Morphological and morphometric study of insular cortex in human cadaveric brains

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Abstract
Introduction and Aim: The insular cortex is hidden 5th lobe of brain with variable gross anatomical patterns. Insula is situated in operculoinsular compartment of sylvian cistern.

Materials and Methods: 58 human formalin fixed cerebral hemispheres were studied for the gyri and sulci variations of insular cortex and their lengths were recorded using digital vernier caliper. This study was done in department of Anatomy, Gandhi medical college Bhopal.

Result: The morphological normal and variable pattern, discontinuous sulci and joined gyri were observed. Out of the (85/406) 21% variable pattern we observed (44/406) 10.3% Bifid, (31/406) 7.63%, Hypoplastic Gyri and (10/406) 2.46% Trifid. The Bifid pattern was most commonly seen in Anterior Short Gyrus18 /44 (41%). The Hypoplastic pattern was most commonly seen in Middle Short Gyri 18/31 (58%). There was presence of Transverse Gyri in 13/58 (22.41%) and Accessory gyri in 39/58 (65.51%) cerebral hemispheres. Transverse gyrus & Accessory gyrus both were absent in 19/58 (32.76%) cerebral hemispheres in insular cortex. Total number of gyri in every insula and Mean lengths of gyri were Anterior short=24.54mm, Middle short=25.04, Posterior short=34.08mm, Anterior long=36.87mm, Posterior long=37.1mm measured. The Mean lengths of all insular sulci were Central Insular=35.3mm, Superior Periinsular=52.48mm, Anterior Periinsular=24.5mm, Inferior Periinsular=26.4mm, Posterior Periinsular=12.81mm measured.

Conclusion: Variation in morphological pattern of gyri are Bifid, Trifid and Hypoplastic. The Transverse and Accessory gyri were present in anterior lobule, but not observed in each insula. There was variation in number of gyri because of presence of transverse and accessory gyri. Total number of gyri are more in anterior lobule so it is larger than posterior lobule. The gyri of anterior lobule are shorter than gyri of posterior lobule. Such morphological features and variations are important for surgeries.

Keywords: Morphology, Morphometric, Insular cortex gyri and sulci.

Introduction

Insular cortex is called hidden 5th lobe of brain with paralimbic and somatosensory, viscerosensory functions.¹ Pathology in this integrated cortical area results in many disorders in body.² So anatomical basis of these disorders are very important in early diagnosis and treatment. Trans-sylvian and trans-insular approach are very common in neurosgeries, it demands detailed knowledge of normal gross anatomy and variations to reduce post-operative complications.³

Insular cortex was considered to be asymmetric pyramid or triangle with three peripheral sulci or perinsular sulci or limiting sulci (anterior, superior and inferior).⁴ However, later the radiological and cadaveric studies conducted on insula described it to have a trapezoid structure. The posterior periinsular sulcus was differentiated from inferior periinsular sulcus and these two sulci have two different axis separated by an angle.⁵ The Insula is a trapezoid shaped cortical structure with its apex directed anteriorly and inferiorly toward the limen insulae. The limen is located at the junction of sphenoidal and operculoinsular compartments of the sylvian fissure.⁵,⁶ There are four periinsular sulci, cited superiorly and posteriorly in a radial manner from the apex at the limen insulae.⁵,⁶

The central insular sulcus, the main and the deepest sulcus of the insula, courses obliquely across the insula, and extends uninterrupted from the limen insula to the superior peripheral sulcus. It divides the insula into two unequal zones: the larger anterior insula, and the smaller posterior insula.⁷

The larger anterior lobule of insula is composed of three principal short insular gyri (anterior, middle and posterior). Sometimes accessory and transverse gyri are also present. The anterior, middle and posterior short insular gyrus are separated by the short insular sulcus and the pre-central insular sulcus respectively.⁸ Precentral gyrus of insula is posterior short gyrus term used by Nagao M.⁹ The Anterior Long Gyrus and Posterior Long Gyrus form the smaller posterior lobule and are separated by the post-central insular sulcus.⁸

