal part of the operculum and internally by the insular cortex. The anterior extremity of the recess is wide, and a very short and narrow handle is detached laterally. From this wide anterior end, the LFB extends and narrows backwards and slightly inwards to end in a point. The arterial network of the M2 segment of the MCA is visible in the SAS, which occupies the recess.

5. "Triangular" shape: 2.5%

The posterior extension of the frontal part of the operculum and the anterior prolongation of the temporal part of the operculum are narrowed and very close together to form the apex of this triangular shape. The base is medial and corresponds to the cortical ribbon of the insula. The anterolateral side is formed by the medial side of the frontal part of the operculum and the posterolateral side is formed by the medial side of the temporal part of the operculum. The deep SAS of the LFB is wider and traversed by the arterial network of the M2 segment of the ACM.

Among these five forms found on transverse sections at SI level, the "atypical fork" is the modal or predominant form with the highest occurrence (72.5%) (Fig. 4a).

In sagittal section

1. "Indeterminate" shape: 2.5%

This includes all the forms whose proposed names were ambiguous after their description.

2. "Fringed triangular" shape: 95%

The frontal, parietal and temporal parts of the operculum delimit a triangular space corresponding to the LFB. Thus, this triangular shape has three edges and a lower top. The anterior border is rectilinear and slightly oblique upwards and forwards. The upper edge that corresponds to the base is fringed by the folds of the fronto-parietal portion of the operculum of the LFB. The latter gives a fringed aspect in sagittal section because it intimately covers all of the upper part of the insular gyri, thus taking their shape. The posterior border has an upper end raised by the convexity of the transverse temporal gyrus (Heschl's gyrus). In the center of this triangle is the insula fan. The three adjacent edges are traced by the CSF which fills the circular sulcus of the insula. Thus, they clearly separate the central portion (insular) of the peripheral portion (opercular) of the LFB on this sagittal section.

3. "Trapezoidal" shape: 2.5%

This form has a small lower base and two edges that create an upward open angle. The insula is inserted between the two edges of the angle. The anterior edge is rectilinear and slightly oblique upwardly and forwards, lying opposite to the frontal part of the operculum. The posterior edge rests straight and slightly oblique upwards and backwards, opposite to the temporal part of the operculum. The fronto-parietal part of the operculum and the insular cortex appears fused together. Only the two visible edges are traced by CSF filling the anterior and posterior part of the circular sulcus of the insula.

Of these three forms found on sagittal section at SI, the "fringed triangular" form is the modal or predominant form with the highest occurrence (95%) (Fig. 4b).

In frontal section

1. "Atypical fork" shape: 85%

This shape includes a short narrow handle laterally, which is almost horizontal and corresponds to the LS.

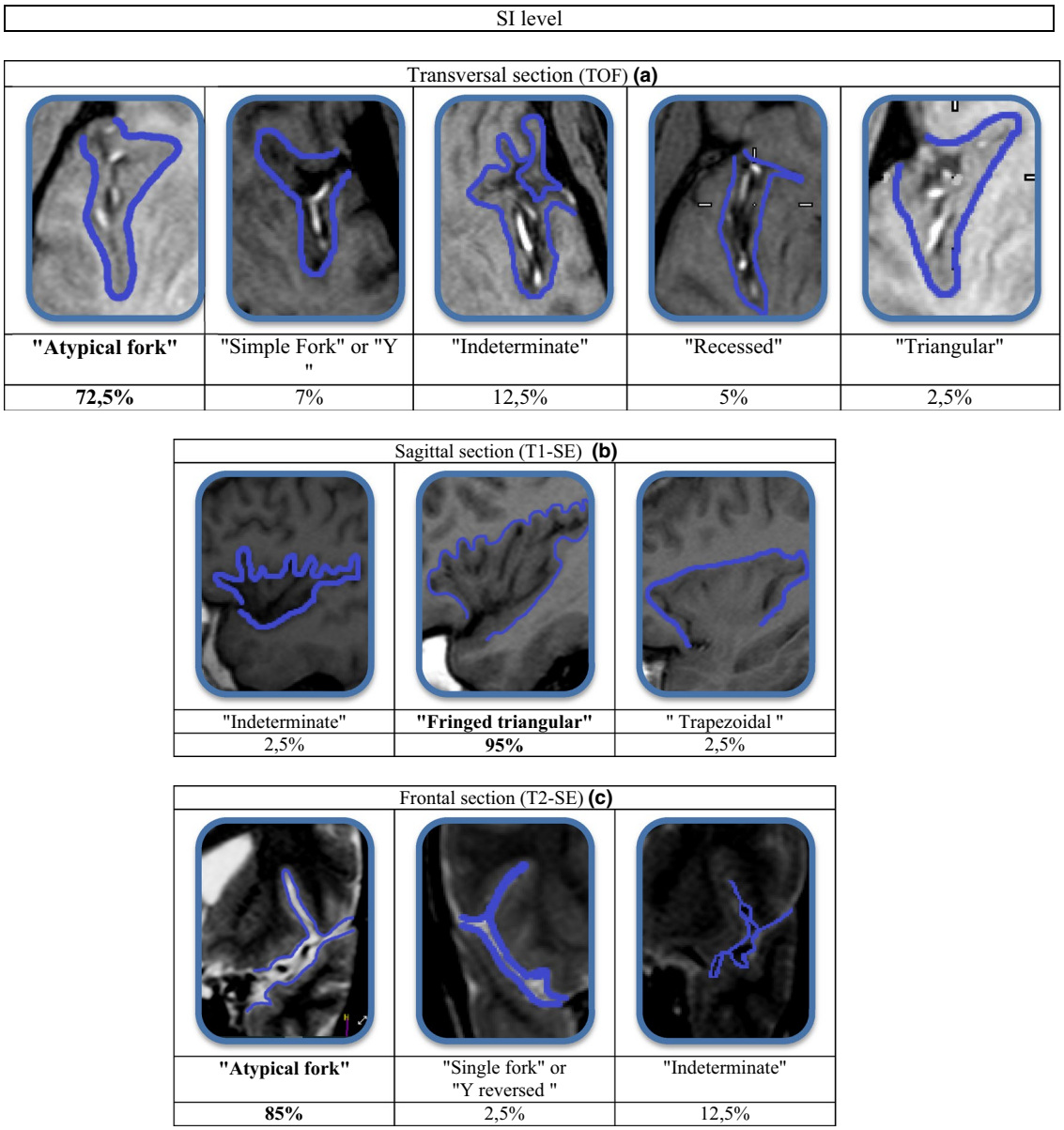
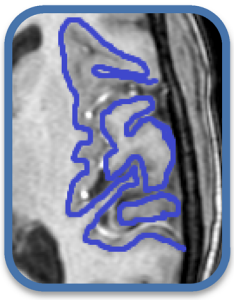
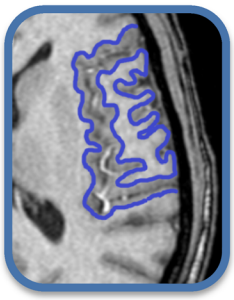
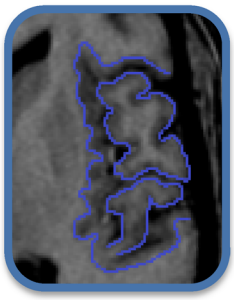
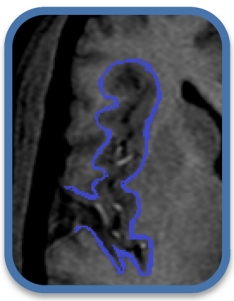
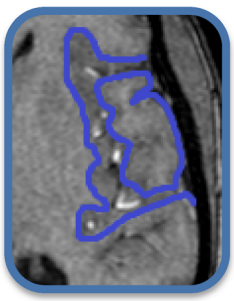
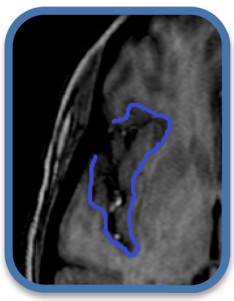


