Original Article

A Comprehensive Study of Prominent Sulci on the Superolateral Surface of the Frontal Lobe in Cadaveric Brains of South Indian Population

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Abstract

Background: Anatomical knowledge of the human brain's gyri and sulci is important in neurosurgical procedures despite of various technological advances in the medical field. The neurosurgeon benefits from their understanding of sulci and gyri morphology and morphometry to plan the appropriate surgical approaches or to reach the deeper lesions of the brain through the normal brain parenchyma minimising the necessity of performing corticotomy. **Material and Methods:** The present study was conducted on 70 (35 right and 35 left) cerebral hemispheres obtained from the department of anatomy, MVJ Medical College and Research Hospital, Bangalore. The length of central sulcus,precentral sulcus, superior frontal sulcus ,inferior frontal sulcus ,anterior horizontal ,anterior ascending and posterior ramus of lateral sulcus ,depth of central sulcus, distance of central sulcus from frontal pole of cerebral hemisphere was measured with the help of thread and digital vernier caliper. **Results:** The superolateral surface of brain showed all the sulci except the inferior frontal sulcus which was discontinuous in 11 hemispheres. The mean lengths of sulci were more on the left side compared to right cerebral hemisphere suggesting cerebral asymmetry between the hemispheres, which can be associated with other functional significance. The distance of the central sulcus from the frontal pole was 11.46 ±1.8cm on the right side and 11.3 ±1.13 cm on the left side. On the left, the central sulcus measured 2.12 ±0.66 cm, while on the right; it measured 3.12 ±0.53 cm. **Conclusion:** The results of this study will be helpful for neurosurgeons and intervention radiologist for the successful outcome of any brain surgeries.

Keywords: Central Sulcus; Precentral Sulcus; Superior Frontal Sulcus; Inferior Frontal Sulcus; Neurosurgical Procedures.

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Introduction

The area on the superolateral surface of the brain demarcated posteriorly by the central sulcus and inferiorly by the posterior ramus of the lateral sulcus forms the frontal lobe.[1] It has four prominent gyri separated by three sulci. The precentral sulcus lies in front of the central sulcus, differentiating the precentral gyrus, which is motor in function controlling the voluntary movements of opposite sides of the body. The Superior and inferior frontal sulcus divide the area in front of the precentral gyrus into superior, middle, and inferior frontal gyrus. The lateral sulcus's anterior horizontal and anterior ascending rami infiltrate the inferior frontal gyrus. The motor, premotor, frontal eye field, prefrontal area, and These sulci are strongly associated with the speech area, which is situated on the superolateral surface of the frontal lobe.[2] The Central sulcus is the demarcating landmark located between the frontal and parietal lobe, separating the agranular primary motor cortex from the granular primary somatosensory cortex.[3] It is the most crucial limiting sulcus, making it challenging to locate the exact position. Standard anatomy textbooks also mentioned the difficulty in identifying the precise location of the central sulcus. Hence, in the present study, along with the length of the central sulcus, the distance of the central sulcus from the frontal pole is also measured.[4] The Lateral sulcus or Sylvian fissure is the first sulcus to develop during intrauterine life, which separates the frontal and parietal lobe from the temporal lobe. It has three rami- anterior horizontal, anterior ascending and posterior. The point of confluence of these three rami is called the anterior Sylvian point. The frontal and temporal veins lie in front of this point, whereas middle cerebral artery branches lie deep to it.[5] The Brocas speech area and Wernicke's speech area are located around the lateral sulcus known as the perisylvian area and perisylvian speech area respectively. Insular cortex is hidden within it. It is the passageway for many neurosurgical procedures; hence this corridor can be used to reach the deeper regions of the brain. Anatomy of the lateral sulcus is of great clinical significance in surgical intervention for insular cortex lesions or temporal lobe epilepsy.[6] The precentral sulcus is located parallel and in front of the central sulcus. Between the central and precentral sulcus lies the precentral gyrus constituting primary motor area.[7] The frontal lobe's superior frontal sulcus is situated horizontally between the frontal pole and the superior precentral sulcus. It separates the Broadmann

