Gross Anatomy of the Human Insula

Igor Lima Maldonado, MD, PhD[1,2], Ilyess Zemmoura, MD, PhD[3,4], Christophe Destrieux, MD, PhD[3-4]

Abstract When the lips of the lateral fissure are separated from each other, a new group of sulci and gyri appear. They are arrayed together in the form of an island, which is the reason why the German anatomist Johann Christian Reil named them "the insular lobe". Bordered by the limiting sulci, its general form resembles that of an oblique pyramid with a triangular base and low height. Although some anatomical variation exists, the insula presents a systematizable internal organization and well-defined anatomical relationships with deep and superficial cerebral structures, such as the extreme capsule and the cerebral opercula. In this chapter we review concepts of the insular morphology that are important to the fields of neurosurgery and neuroimaging.

Keywords Insula, anatomy, cerebrum, cerebral cortex.

1. Universidade Federal da Bahia, , Instituto de Ciências da Saúde, Departamento de Biomorfologia, Salvador-Bahia, Brazil

2. Universidade Federal da Bahia, Complexo Hospitalar Universitário Prof. Edgard Santos, Serviço de Neurocirurgia, Salvador-Bahia, Brazil

3. Université François-Rabelais de Tours, Inserm, Imagerie et cerveau UMR 930, Tours, France

4. CHRU de Tours, Tours, France

Introduction

When the lips of the lateral fissure are separated from each other, a new group of sulci and gyri appear. They are arrayed together in the form of an island, which is the reason why the German anatomist Johann Christian Reil designated them as "the insular lobe".

Vicq d'Azyr and Monro also paid some attention to this region in the eighteenth century, but Reil was the first to publish a description with some degree of detail in 1809 [1-4]. Since the publication of the fourth edition of the Paris *Nomina Anatomica* in 1975, it has been systematically considered a cerebral lobe [5,6].

The insula is partially composed of the so-called mesocortex. Its topography and physiology are intermediate to the isocortex, which covers most of the cerebral hemispheres, and the alocortex, which is present in the (phylogenetically older) amygdala and hippocampus, [5,4].

Topography

Embedded in and covered by the adjacent brain lobes, the insula forms the medial limit of the lateral (Sylvian) fissure in each cerebral hemisphere. However, it does not occupy the full extent of that fissure. Antero-inferiorly, the initial portion of the fissure has a pre-insular topography. Similarly, it extends posterior to the last gyri of the insula, forming the retro-insular segment.

The two lips of the lateral sulcus correspond to portions of the cerebral hemisphere that have developed laterally to the insula [7]. They completely cover it and assume the role of true opercula. We distinguish two opercula: one is superior or frontoparietal, and the other is inferior or temporal. The lower border of the frontal and parietal lobes forms the superior opercu-

lum, while the inferior operculum is formed entirely by the superior temporal gyrus (Fig. 1A).

From a topographic point of view, the insula is considered the outer shield of a well-defined cerebral central core [8,5,9]. Attached to the upper portion of each half of the midbrain, the central core corresponds in each hemisphere to the insula, basal nuclei, thalamus and internal capsule.

Limits

The contour of the insular lobe is delimited by the circular or peri-insular sulcus, which is quite marked, but interrupted by the transverse gyrus of the insula. Considering the roughly triangular shape of the insular base, this sulcus is generally divided into three parts, the anterior, posterior and inferior (or postero-inferior) limiting sulci (Fig. 1B).

The very deep anterior limiting sulcus separates the anterior border of the insula from the orbital portion of the inferior frontal gyrus and from the posterior orbital gyrus. Being in the form of a true fissure, it is vertically oriented or has a slightly oblique direction, pointing inferiorly and posteriorly. The depth of this sulcus is in relation to the anterior limb of the internal capsule. The upper extremity of the anterior limiting sulcus is at the level of the anterior horn of the lateral ventricle, where the ventricle surrounds the head of the caudate nucleus [5].

The superior limiting sulcus is the longest of the three. It separates the superior surface of the insula from the superior operculum. It is related successively from anterior to posterior to the medial aspect of the triangular portion of the inferior frontal gyrus, the opercular portion of the same gyrus, the precentral gyrus, and the subcentral gyrus, a cortical fold that closes inferiorly the central sulcus communicating the pre- and postcentral gyri.

The inferior limiting sulcus has a strong obliquity, pointing inferior and anteriorly. While the posterior segment of this

sulcus separates the insula from the retro-insular part of the lateral fissure, the anterior segment separates it from the superior temporal gyrus.