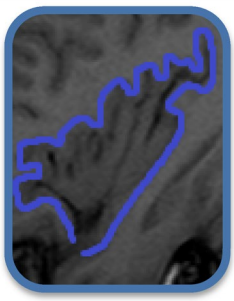
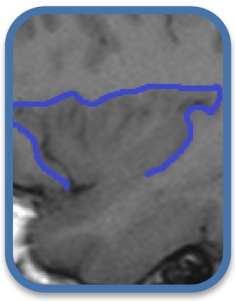
Fig. 4 Distribution of the 40 cerebral hemispheres according to the shape of the LFB on the transverse (**a**), sagittal (**b**) and frontal (**c**) sections at the level of the SI. a1: atypical fork; a2: single fork or Y; a3: undetermined; a4: recess; a5: triangular. b1: indetermined; b2: fringed triangular; b3: Trapezoidal. c1: atypical fork; c2: single fork or Y reversed; c3: indetermined

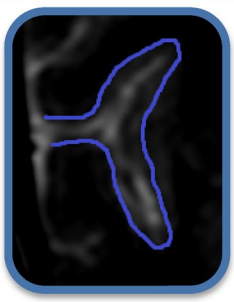
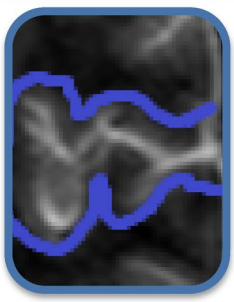
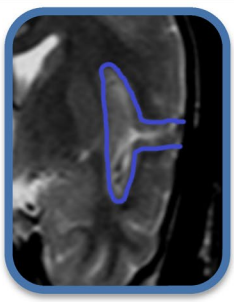
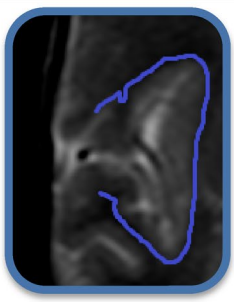
This handle bifurcates at its medial end into two upper and lower branches. The upper branch is angeled obliquely upwards and inwards. It is narrow and stiff, uniting the opercular superolateral medial wall and the insular medial wall of the LFB. It contains the first ascending collateral of M2 that runs through the insular cortical surface. The inferior branch is formed by the infero-lateral opercular wall and the insular medial wall of the LFB. It is oblique at the bottom and inwards and continuously widens in a downward direction. Additionally, it shows crenellated and irregular features. The region is occupied by the horizontal M1 segment (sphenoidal) and the M1–M2 knee of the main MCA trunk. These vascular elements are surrounded by CSF. The two upper and lower branches are of equal length, they differ only in their width relative to the vascular content and the irregular contour of the cortical ribbon. Exceptionally, the shape is determined by the contour of the outer edge of the cortical ribbon of the LFB because at this level of SI, the medial insular wall and the opercular superolateral wall are very thick, making the contour of the medial edge difficult to determine.