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regions 6, 8, and 9 of the superior frontal gyri from the middle frontal gyrus. Researchers have concluded that the cognitive attentional selection of eye movements is actively influenced by the posterior region of the superior frontal sulcus. The surgical approach through the superior frontal sulcus act as an aisle to the lateral ventricle and Foramen of Monro, avoiding cortical damage. The Inferior frontal sulcus acts as a landmark differentiating Broca's speech area from the prefrontal cortex. The development of the inferior frontal sulcus is late when compared to other significant sulci hence it is prone to high variation.[8] In the latter part of the 20th century, surgeons were using sulci as an access to intrinsic lesions; hence, sulci were considered as a gateway for neurosurgery. Numerous investigations on the brain's gyri and sulci using radiological techniques can be found in the literature, as identifying these structures is easier with MRI. However, due to anatomical variations, it can be difficult to locate during surgical interventions.[9] It is essential for radiologists and neurosurgeons to understand the anatomy of the brain's sulci. It helps them locate and plan appropriate neurosurgical procedures by using the sulci as corridors to access more profound and eloquent brain areas. This understanding ensures precise targeting while minimizing damage to surrounding tissues. Hence, finding out the morphometry of the major sulci on the cerebral hemispheres' superolateral surface and examining any interhemispheric asymmetry are the goals of this study.

Materials and Methods

For the purposes of this cross-sectional investigation, 70 cerebral hemispheres—35 left and 35 right—fixed in formalin solution for dissection were acquired from the Department of Anatomy at MVJ Medical College and Research Hospital in Bangalore. The sample was gathered using the convenience nonprobability sampling technique. They only included adult embalmed hemispheres. The study excluded the brains of infants and fetuses as well as cerebral hemispheres with damage or intracranial abnormalities. The arachnoid mater and blood vessels were removed to locate the cerebral sulci precisely. Sulci are identified as per standard textbook explanations.

Figure 1: Specimen showing the sulci on the frontal lobe of superolateral surface of cerebral hemisphere. (1-Central sulcus, 2-Precentral sulcus, 3-Superior frontal sulcus, 4-Inferior frontal sulcus, 5-Anterior horizontal sulcus,6-Anterior ascending sulcus, 7-Posterior ramus of lateral sulcus 8-Anterior Sylvian point,Ant-Anterior end,POSt-Posterior end)

Starting and terminal ends of sulcus was identified, and thread was placed along the curvature of the sulcus between the two ends. The distance between the both the ends of thread was taken with help of digital vernier caliper.

Figure 2A: Specimen showing the measurement of central sulcus using thread along the curvature (Arrows showing beginning and terminal end of central sulcus)

Figure 2B: Specimen showing the measurement of depth of central sulcus

The following parameters were measured.

- Length of central sulcus - from superomedial border to termination directly above the lateral sulcus's posterior ramus. [Figure 2A]
- Precentral sulcus-in front and parallel to precentral sulcus.
- Depth of central sulcus-measured with vernier caliper by palcing it inside the sulcus. [Figure 2B]
- Distance between central sulcus and frontal pole along the superomedial border.
- Length of anterior horizontal sulcus-from anterior Sylvian point to terminal end.
- Length of Anterior ascending sulcus-From anterior Sylvian point to terminal end.
- Length of posterior ramus of lateral sulcus- anterior Sylvian point to terminal end.
- Length of superior frontal sulcus-Measured between the starting and terminal end.
- Length of inferior frontal sulcus- Measured between the starting and terminal end (The specimens with discontinuous inferior frontal sulcus were excluded from the study).

All the measurements were taken twice to avoid any interobserver bias. Mean and standard deviations of all measurements were taken using IBM SPSS 22 Software.

Results

The frontal lobe on the brain's superolateral surface was defined in accordance with Cunningham's Practical Anatomy Manual, Volume 3.10 and the length of the central sulcus, one of the main sulci on the brain's superolateral surface, anterior ascending, anterior horizontal, superior frontal, inferior frontal, precentral sulcus, and posterior ramus of lateral sulcus were measured. Distance of central sulcus from frontal lobe as well as depth of central sulcus was measured.