Since the pole of the insula is connected to the inferior frontal gyrus and the superior temporal gyrus at the level of the limen insulae, the aforementioned sulci do not surround the insula completely. This conformation prevents the inferior limiting sulcus from being continuous with the anterior limiting sulcus. As a consequence, this lobe is not a true island, as it remains connected to superficial gyri of the neighboring lobes. It may thus be compared to a quasi-island or peninsula [10].

General form

The insula presents a general form that resembles that of an oblique pyramid with a triangular base and a low height. Its base is large and is medially orientated in continuity with the rest of the cerebral hemisphere. One of the vertices of the base is directed antero-inferiorly and corresponds to the insular pole.

The apex, situated posterior and lateral to the pole is the lateral-most portion of the insular cortex. It is directed laterally, anteriorly and inferiorly. It therefore has a location eccentric to the base. It is also directed towards the external opening of the Sylvian fissure, without reaching or exceeding this aperture. Under surgical conditions it can be seen or directly accessed through the so-called anterior sylvian point, the site of the lateral sulcus in which the triangular portion of the inferior frontal gyrus separates from the superior temporal gyrus widening the sulcus. From this point, the lateral sulcus sends out its anterior, ascending and posterior rami.

Anteriorly and inferiorly to the apex, the limen insulae connects the frontal, insular, and temporal lobes. The middle cerebellar artery turns approximately 90 degrees just anterior or immediately distal to the limen, as it changes direction to enter the posterior ramus of the lateral fissure [11].

Two aspects of the insula are more clearly distinct: the anterior and the lateral. The anterior aspect is smaller in extension. It is covered by the fronto-orbital portion of the superior operculum, consisting of the posterior portion of the posterior orbital gyrus and the orbital portion of the inferior frontal gyrus.

The lateral aspect is rich in insular sulci and gyri. Thus, it has a more complex shape than the anterior one. Its upper third is covered by parts of the frontal-parietal operculum, namely the triangular and opercular portions of the inferior frontal gyrus, the subcentral gyrus and the anterior basal portion of the supermarginal gyrus. The lower two thirds is covered by the superior temporal gyrus.

Sulci and gyri

In relation to its internal anatomical organization, the insula is formed by a set of gyri that are arranged centrifugally and extend from the apex to the base. These gyri have significant individual variations so it is not possible to determine a pattern that corresponds to all cases, only to most of them.

At its lateral surface, a sulcus that is much longer than the others leaves the superior limiting sulcus and describes a strongly oblique trajectory anteriorly and inferiorly until the limen insulae. This sulcus, namely the central sulcus of the insula, is easily recognizable since no other sulcus in the lateral aspect of the insula descends as inferiorly as it does. Its direction is roughly the same as that of the central sulcus of the superolateral surface of the cerebral hemisphere. It divides the insula into two clearly distinct parts: one is anterior, the anterior lobule of the insula, the other is posterior, the posterior lobule of the insula. In a minority of cerebral hemispheres, estimated to be less than 10%, the central sulcus of the insula may be not very well defined or may be interrupted by connecting gyri [4].

The anterior lobule of the insula consists of three short gyri that have a common origin in the irregularly rounded apex.

They are distinguished according to their position as anterior, middle and posterior.

The anterior short gyrus extends along the anterior limiting sulcus. It is directed obliquely superiorly and anteriorly towards the inferior frontal gyrus. There may be an anatomical variation with bifurcation of its upper extremity. The point at which the anterior border of this gyrus joins the anterior and superior limiting sulci has been named the "anterior insular point" [4].

The middle short gyrus is the smallest of the three. It follows a roughly vertical trajectory, starting from the apex towards the opercular portion of the inferior frontal gyrus. It is separated from the anterior insular gyrus by the short insular sulcus, not very deep, and from the posterior gyrus by the precentral sulcus of the insula.

The posterior gyrus also arises from the insular apex. Its inferior extremity is tip-shaped. It extends obliquely, superiorly and posteriorly along the central sulcus of the insula, forming the anterior bank of that sulcus and terminating superiorly with a generally bifurcated (or even trifurcated) extremity. In a lateral view, this extremity projects approximately at the level of the subcentral gyrus of the cerebral hemisphere.

Regardless of the three main gyri mentioned above, one or two accessory gyri are also often present. They are variable and usually very short and deeply situated, anterior to the apex and to the anterior gyrus of the insula. They connect the anterior lobe of the insula to the anterior portions of the inferior frontal gyrus.