2. “Single fork” or “Y reversed” shape: 2.5%

SCI level

Transversal section (TOF) **(a)**		
		
"Indeterminate"	**"Comb"**	"Puzzle"
17,5%	**45%**	10%
		
"Channel"	"Trapezoidal"	"Triangular"
15%	7,5%	5%

Sagittal section (T1-SE) **(b)**	
	
"Fringed triangular"	"Trapezoidal"
97,5%	2,5%

Frontal section (T2-SE) **(c)**			
			
" Single fork"	"Indeterminate"	**"T reversed"**	"Triangular"
12,5%	15%	**67,5%**	15%

◂**Fig. 5** Distribution of the 40 cerebral hemispheres according to the shape of the LFB on transverse (**a**), sagittal (**b**) and frontal (**c**) sections at the level of the CSI middle. a1: indeterminate; a2: comb; a3: puzzle; a4: channel; a5: trapeze; a6: triangular. b1: fringed triangular; b2: trapezoidal. c1: atypical fork; c2: indetermined; c3: T reversed; c4: triangular

This shape comprises a short narrow handle laterally, which is almost horizontal and corresponds to the LS. This handle bifurcates at its medial end into two divergent upper and lower branches. They are narrow, stiff and almost symmetrical. The upper branch is oblique upwards and inwards. It is limited outside by the opercular superolateral wall and internally by the insular medial wall of the LFB. The lower branch is oblique below and inside. It is formed by the opercular inferolateral wall outside and the insular medial wall of the LFB inside. The walls are contiguous and the arterial network of the MCA is not visible, nor the CSF.

3. "Indeterminate" shape: 2.5%

This includes all the forms whose proposed names were ambiguous after their description.

Of these three forms found on the frontal section at SI level, the "atypical fork" is the modal or predominant form with the highest proportion occurring (85%) (Fig. 4c).

In the middle of the CSI

In transverse section

1. "Indeterminate" shape: 17.5%

This includes all the forms whose proposed names were ambiguous after their description.

2. "Comb" shape: 45%

This form describes two parts that create the frame and teeth of a comb. The frame of the comb has three edges: anterior (frontal), medial (insular) and posterior (temporal). The anterior edge extends horizontally from the anterior end of the insular cortical ribbon to the surface of the frontal cortex. It represents the first fold of the fronto-parietal part of the operculum of the LFB. The insular medial edge is represented by the long curvilinear ribbon of the insular cortex. The posterior border extends horizontally from the posterior end of the insular cortical ribbon to the surface of the temporal cortex. It represents the posterior fold of the temporal part of the operculum of the LFB.

The teeth of the comb are located laterally and correspond to the folds of the fronto-parietal part of the operculum.

Between the frame and the teeth of the comb, a curvilinear channel corresponds to the SAS of the LFB. At the bottom of the channel, flanges of arterial vessels appear in the foreground. More precisely, the collateral branches of the M2 and M3 segments of the MCA occur with a significant vascular density at the posterior end.

3. "Puzzle" shape: 10%

Externally, the fronto-parietal part of the operculum presents with deep and tortuous folds, giving it the appearance of a puzzle piece; the insular wall is medial. Between these two medial and lateral walls, the SAS of the LFB takes a labyrinthine form; the collateral branches of the M2 and M3 segments of the MCA appear in the inferior foreground.

4. "Channel" shape: 15%

The insular wall inside and the fronto-parietal part of the operculum outside delimit a serpentine channel directed from front to back. This channel represents the SAS and contains collateral branches of the M2 segment of the MCA.

5. "Trapezoidal" shape: 7.5%

The insular wall inside and the fronto parietal part of the operculum outside delimit a trapezoidal channel. This channel represents the SAS and contains collateral branches of the M2 and M3 segment of the MCA.

6. "Triangular" shape: 5%

This form presents as a triangle with a medial base, lateral vertex and three edges: anterolateral (medial side of the frontal part of the operculum), posterolateral (medial side of the temporal part of the operculum) and medial (insular cortex). There is more CSF than arterial vessels in SAS.

Among these six forms found on transverse section at the middle of the CSI, the "comb" form is the modal or predominant form with the highest occurrence (45%) (Fig. 5a).

In sagittal section

1. "Fringed triangular" shape: 97.5%

The frontal, parietal and temporal parts of the operculum delimit a triangular space corresponding to the LFB. Thus, they form three edges and a lower vertex. The anterior edge (frontal part of the operculum) is rectilinear and slightly oblique upwards and forwards. The upper edge which corresponds to the base is fringed by the folds of the fronto-parietal part of the operculum. This upper fronto-parietal part gives a fringed aspect in sagittal section because it

intimately covers all the upper part of the insular gyri. The posterior border (the temporal part of the operculum) has its upper end raised by the convexity of the transverse temporal gyrus (Heschl's gyrus). In the center of this triangle is the insula fan. The three adjacent edges are traced by the CSF which fills the circular sulcus of the insula. Thus, they clearly separate the central portion (insular) of the peripheral portion (opercular) of the LFB on this sagittal section.

2. "Trapezoidal" shape: 2.5%

It has a lower and small base and two edges (anterior and posterior). The anterior edge (frontal part of the operculum) is rectilinear and slightly oblique upwards and forwards. The posterior edge (temporal portion of the operculum) is rectilinear and slightly oblique upwards and backwards. The upper edge of the circular sulcus of the insula located between the fronto-parietal portion of the operculum and the insular cortex is not visible.

Among the two forms found on sagittal section at the middle of the CSI, the "fringed triangular" shape is the modal or predominant form with the highest occurrence (97.5%) (Fig. 5b).

It was identical to the "fringed triangular" form found on the sagittal section at SI.