Table 1: Measurement of various sulci on the superolateral surface of frontal lobe of cerebral hemisphere

	Right (cm)					Left (cm)				
	Range	**Min**	**Max**	**Mean**	**SD**	**Range**	**Min**	**Max**	**Mean**	**SD**
Length of central sulcus	5.80	7.60	13.40	9.33	1.16	6.65	6.34	12.99	9.44	1.33
Depth of central sulcus	1.97	1.15	3.12	1.94	0.53	2.88	1.24	4.12	2.12	0.66
Distance of central sulcus from frontal pole	5.68	7.80	13.48	11.46	1.18	5.79	8.87	14.66	11.37	1.13
Length of precentral sulcus	3.08	6.85	9.93	8.23	0.74	3.01	6.49	9.50	8.24	0.83
Length of posterior ramus of lateral sulcus	6.19	3.00	9.19	5.51	1.47	5.67	3.15	8.82	5.86	1.56
Length of anterior Horizontal sulcus	1.53	1.34	2.87	2.01	0.47	1.91	1.18	3.09	2.06	0.53
Length of anterior Ascending sulcus	3.13	1.78	4.91	2.70	0.60	2.52	1.34	3.86	2.72	0.53
Length of superior frontal sulcus	5.54	6.34	11.88	9.18	1.15	6.14	7.16	13.30	9.45	1.20
Length of inferior frontal sulcus	3.01	6.40	9.41	7.81	0.68	3.47	5.64	9.11	7.83	0.769

Discussion

During the fetal period, around the 28th-30th week of gestation, the cerebral cortex's surface exhibits morphological alterations in the form of foldings to enable the brain to fit inside the skull's restricted space. Cerebral hemispheres are developed from the cranial part of the brain vesicle. The subarachnoid space extensions are usually present as sulci, the positions of which remain constant. Development of the human brain shows structural asymmetry manifesting with functional differences between the hemispheres. A phenomenon called Yakovlevian torque causes the left half of the brain to twist backward while the right side twists forward.[12] Sulci is a route to reach the corresponding ventricles or the location of deeper lesions. Louis Pierre Gratiolet (1815-1865) was the first scientist to provide essential insight into the complex structure of brain sulci and gyri. Later Broca's studies contributed significantly to the functional organization of these structures.[8]

The Central sulcus is a limiting sulcus that separates the primary motor cortex from the primary somatosensory cortex. It is the most constant macroscopic structure on the superolateral surface of the brain developed around the 20th week of intrauterine life. It plays a crucial role in anatomical orientation because many other brain structures and landmarks are described in relation to it. Hence, while identifying a functional area, anatomical landmark, or pathological entity, the central sulcus is often used as a reference point to ensure accurate localization.[13] Crossman described that the central sulcus runs downward and forward, cutting the superomedial border of the cerebral hemisphere and ends slightly above the lateral sulcus, measuring about 8-10cm.[14] In the present study, The left side of the central sulcus had a longer mean length than the right. The survey conducted by Sun et al on 18 cadaveric brain specimens concluded that the left and right sides of the central sulcus had average lengths of 9.32 and 8.45 cm, respectively.[15] A study conducted by Singh & Gupta 2015 on 18 cadaveric brains of Uttar Pradesh regions showed the length of the central sulcus on the right side 9.47cm and 9.60cm on the left side, the finding of which is closely correlating with the present study.[16]

In the current study, the distance of the central sulcus from the

frontal pole was 11.46±1.8cm on the right side and 11.3±1.13 cm on the left side. The exact distance was 11.61±0.418cm on the right side and 11.9±1.33 cm on the left side, observed in a study conducted by Nayak S et al 2023 on 31 cadaveric brain specimens. The depth of the sulcus is indirectly proportional to an individual's age. As age advances, the depth decreases by 0.4mm/decade.[5] Handedness and manual skill also determine the sulcal depth. Right-handers have a deeper central sulcus when compared to the left. Pathological conditions like Alzheimer's disease and CADASIL (Cerebral Autosomal Dominant Arteriopathy with Subortical Infarcts and Leucoencephalopathy) are also associated with a decrease in the depth of the central sulcus.[16] Previous radiological studies considered measurement of sulcal depth as one of the important parameters and the reports of the study suggested that sulcal depth correlates with atrophy of cerebral cortex and pial surface.[17]