At a lower location, crossing the middle cerebral artery, a small transverse gyrus connects the apex area to the orbital region in the inferior aspect of the frontal lobe. It reaches the postero-medial lobule of the frontal lobe, which is composed of the posterior portion of the medial orbital gyrus and the medial portion of the posterior orbital gyrus, extending along and lateral to the lateral olfactory stria [5,4]. The transverse gyrus of the insula may be hypoplastic in up to 14% of cerebral hemispheres [4]. The transverse and accessory gyri form the insular pole, located in the inferior-most and anterior-most portion of this lobe. [4].

The posterior lobule of the insula is smaller than the anterior one. It is delimited anteriorly by the central insular sulcus and posteriorly by the inferior limiting sulcus. It comprises two long, strongly oblique gyri: one is anterior, along the central sulcus of the insula; the other is posterior, adjacent to the inferior limiting sulcus.

These two gyri are sometimes only slightly separated from each other because of the shallow, undeveloped character of the postcentral insular sulcus in approximately one-fourth of cerebral hemispheres [4]. They originate from an inferior common tip that is continuous with the superior temporal gyrus. In their superior portions, they may bifurcate and thus form two to four secondary gyri that meet the frontoparietal operculum at the level of the post-central gyrus. The term "posterior insular point" has been used to describe the posterior-superior limit of the posterior insular lobule, where the superior and inferior limiting sulci meet. From this point, the posterior ramus of the lateral fissure continues as a retroinsular space.

Deep relationships

Deep to the insular gyri, the subcortical white matter of the extreme capsule roughly accompanies the contours and accidents of the insular sulci and gyri. In horizontal sections, small conical extensions of this capsule are seen in the form of spines that are directed towards the insular cortex (Fig. 3A).

Through it, the insular gyri are indirectly related to the claustrum, the most superficial nucleus of that region. The claustrum consists of a thin sheet of gray matter with a thickness of 1 to 2 millimeters, extending along the deep face of the insula, interposed between the extreme capsule and the external capsule, a portion of white matter that covers the lenticular nucleus laterally.

In horizontal and coronal sections, the periphery of the claustrum curves laterally, following the form of the cerebral

cortex that covers the Sylvian fissure. In its lower portion, it widens considerably, except for the antero-inferior part in proximity to the limen of the insula. At this site, the great thickness of the white matter bundles (uncinate and inferior fronto-occipital) competes for space with the gray substance of the claustrum [12-14].

The lateral aspect of the lentiform nucleus corresponds to the lateral aspect the putamen. Since it has a surface area that is smaller than that of the insula itself, and considering the fact that the internal capsule laterally inclines around this nucleus, the depths of the anterior, superior and inferior limiting sulci get significantly close to fibers of the internal capsule [5].

In relation to the other, deeper basal nuclei, the anterior half of the lateral face of the insula corresponds internally to the head of the caudate nucleus. Its posterior half corresponds to the thalamus and other portions of the caudate nucleus. The distance from one of the insular points (anterior or posterior) to the ventricular ependyma is little more than one centimeter. Beyond the limiting sulci, the insula is surrounded by the arcuate fasciculus, which is part of the Superior Longitudinal Fasciculus complex (Figs. 2 and 3).

The superior limiting sulcus follows the course of the frontal horn of the lateral ventricle, as well as the body and part of the atrium. The inferior limiting sulcus accompanies the temporal horn and part of the atrium for about 80% of its length [4]. About one centimeter of the anterior portion of that sulcus corresponds to the temporal stem.

Superficial relationships

As mentioned, the fronto-orbital portion of the superior operculum covers the anterior aspect of the insula. Through the lateral fissure, it is in relation with the posterior portion of the posterior orbital gyrus, a small portion of the lateral orbital gyrus, and the orbital portion of the inferior frontal gyrus. In the medial surface of the fronto-orbital operculum, two small gyri,

the (superior and inferior) suborbital gyri are continuous with the cortex of the insula in the region of the accessory and short anterior gyri.

Similarly, the medial aspect of the triangular portion contains the subtriangular gyrus, which is continuous with the cortex of the anterior short insular gyrus and covers it laterally. The suborbital gyri covers the anterior short gyrus anteriorly and the subopercular gyrus covers it posteriorly [4].

The subopercular gyrus also covers the short insular sulcus and part of the middle short insular gyrus. The subprecentral gyrus covers the rest of the middle short insular gyrus and the precentral sulcus of the insula. Since in most cerebral hemispheres the central sulcus of the cerebral hemisphere does not reach the lateral fissure, the subcentral gyrus recovers part of the central sulcus of the insula. As a consequence, the posterior short insular gyrus is covered anteriorly by the subprecentral gyrus and posteriorly by the subcentral and subpostcentral gyri.