In frontal section

1. "Single fork" shape: 12.5%

This shape comprises a short narrow handle laterally, which is almost horizontal and corresponds to the LS. This handle bifurcates at its medial end into two divergent upper and lower branches, which are narrow, stiff and symmetrical. The upper branch is oblique upwards and inwards. It is limited laterally by the opercular upper-lateral wall and medially by the insular medial wall of the LFB. The lower branch is oblique below and inside and formed by the opercular infero-lateral wall laterally and the insular medial wall of the LFB medially. Arterial vessels are not visualized.

2. "Indeterminate" form: 15%

This includes all the forms whose proposed names were ambiguous after their description.

3. "T reversed" shape: 67.5%

This region consists of the union of three branches: a horizontal branch outside and two vertical branches (upper and lower) perpendicular to it inside. The horizontal branch corresponds to the LS. It is narrow and deep at this planar level of cut. It starts from the cerebral lateral convexity at the medial end of the LS and often crossed by a collateral branch of the M2 segment or by the M3 segment of the MCA. The upper vertical branch is narrow, created by the joining of the opercular superolateral wall of the LFB outside and insular medial wall inside. The SAS located between the two walls appears as a thin CSF blade. There is no main arterial trunk running through it. The lower vertical branch is narrow and deeper, consisting of the joining of the opercular infero-lateral wall outside and the insular medial wall inside. These last two are separated by a thin CSF blade. The lower end of this branch consists of the posterior part of the circular sulcus of the insula. It is occupied by the M2 segment of the main MCA trunk.

4. "Triangular" shape: 5%

This form presents as a triangle with a medial base, a lateral vertex and with three edges: supero-lateral (medial side of the frontal part of the operculum), infero-lateral (medial side of the temporal part of the operculum) and medial (insular cortex). The SAS is wide and contains the CSF in addition to the entire divisional trunks of the M1 segment of the MCA.

Among these four forms found using frontal section at the middle of the CSI, the "T reversed" is the modal or predominant form with the highest occurrence (67.5%) (Fig. 5c).

Distribution of LBC forms by cerebral hemisphere and gender

The modal forms of the FLB found on transverse (Fig. 6), sagittal and frontal sections at the level of SI did not vary with cerebral hemisphere or sex. The same results were obtained with the modal forms found on transverse, sagittal and frontal sections at the level of the CSI middle.

Coding of modal or predominant forms of the LFB

We identified six modal forms according to the plane and the level of section. By correspondence, each modal form was connected to a numbered type. Thus, all the forms we classified varied from 1 to 6; types 5 and 2 are identical despite their different section levels (Figs. 7, 8).

Identification of the reference subject

The modal or predominant forms found in LFB contributed to the identification of a reference subject among the 20 right-handed adults. This subject had in each cerebral hemisphere, the most typical morphological characteristics of the LFB. After her selection, the reference subject was identified by his patient registration code; it was a 34-year-old woman.

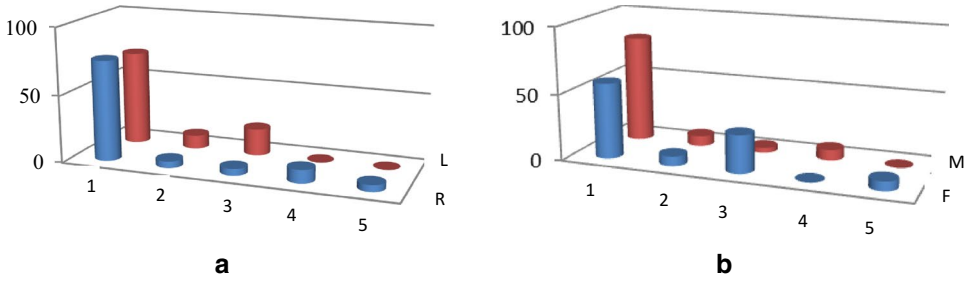


Fig. 6 Distribution of LFB shapes on the horizontal section at the SI level by cerebral hemisphere (**a**) and sex (**b**). a1: atypical fork; a2: single fork; a3: undetermined; a4: recess; a5: triangular. b1: atypical fork; b2: single fork; b3: indeterminate; b4: recess; b5: triangular. *L* left cerebral hemisphere; *R* right cerebral hemisphere; *M* masculine; *F* feminine

Subdivision of the LFB

The LFB had four compartments at its deep SAS. These included the antero-superior (1), antero-inferior (4), postero-superior (2) and posteroinferior (3) compartments. Laterally, the entrance door of the LFB, which corresponded to LS, was considered as a fifth compartment (Fig. 9).

On frontal sections, the forms at SI levels showed the anterior (1 and 4) compartments of the LFB and those at the CSI middle revealed the posterior compartments (2 and 3). The LS (5) was always visible regardless of the section level.

Discussion

Terminology

In 1600, Fabrici d'Acquapendente's work of art showed the surfacial part of the LFB, the LS which at that time was called the "*lateral fissure* or *scissure*" [9]. This same name was used by Caspar Bartholin for the description of the first graphic representation of the LS engraved by J. Voort Kamp before his son Thomas Bartholin attributed the name to Franciscus Sylvius (F. De le Boë) as an honorary in 1641 [9]. The name evolves from "*lateral fissure*" to "*Sylvius's fissure* or *sylvian fissure*".

However, this first graph illustrating the "*lateral fissure*", as it is written on its legend [9], shows the two lips of the LS as distant, thus revealing a wide and deep depression located on the lateral face of the cerebral hemisphere. From 1895, this same region of the brain was named "*sylvian fossa*" or "*sylvian valley*" or "*fossa of Sylvius*" by Dejerine, Broca and Dubret [8, 10, 11]; Rouvière and Delmas describe it under the same term "*sylvian fossa*" [23]. Finally, from 1998, the authors of various anatomical works or Atlases [11, 12, 15, 24, 30] used the new terminology of "*lateral cerebral fossa*" or "*lateral fossa of the brain*" in connection with international anatomical terminology.