Materials and Methods

This study was done in 29 formalin fixed brains (58 right and left cerebral hemispheres) with intact arachnoid matter, all segments of sylvian fissure, gyri and sulci of insular cortex. The study was approved by Scientific Review and Institutional Ethics Committee, Gandhi Medical College, Bhopal (M.P.).
The formalin fixed brains satisfying inclusion criteria were dissected and studied. In order to expose and visualize the insular region, the arachnoid and piamater over the sylvian fissure and middle cerebral artery branches in specially operculoinsular compartment were removed. Following standard dissecting procedure, structures under study were observed and recorded. Morphometry was done with the help of Digital Vernier caliper (sensitivity 0.1mm). Statistical analysis of results and comparisons among right and left hemispheres was done and Mean, SD, p value, Unpaired T test, Degree of freedom, SED, and r value Pearson correlation coefficient were analyzed and recorded.

**Inclusion criteria:** Undamaged specimens of both right and left sided cerebral hemispheres cadaveric brains with intact Insula and sylvian fissure, middle cerebral artery branches of this particular area of concern.

**Exclusion criteria:** Damaged brain specimens. Infant and Pediatric age group cadaveric brains.

**Morphology:** The morphological normal and variable patterns as Hypoplastic, Bifid, Trifid gyri, discontinuous sulcus and some joined gyri were observed. Total number of gyri in every insula were also recorded. There was variation in number of gyri because of presence of transverse and accessory gyrus.

**Morphometry:** According to method of Kaneko et al (2012), the four points on the angles were marked as Anterosuperior insular point (ASIP), Posterosuperior insular point (PSIP), Anteroinferior insular point (AIIP), Posteroinferior insular point (PIIP). Morphometric measurements were done by using Digital Vernier Caliper and all curved, irregular measurements by using thread and recorded systematically.

(a) Superior peripheral sulcus- from Anterosuperior insular point to Posterosuperior insular point.
(b) Inferior peripheral sulcus- from Anteroinferior insular point to Posteroinferior insular point.
(c) Anterior peripheral sulcus- from Anterosuperior insular point to Anteroinferior insular point.
(d) Posterior peripheral sulcus- from Posterosuperior insular point to Posteroinferior insular point.
(e) Central insular sulcus- from superior peripheral sulcus to inferior peripheral sulcus, parallel to Posterior short gyrus and anterior long gyrus exactly between them.

**Fig. 1:** Insular cortex gyri: 1-transverse gyrus, 2-accessory gyrus, 3-anterior short gyrus, 4-middle short gyrus, 5-posterior short gyrus, 6-anterior long gyrus, 7-posterior long gyrus

Points: B-Anterosuperior insular point (ASIP), C-Posterosuperior insular point (PSIP), A-Anteroinferior insular point (AIIP), D-Posteroinferior insular point (PIIP), E- Upper central insular point (UCIP).

Insular cortex sulci:
- Central insular sulcus (CIS) = from superior peripheral sulcus to inferior peripheral sulcus, parallel to Posterior short gyrus and Anterior long gyrus exactly between them.
- Superior peripheral sulcus (SPS) = from Anterosuperior insular point to Posterosuperior insular point.
- Anterior peripheral sulcus (APS) = from Anterosuperior insular point to Anteroinferior insular point.
- Inferior peripheral sulcus (IPS) = from Anteroinferior insular point to Posteroinferior insular point.
- Posterior peripheral sulcus (PPS) = from Posterosuperior insular point to Posteroinferior insular point.