The lateral sulcus (Sylvian fissure)divides into three rami on the superolateral surface of the brain-anterior horizontal rami separates the pars triangularis and pars orbitalis, and the anterior ascending rami separates the pars triangularis from pars opercularis. Middle cerebral artery and superficial, deep middle cerebral veins lie along the stem and posterior ramus of lateral sulcus.[7] The surgical approach through lateral sulcus is used for neurosurgical treatment of temporal lobe epilepsy and deeper lesions involving the insula and basal ganglia. The lateral sulcus is also exposed in frontotemporal craniotomy surgeries using the pterion as a landmark.[6] The lateral sulcus provides access for surgery on aneurysms of the basilar and middle cerebral arteries.[18] The lateral sulcus is strongly related to Wernicke's and Broca's regions, responsible for speech production and comprehension. These areas may also help describe the range of human capabilities, diseases affecting them, and developmental disabilities in childhood. Studies by Falki et al suggested that Schizophrenic patients have shorter lateral sulcus and such cranial asymmetry is more prounced in females.[19]

Right and left measurements for the anterior ascending and horizontal ramuses were 2.7±0.3 and 3.13±0.3 cm, respectively, and 2.34± 0.37 and 2.55±0.4 cm, respectively, according to a study by Valli S et al. in 2022. On the right side, the lateral sulcus posterior ramus measured 5.6±0.65 cm, while on the left, it was 6.1±0.3 cm12. Results of current closely correlate with the findings of study by Valli S et al. All 70 specimens in the present study showed the presence of all three rami. A survey conducted by Tomaiuolo in 104 specimens noticed the absence of ascending ramus in 1.9% of cases.[20]

The precentral sulcus is divided into three parts, forming a precentral sulcal complex. The intermediate precentral sulcus is the region of the intersection of the middle frontal gyrus and precentral sulcus. The part cranial to intermediate precentral sulcus forms the superior precentral sulcus, and the caudal to intermediate precentral sulcus forms the inferior precentral sulcus. Hence, the precentral sulcus combines cranial, intermediate, and caudal parts. Beginning in the frontal pole, the superior frontal sulcus spreads posteriorly. Focal cortical dysplasia and frontal lobe epilepsy are linked to the superior frontal sulcus. In focal cortical dysplasia, there is an unusual growth of cortical tissue within the substance of the superior frontal sulcus, which is resected using a transsulcal approach.[21] Hence, in-depth anatomical knowledge of the variations of the precentral and superior frontal sulcus is crucial in the analysis of neuroimaging data and in reducing surgical complications.[22]

Vijayalaxmi et al. found that the precentral sulcus measures 9.2 cm on the right side and 9.1 cm on the left, and the superior frontal sulcus length on the right side and left side are 9.7cm and 8.6cm respectively. The length of the inferior frontal sulcus was 8.8 cm on the right side and 8.6cm on the left side. The precentral sulcus in our study measures 8.23±0.74 cm on the right side and 8.24±0.83 cm on the left, and the length of the superior frontal sulcus is 9.18±1.15cm on the right side and 9.45±1.2cm on the left side. The inferior frontal sulcus measures 7.81±0.68 cm on the right side and 7.83±0.76 cm on the left. Eleven specimens (five on the right and six on the left) in the current investigation have a discontinuous inferior frontal sulcus. It shows high variations due to its late appearance during development.[19]

Conclusion

Asymmetry between the cerebral hemispheres was concluded by the fact that the left cerebral hemisphere has more lateral sulcus and its rami, superior, and inferior frontal sulcus than the rght. Further studies needed to correlate the cerebral asymmetry with functional significance. Anatomical knowledge of sulci and gyri on the cerebral hemisphere is vital for radiologists and neurosurgeons to interpret the neuroimaging and to decide and execute appropriate surgical interventions with precisions. Mastery of neuroanatomy is essential for safe and effective surgical interventions. It is a fundamental support for budding neurosurgeons during their initial years of residency, aiding in both surgical practice and planning for future procedures.

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Conflicts of interest

There are no conflicts of interest.

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