Also, in the frontoparietal operculum, three small transverse parietal gyri (anterior, middle and posterior) are located on the medial (internal) opercular surface. The anterior one covers part of the post-central insular sulcus and the superior portion of the two long insular gyri. The anterior transverse parietal gyrus converges with the anterior transverse temporal gyrus of Heschl close the posterior insular point.

In the temporal operculum, the superior temporal gyrus and the lower portion of the supramarginal gyrus cover the insula. The polar planum covers the limen of the insula and its inferior surface. About two-thirds of the inferior limiting sulcus is adjacent to the polar planum [4]. The remaining third closely follows the anterior transverse temporal gyrus of Heschl.

Pre-insular area

In the inferior aspect of the brain, when examining the anterior portion of the lateral fissure, a pronounced curvature is observed. It is present at the level of the limen of the insula,

where the fissure passes from the inferior aspect of the cerebral hemisphere to its lateral face. This curved portion of the fissure (namely, the falciform sulcus), crosses anteriorly the limen of the insula (the falciform fold). Anterior to this, we see the diagonal band of Broca and the lateral olfactory stria, landmarks that limit the anterior perforated substance.

The trunk of the lateral fissure thus presents as a preinsular segment (sylvian vallecula) and its roof contains the anterior perforated substance. The trunk of the lateral fissure follows the contours of the posterior border of the lesser wing of the sphenoid bone.

Retro-insular area

By this name we designate the entire portion of the lateral fissure that is located posterior to the insula, or, more precisely, behind the inferior limiting sulcus. It is a deep depression in which are situated the posterior- most branches of the middle cerebral artery.

Immediately behind the insula, a *pli de passage* is observed, often well developed and of varying depth, running obliquely from inferior to superior and from anterior to posterior. It corresponds to an extension of the transverse temporal gyrus of Heschl behind the insula until the anterior transverse parietal gyrus as a temporo-parietal connection. This cortical fold behaves as a significant anastomosis between the superior temporal gyrus and the supramarginal gyrus. It is usually unique in its origin, but it may divide in its trajectory into two (or more) secondary gyri that connect themselves with similar parenchymal extensions from the parietal lobe — the anterior, middle and posterior transverse parietal gyri.

Such cortical folds do not belong to the insula because they are clearly separated from it by the inferior limiting sulcus. It is interesting to note that the entire lenticular nucleus is also located anterior to that sulcus, which makes it an important landmark. As a consequence, this nucleus maintains an anatomi-

cal relationship with the insula, but not with the retroinsular area.

Conclusion

The study of the descriptive and topographic anatomy of the insula, its internal organization and its anatomical relationships allow an overview of concepts that are important in a number fields, such as neuroimaging and neurosurgery. An adequate nomenclature is important for better communication, while a good understanding of its morphology is one of the bases for development of precise radiological interpretations and operative techniques. These concepts must be accompanied by the study of the functional aspects of the insular lobe.

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FIGURE LEGENDS

Figure 1. General anatomy of the human insula. ***A.*** Sulci and gyri of a left insular lobe as seen when the superior and inferior opercula are separated from each other. ***B.*** Schematic representation showing the main anatomical features of the insula. *aip,* anterior insular point; *als,* anterior limiting sulcus; *ap,* insular apex; *asg,* accessory short insular gyrus; *fs,* falciform sulcus; *ics,* insular central sulcus; *ils,* inferior limiting sulcus; *ips,* insular precentral sulcus*; li,* limen of the insula; *lig,* long insular gyrus; *msg,* middle short gyrus; *pip,* posterior insular point; *psg,* posterior short gyrus; *sis,* short insular sulcus; *sls,* superior limiting sulcus.

Figure 2. Deep anatomical relationships of the insula. ***A.*** The arcuate fasciculus surrounds a significant portion of the circular sulcus of the insula. ***B.*** Extensions of the extreme capsule white matter reproduce the form of the insular sulci and gyri. ***C.*** Deep to the extreme capsule, the insula maintains indirect relationships with the claustrum, the external capsule and elements of the lentiform nucleus.

Figure 3. Deep and superficial anatomical relationships of the insula in a T1-weighted magnetic resonance examination. ***A.*** Axial view. The relationships with basal nuclei and the ventricular system are exposed. ***B.*** Parasagittal view. The superficial relationships with the frontoparietal and temporal operculum are shown.