**Fig. 2:** Left side insular cortex: anterior short gyrus, middle short gyrus, Posterior short gyrus, All 3 Short gyri BIFID. Right side insular cortex: anterior long gyrus BIFID, Posterior long gyrus hypoplastic

**Fig. 3:** Discontinuous Central insular sulcus & joined Posterior short gyrus and anterior long gyrus (specimen No. 2 right).
Observation and Result

Table 1(a): Insular cortex gyri morphology

| S. No. | Gyrus            | Normal gyrus | Bifid gyrus | Hypoplastic gyrus | Trifid gyrus | Total Gyrus |
|--------|------------------|--------------|-------------|-------------------|--------------|-------------|
| 1      | Anterior Short Gyrus | Rt 18        | 08          | 0                 | 03           | 29          |
|        |                   | Lt 17        | 10          | 0                 | 02           | 29          |
| 2      | Middle Short Gyrus  | Rt 11        | 06          | 11                | 01           | 29          |
|        |                   | Lt 19        | 03          | 07                | 0            | 29          |
| 3      | Posterior Short Gyrus | Rt 24        | 04          | 0                 | 01           | 29          |
|        |                   | Lt 24        | 04          | 0                 | 01           | 29          |
| 4      | Anterior Long Gyrus  | Rt 22        | 06          | 0                 | 01           | 29          |
|        |                   | Lt 25        | 03          | 0                 | 01           | 29          |
| 5      | Posterior Long Gyrus  | Rt 20        | 0           | 09                | 0            | 29          |
|        |                   | Lt 25        | 0           | 04                | 0            | 29          |
| **Total** |                   | Rt 95        | 24          | 20                | 6            | 145         |
|        |                   | Lt 110       | 20          | 11                | 4            | 145         |

Table 1(b):

| S. No. | Morphological Parameter | Number (No.) | Percentage (%) |
|--------|-------------------------|--------------|----------------|
|        |                         | Rt. | Lt. | Total | Rt. | Lt. | Total |
| 1      | Bifid Gyri               | 24  | 20  | 44    | 11.82% (24/203) | 9.85% (20/203) | 10.3% (44/406) |
| 2      | Trifid Gyri              | 06  | 04  | 10    | 02.95% (6/203)  | 01.97% (4/203) | 02.46% (10/406) |
| 3      | Hypoplastic Gyri         | 20  | 11  | 31    | 09.85% (20/203) | 05.41% (11/203) | 07.63% (31/406) |

Table 2: Transverse and accessory gyri

| S. No. | Morphological Parameter   | Left side Insula | Right side Insula | Total |
|--------|----------------------------|------------------|-------------------|-------|
| 1      | Transverse Gyri present   | 6/29 (20.68%)    | 7/29 (24.13%)     | 13/58 (22.41%) |
| 2      | Accessory Gyri present    | 19/29 (65.51%)   | 20/29 (68.96%)    | 39/58 (67.24%) |
Our study found in these groups and study and same result was observed. Thomas P. Naidich and Kang et al., (2004) also found in their radiological study that the long gyri 13/31(42%). Thomas P. Naidich and Kang et al. (18.0%) and Anterior long gyri 9/44 (20.5 %).

The Hypoplastic pattern was also observed in some Posterior long gyrus were seen to be joined (specimen No. 2 right). In another insula discontinuous Post central short gyrus was found with joined Anterior and Middle short gyrus (specimen No. 6). Similar type of joined gyri were also reported in radiological study done by Thomas P. Naidich and Kang et al. (2004)\textsuperscript{7}.

Bifid Gyri: In our study 44 Bifid gyri were observed. The Bifid pattern of gyrus was most commonly seen in Anterior Short Gyrus (20.5 %), Posterior short gyri 8/44 (18.0%) and Anterior long gyri 9/ 44 (20.5 %). None of the Posterior long gyrus was bifid. Our study is similar and correlates with radiological study done by Thomas P. Naidich and Kang et al. (2004)\textsuperscript{7}.

Hypoplastic Gyri: In our study 31 Hypoplastic gyri were observed. The Hypoplastic pattern was most commonly seen in Middle Short Gyri 18/31(58%). Hypoplastic pattern was also observed in some Posterior long gyrus 13/31(42%). Thomas P. Naidich and Kang et al., (2004) also found in their radiological study that the Middle short gyri and posterior long gyri were often hypoplastic on sagittal MR images. None of the Anterior short gyrus, Posterior short gyrus or Anterior long gyrus was hypoplastic in our study and same result was reported in the study done by Thomas et al. (2004)\textsuperscript{7}.