In addition, other authors of articles specialized in neurosurgery, such as Gibo [13], Park [20], Wen et al. [31] and Maslehaty and Cornelius [17] continue to use the term "*sylvian fissure*" or "*lateral sulcus*" to study the same area, which is the LFB including both its parts, superficial and deep. There is a difference in the works of Aboitiz and Scheibel [1], Balak [6] and Safaee and Englot 25] where only the superficial part of the region, that is the LS, is called the "*sylvian fissure*". Thus, the use of the term "*sylvian fissure*" is confusing because it is presented in many articles with different definitions from one author to another.

The term "*LFB*" is mostly used by anatomists. This term is more complete and precise because it includes the embryonic, morphological and topographical aspects of this region.

At first embryologically, the existence of the region is related to the rotation of the telencephalon during intrauterine development (IUD). Very early, between the beginning of the 2nd month and the 4th month of IUD, the LFB appears in the form of a small invagination [10, 15, 23] in the middle and inferio-lateral part of the hemispheric vesicle. It becomes deeper and deeper as the rest of the hemispheric vesicle takes on greater development. In the 7th month, the LFB is largely open [15]. Gradually, its upper and lower edges come closer, then touch and cover the lobe of the insula that occupies the bottom of the LFB [24]. Thanks to this approximation, the LS is formed on the surface of the hemispheric vesicle and an SAS more or less wide in depth, which is called the *sylvian cistern* or *sylvian lake* by Dubret and Cousin [11].

Morphologically, the shape then composed of the LFB corresponds more to that of a fossa because of the extent of its depth of invagination. However, a superficial part of the region corresponds to the LS, defined as a narrow linear depression traversing the lateral face of the cerebral hemisphere.

Finally, topographically, the region is located on the lateral slope of the cerebral hemisphere with a larger

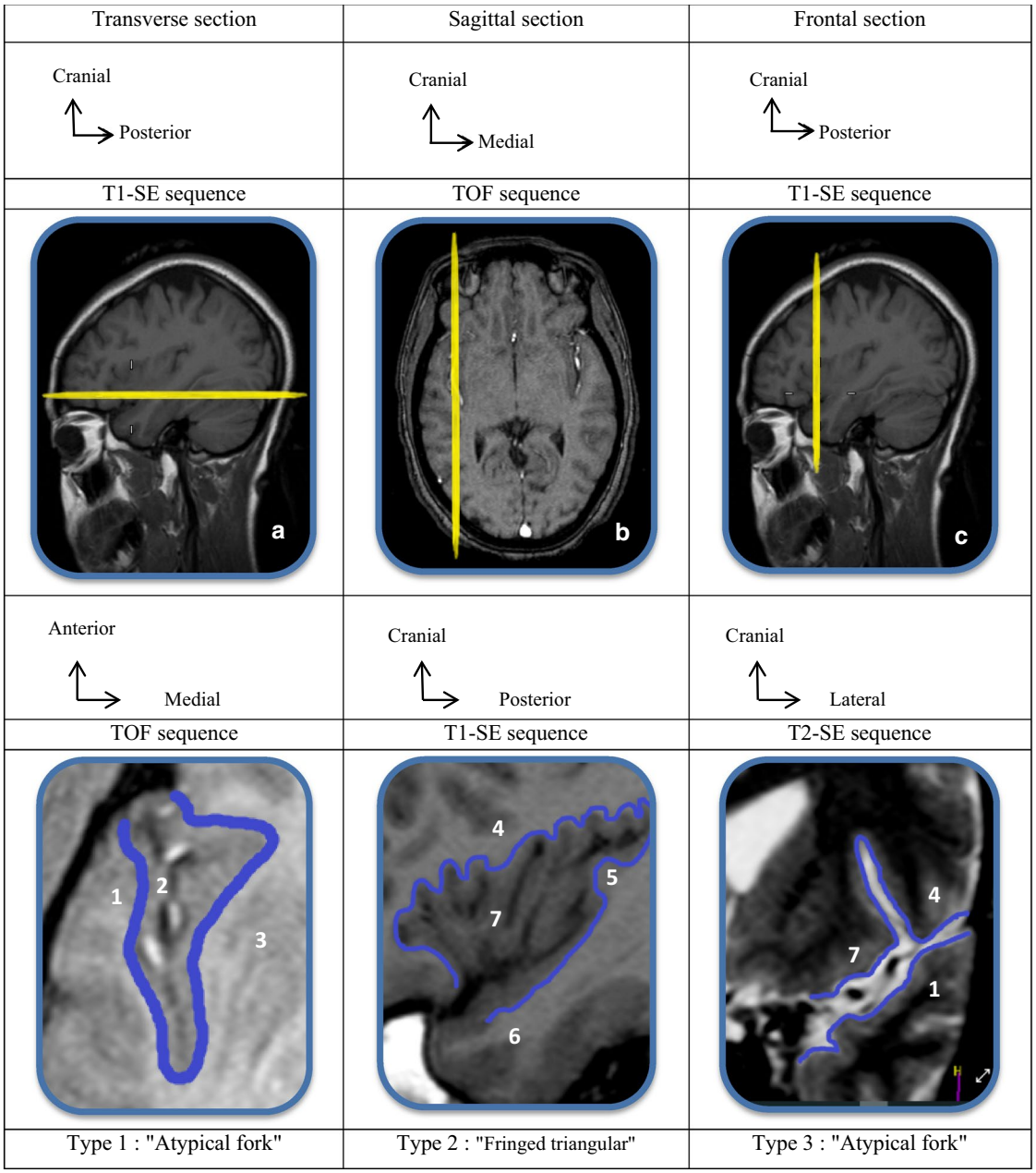


Fig. 7 Description of the modal shapes of LFB on transverse (**a**), sagittal (**b**) and frontal (**c**) sections of cerebral hemisphere at the SI level. 1: Temporal part of the operculum of the LFB; 2: LFB; 3: lenticular nucleus; 4: fronto-parietal part of the operculum of the LFB; 5: transverse temporal gyrus (Heschl's gyrus); 6: temporal lobe; 7: insula; section level: transverse sections (**a**), sagittal (**b**) and frontal (**c**) at SI level

anteroposterior axis. All these points explain why we chose to use term LFB in our study.