**Discussion**

**Insular Cortex- Morphology**

**Joined Gyri:** In joined gyri pattern, there was discontinuous Central insular sulcus so Posterior short gyrus and Anterior long gyrus were joined (specimen No. 2 right). In another insula discontinuous Post central insular sulcus was there and Posterior long gyrus and Anterior long gyrus were seen to be joined (specimen no. 29 right). One insula with discontinuous short insular sulcus was found with joined Anterior and Middle short gyrus (specimen No. 6). Similar type of joined gyri were also reported in radiological study done by Thomas P. Naidich and Kang et al. (2004)\textsuperscript{7}.

**Bifid Gyri:** In our study 44 Bifid gyri were observed. The Bifid pattern of gyrus was most commonly seen in Anterior Short Gyrus 18/44 (41%) followed by Middle short gyri 9/44 (20.5 %), Posterior short gyri 8/44 (18.0%) and Anterior long gyri 9/44 (20.5 %). None of the Posterior long gyrus was bifid. Our study is similar and correlates with radiological study done by Thomas P. Naidich and Kang et al. (2004)\textsuperscript{7}.

**Hypoplastic Gyri:** In our study 31 Hypoplastic gyri were observed. The Hypoplastic pattern was most commonly seen in Middle Short Gyri 18/31(58%). Hypoplastic pattern was also observed in some Posterior long gyri 13/31(42%). Thomas P. Naidich and Kang et al., (2004) also found in their radiological study that the Middle short gyri and posterior long gyri were often hypoplastic on sagittal MR images. None of the Anterior short gyrus, Posterior short gyrus or Anterior long gyrus was hypoplastic in our study and same result was reported in the study done by Thomas et al. (2004)\textsuperscript{7}.

**Transverse Gyri and Accessory Gyri**

In our study total 58 cerebral hemispheres, were observed, out of which there was presence of Transverse Gyri in 13/58 (22.41%) cerebral hemispheres and Accessory gyri in 39/58(65.51%) cerebral hemispheres. The transverse and accessory gyri are present in anterior lobe of insular cortex. Transverse gyrus & Accessory gyrus both were absent in 19/58 (32.76%) cerebral hemispheres in insular cortex & therefore a total no of 5 gyri were found in them. Presence of Accessory gyri but absence of Transverse gyrus was observed in 26/58 (44.82 %) cerebral hemispheres in insular cortex & therefore total no of 6 gyri were found in these hemispheres. Our observation is similar to Thomas et al. (2004), Rhoton et al (2003), regarding presence of transverse and accessory gyri.\textsuperscript{1,4}

**Insular Cortex Gyri - Morphometry**

In present study the lengths of all the gyri namely Transverse gyrus, Accessory gyrus, Anterior short gyrus, Middle short gyrus, Posterior short gyrus and Anterior long gyrus, Posterior long gyrus were measured which can be of great clinical significance.

### Table 3: Insular cortex gyri morphometry

| S. No. | Gyri               | Side | Minimum (mm) | Maximum (mm) | Mean (mm) | SD (mm) |
|--------|--------------------|------|--------------|--------------|-----------|---------|
| 1      | Anterior Short Gyrus| Rt.  | 16.31        | 34.12        | 23.87     | 4.21    |
|        |                    | Lt.  | 19.10        | 33.02        | 25.22     | 3.78    |
| 2      | Middle Short Gyrus | Rt.  | 14.11        | 34.31        | 24.70     | 4.98    |
|        |                    | Lt.  | 16.32        | 34.48        | 25.39     | 4.76    |
| 3      | Posterior Short Gyrus| Rt.  | 19.21        | 43.21        | 33.37     | 4.46    |
|        |                    | Lt.  | 25.82        | 44.91        | 34.60     | 4.43    |
| 4      | Anterior Long Gyrus | Rt.  | 31.13        | 48.31        | 36.70     | 3.64    |
|        |                    | Lt.  | 28.32        | 47.31        | 37.05     | 4.66    |
| 5      | Posterior Long Gyrus| Rt.  | 31.64        | 49.11        | 38.50     | 4.65    |
|        |                    | Lt.  | 20.12        | 47.80        | 35.31     | 6.37    |

### Table 4: Insular cortex (SULCI) morphometry

| S. No. | Sulci                  | Side | Minimum (mm) | Maximum (mm) | Mean (mm) |
|--------|------------------------|------|--------------|--------------|-----------|
| 1      | Central Insular – Sulcus(CIS) | Rt.  | 29.8         | 44.94        | 35.22     |
|        |                        | Lt.  | 29.08        | 45.69        | 35.38     |
| 2      | Superior Periinsular sulcus (SPS) | Rt.  | 45.32        | 63.32        | 53        |
|        |                        | Lt.  | 46.34        | 83.91        | 53.61     |
| 3      | Anterior Periinsular sulcus (APS) | Rt.  | 17.28        | 32.11        | 23.53     |
|        |                        | Lt.  | 18.13        | 34.04        | 25.47     |
| 4      | Inferior Periinsular sulcus (IPS) | Rt.  | 22.57        | 35.56        | 27.75     |
|        |                        | Lt.  | 16.78        | 33.72        | 25.06     |
| 5      | Posterior Periinsular Sulcus (PPS) | Rt.  | 10.89        | 16.89        | 12.95     |
|        |                        | Lt.  | 8.32         | 15.82        | 12.69     |
Insular Cortex Sulci Morphology

Peripheral sulci - Asymmetric pyramid or Triangle Shape Insula

Thomas P. Naidich and Grant et al., (2004), Oppenheimer and Martin et al., (1996), Ture, Yasargil et al (1999), Feng Wang et al (2011), and Zhang Y et al (2014) considered insular cortex to be asymmetric pyramid or triangle.7,10-13

Rhoton and Tanriover et al (2003), Guenot M (2004) also mentioned it as triangle shaped. So 3 peripheral sulci or peri-insular sulci or limiting sulci were measured (anterior, superior and inferior).5,15

Table 5: Comparison of lengths insular cortex sulci morphometry

| S. No | Insular Cortex (Sulci) | CIS (mm) | SPS (mm) | APS (mm) | IPS (mm) | PPS (mm) | AC (mm) | Old IPS (mm) |
|-------|------------------------|----------|----------|----------|----------|----------|---------|-------------|
| 1     | Ture et al (1999)      |          |          | 57.6     | 28.4     |          | 49.2    |             |
| 2     | Feng Wang et al (2011) | 32.53    | 51.61    | 23.15    | 15.9     | 44.5     |         |             |
| 3     | Kaneko et al (FFB)     | 34.4     | 53.1     | 28.9     | 31.9     | 15.9     | 44.5    |             |
| 4     | Kaneko et al (MRI)     | 34.4     | 56       | 29.3     | 33.5     | 15.9     | 45.9    |             |
| 5     | Zhang (Rt) et al (2014)| 31.52    | 51.56    | 22.5     |          |          |         |             |
| 6     | Zhang (Lt) et al (2014)| 31.36    | 52.05    | 22.6     |          |          |         |             |
| 7     | Present Study (2017)   | 35.38    | 52.48    | 24.5     | 26.4     | 12.81    | 37.96   |             |