Cortical structures of the LFB

From an anatomical point of view and on frontal section, the LFB as a container has two cortical structures: the operculum of the LFB laterally and the insula medially.

1. The operculum of the LFB corresponds to all the gyri of the frontal, parietal and temporal lobes bordering the LS. It resembles a lateral cover that overlays the insula. It comprises three parts: a fronto-parietal part, a parieto-temporal part and a temporal part.

   – The fronto-parietal portion of the operculum comprises from front to back [10]: (1) the horizontal anterior branch of LS; (2) the triangular part of

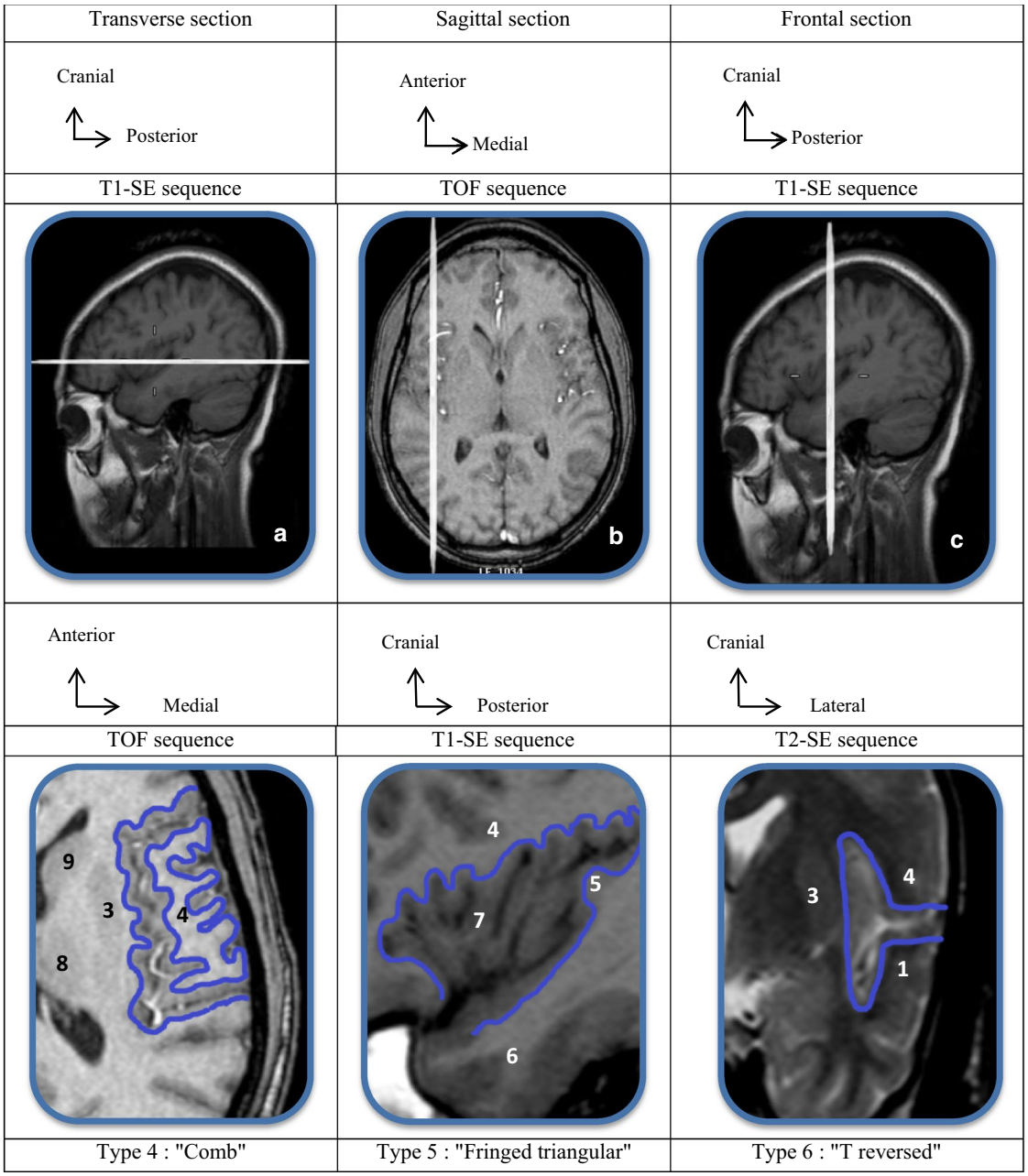


Fig. 8 Description of the modal shapes of LFB on the transverse (**a**), sagittal (**b**) and frontal (**c**) sections of the cerebral hemisphere in the middle of the CSI. 1: Temporal part of the operculum of the LFB; 3: lenticular nucleus; 4: fronto-parietal part of the operculum of the LFB; 8: thalamus; 9: caudate nucleus; in white: transverse (**a**), sagittal (**b**) and frontal (**c**) sections in the middle of CSI (color figure online)

the inferior frontal gyrus; (3) the anterior vertical ascending branch of LS; (4) the opercular part of the inferior frontal gyrus; (5) the sub-central gyrus or the lateral fronto-parietal passage fold; (6) the inferior parietal gyrus and (7) the gyrus supra-marginalis. This fronto-parietal part of the operculum has three faces: a lateral face on the convexity, a lower face corresponding to the upper lip of the LS and a medial face that forms the supero-lateral wall of the LFB. Only the lower and medial faces belong to the container of the LFB.