Table 6: Comparison of lengths insular cortex sulci morphometry (Zhang & Feng Weng) & present study

| S. No | Insular Cortex (Sulci) | Feng Weng (2011) (mm) | Zhang Y (2014) Right (mm) | Zhang Y (2014) Left (mm) | Present study (2017) Right (mm) | Present study (2017) Left (mm) |
|-------|------------------------|-----------------------|---------------------------|--------------------------|---------------------------------|-------------------------------|
| 1     | Anterior Periinsular sulcus (APS) | 23.15 ±0.47 | 22.5 ±1.57 | 22.6 ±3.30 | 23.53 ±3.55 | 33.43 ±4.18 |
| 2     | Superior Periinsular Sulcus (SPS) | 51.61 ±1.48 | 51.56 ±2.90 | 52.05 ±3.30 | 51.36 ±4.23 | 53.61 ±6.75 |
| 3     | Central Insular Sulcus (CIS) | 32.53 ±0.68 | 31.52 ±2.53 | 31.36 ±2.68 | 35.22 ±3.35 | 35.38 ±4.29 |
| 4     | Inferior Periinsular Sulcus (CIS) | 46.31 ±3.12 | 48.4 ±3.34 | 48.18 ±3.34 | 27.75 ±3.87 | 25.06 ±4.33 |
| 5     | Posterior Periinsular Sulcus (PPS) | 12.95 ±1.43 | 12.67 ±1.87 |             |             |             |

Table 7: Comparison of lengths insular cortex sulci morphometry kaneko et al 2012 and present study

| S. No | Side | CIS (Kaneko et al) | CIS (Present study) | SPS (Kaneko et al) | SPS (Present study) | APS (Kaneko et al) | APS (Present study) | IPS (Kaneko et al) | IPS (Present study) | PPS (Kaneko et al) | PPS (Present study) |
|-------|------|-------------------|---------------------|-------------------|-------------------|------------------|-------------------|-----------------|------------------|----------------|------------------|
| 1     | Min  | Rt                | 27.6                | 29.8              | 46.5              | 45.34            | 25.7              | 17.28           | 29               | 22.57           | 12.7             | 10.89            |
| 2     | Max  | Rt                | 40.8                | 44.94             | 64.3              | 63.32            | 31.4              | 32.11           | 33.2             | 35.86           | 18.3             | 16.89            |
| 3     | Mean | Rt                | 35.9                | 35.22             | 52.8              | 53               | 28.9              | 23.53           | 31.4             | 27.75           | 16.2             | 12.95            |
| 1     | Min  | Lt                | 26                  | 29.08             | 48.8              | 46.74            | 27               | 18.13           | 28.2             | 16.78           | 12.5             | 8.32             |
| 2     | Max  | Lt                | 39.4                | 45.69             | 60.1              | 83.91            | 32.2              | 34.04           | 34.7             | 33.72           | 17               | 15.82            |
| 3     | Mean | Lt                | 32.9                | 35.38             | 53.4              | 53.61            | 28.9              | 25.47           | 32.4             | 25.06           | 15.5             | 12.67            |
| 1     | Min  | Rt & Lt           | 26                  | 29.44             | 46.5              | 46.04            | 27               | 17.05           | 28.2             | 19.67           | 12.5             | 9.6              |
| 2     | Max  | Rt & Lt           | 40.8                | 45.3              | 64.3              | 73.6             | 32.2              | 33.1            | 34.7             | 34.6            | 18.3             | 16.4             |
| 3     | Mean | Rt & Lt           | 34.4                | 35.3              | 53.1              | 52.48            | 28.9              | 24.5            | 31.9             | 26.4            | 15.9             | 12.81            |

Conclusion

Insular cortex has trapezoid shape with 5 to 7 gyri & sulci. Variation in morphological pattern of gyri are Bifid, Trifid, and Hypoplastic. The Transverse and Accessory gyri are present in anterior lobule, but not observed in each insula and total number of gyri in anterior lobule depends on their presence. Total number of gyri are more in anterior lobule so it is larger than Posterior lobule. The gyri of anterior lobule are shorter than gyri of Posterior lobule. Posteriorinferior insular point PIIP (D) and Upper central insular point UCIP (E)
are important surface landmarks of surgical significance. The corticospinal tract in posterior limb of internal capsule is in posterior relation with this area of insular cortex.

Conflicts of Interest
All authors have none to declare.

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