– The parieto-temporal part corresponds to the superficial parieto-temporal passage fold that connects the fronto-parietal part to the temporal part of the LFB operculum.

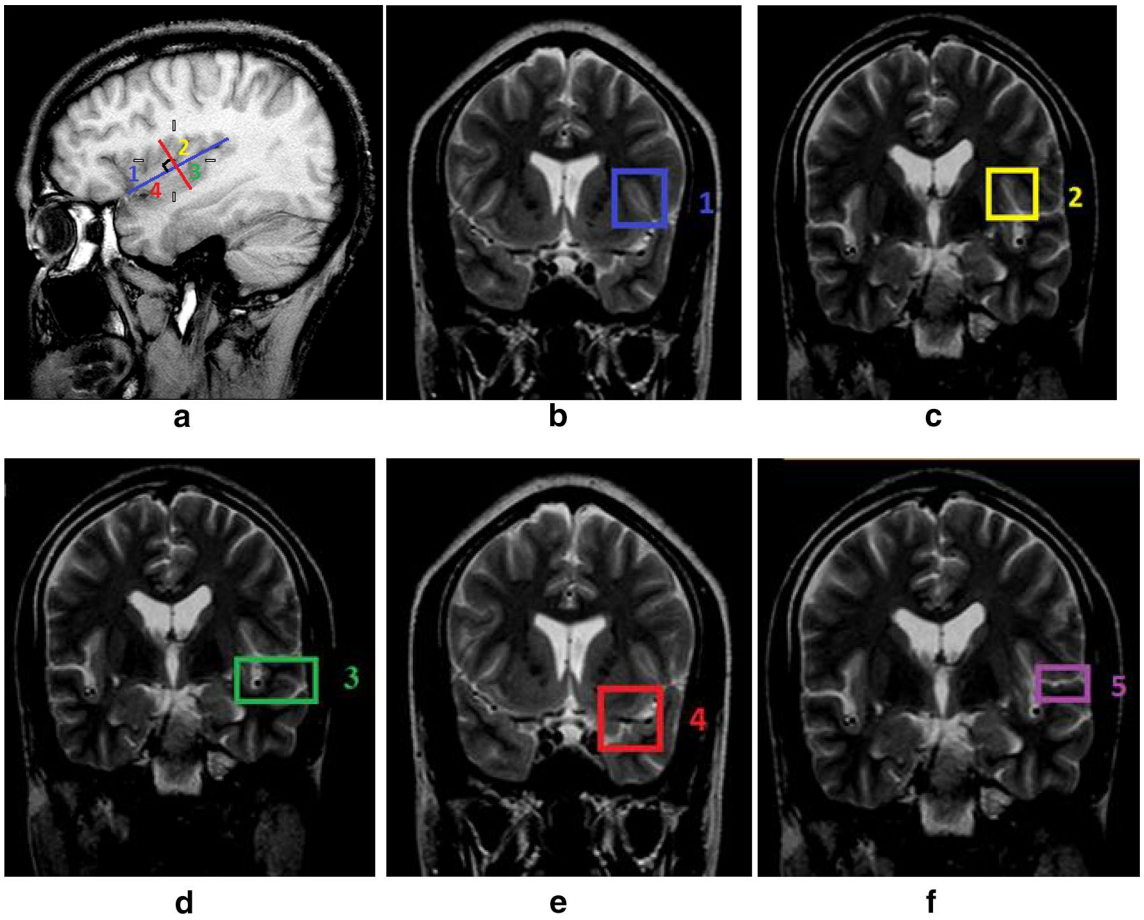


Fig. 9 Subdivision of LFB (**a**) into five compartments [anterosuperior (**b**), posterosuperior (**c**) posteroinferior (**d**), anterior–inferior (**e**) and laterosulcal (**f**)] (color figure online)

- The temporal part comprises from back to front: the temporal plane; the transverse temporal gyrus (Heschl gyrus) and the polar plane. This temporal part of the operculum has three faces: a lateral face on the convexity, an upper face corresponding to the lower lip of the LS and a medial face, which forms the infero-lateral wall of the LFB. Only the upper and medial faces belong to the container of the LFB.

2. The operculum houses areas with highly specific functions, such as language for the dominant hemisphere, hearing, motor skills and somato-sensibility of the face. Thus, in practice, his protection is a key advantage in the transsylvian approach. Also, it can be subjected to pre-operative and intra-operative anatomical mapping during the transcortical approach.
3. The lobe of the insula or "Reil Island" is located in the bottom of the LFB on a lateral view of a cerebral hemisphere. However, to see it, you have to separate the two lips of the LS on an anatomical specimen, use 2D images or reconstructed 3D images in radiology. It was identified for the first time in 1808 by J. C. Reil, German neurologist [8, 14, 19, 30]. It constitutes the medial wall of the LFB on a frontal section of the brain.

The forms of the LFB

The forms of LFB take into account the integrity of the walls and the contents of the LFB. The "comb" shape described on transverse section at the middle level of the CSI is proof of this. If we only included the walls in our account, this form would not be obvious; similarly if the contents were taken in isolation, this morphology would not be obvious. The modal forms described are characterized by the regularity of their internal and external contours. Thus, clearly disfigured forms can testify abnormalities or lesions concerning the cortical ribbon and /or the elements contained in the LFB, in particular the MCA.

The description of these modal forms of the LFB has clinical and radiological implications. The authors such as Ngando and Maslehaty et al. [17, 18] provided results on the significance of the forms of LFB. Their data are derived

from intraoperative observation, CT and MRI. With the method of MRI, Maslehaty and Cornelius [17] note that they found no statistically significant difference compared to CT [17]. These allow us a reasonable comparison of their results with ours.

On the clinical level, Ngando [18] used the classification of LFB described by Yasargil. The proximal part of the "*sylvian fissure*" studied in their work refers to compartment 4 (antero-inferior) of the LFB described in ours. According to Ngando [18], the anatomy of LFB plays a significant role in the formation of postoperative cerebral edema in patients with an unruptured intracranial aneurysm (UIA) and those with subacute arachnoid haemorrhage (SAH) grade 1 and 2. They concluded that LFB Category I, which is described as stiff (wide or narrow), is the anatomical variation that offers an easier approach to the aneurysm and would be more suitable for a surgeon who has just started the procedure of clipping the aneurysm [18]. In our study, the "atypical fork" shape of the anterior part of t he LFB is most frequently found on transverse sections in the normal adult subject appearing in 72.5% of normal cerebral hemispheres. Using our classification, we can correlate its inferior branch to the proximal compartment of the LFB studied by Ngando and Maslehaty [17, 18]. This branch is wide inferiorly and slightly crenellated. Thus, the modal form of "atypical fork" of the anterior compartment could testify to the presence of a dense and complex arterial network that may interest the M1 segment, the M1–M2 knee or the initial M2 part of the MCA. These results explain the frequent difficulty encountered during the TS approach despite its effectiveness. However recent reports associate the TS approach with higher rates of complications (up to 30%) with vascular lesions and pial transgression at exposure [25, 26]. The steep edges are only found in the form of the "simple fork" where the lower branch is stiff and rectilinear. However, this form is found only in 7.5% of cerebral hemispheres compared to the modal form in "atypical fork". This unrepresentative form of "simple fork" would lend itself to an easier TS approach, in contrast to the modal one. Thus, the neurosurgeon can make a quick and justified choice on the TS approach of the anterior compartment of the LFB, when the "simple fork" shape is found during the pre-surgical radiological evaluation of the region. The few patients who will have this type of LFB could benefit from the TS approach hoping for less vascular and cortical complications because of the regular contours of this shape.

The following study by Maslehaty et al. [17] supports the results of Ngando [18]. They attempt to show a positive correlation between the type of LFB and the occurrence of postoperative complications during the treatment of MCA aneurysms, in the same antero-inferior compartment. These authors conclude that the morphology of the anterior–inferior compartment of the LFB influences the configuration and size of the proximal MCA, which in turn influences the choice of the approach of this region.

In addition, the same team showed that people over 60 years of age have a wider LFB at this level. They explain this morphology by cortico-subcortical atrophy. In our study, this atrophy is a criterion of non-inclusion. However, in our subjects under the age of 55, the LFB is wide in front of the middle of the CSI and narrow behind it. In the posterior part, the width of the LFB is reduced to that of the M2 segment of the MCA. According to Safaee et al. [25], the transsylvian approach is severely limited in this narrow posterior corridor consisting of posterior zones 2 and 3 in our study, explaining the high rates of complications. Also, our work provided the classical modal shape in "T reversed" on frontal sections at the level of the middle of the CSI, which testifies to the narrowness of the LFB at the level of the posterior compartments.

It is important to note that other authors conduct work on the shape of the LFB using transverse sections but the section levels are not specified [17, 18]. Moreover, it appears on the diagrams or radiological images that illustrate the different categories of the LFB, different proportions of the temporal lobe involving different section levels have not been clarified and taken into account.

For our work, two landmarks contributed to obtaining our results. These are SI and the middle CSI that can be easily targeted by radiologists. The constancy of easily identifiable anatomical landmarks contributes to a better reproducibility of the anatomo-radiological analysis.

In summary

The interest of our results is major

- At the surgical level, the width and contours of the LFB are decisive for the choice of the surgical approach. Our original and precise description of the distinct forms of LFB and all its compartments can be of considerable contribution in the preoperative evaluation of this region. In addition, Figs. 7 and 8 showing the types of LFB can be completed in our future work by integrating a component on the choice of the appropriate surgical approach. Each type of modal shape could be paired with the best surgical approach recommended.
- In Imaging, these new anatomical data can be used as a reference to systematically analyze the LFB during any morphological MRI examination. With the assimilation of this first complete anatomo-radiological description which takes into account the level and the plane of section, the semiological reading and the interpretation of MRI will be even more refined and easy than it is currently for all specialists who frequently explore this region. These data will positively influence the sensitiv-

ity of brain MRI to the morphological typing of LFB and the early diagnosis of LFB pathologies.

- Moreover, the review on the terminology of the LFB discards any future confusion in the exploitation of the literature on the region or part of the region. It will also facilitate the comparison of the results of the various existing works. The topographic systematization provided in this work allows now a better assimilation of the anatomical configuration of this region.
- In addition, all the most representative anatomo-radiological data contributing to the identification of a reference subject will be used in our next 3D modeling and biometrics work of the LFB.

Conclusion

It is clear that the shape of the LFB varies according to the type and the level of section. The precise knowledge of the anatomical imaging of LFB is crucial for better reading and radiological interpretation and also in the pre-surgical planning.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interests.

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