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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

Introduction: anatomical understanding of sulci and gyri of human brain is important in neurosurgical procedures despite of various technological advances in the medical field. The morphological and morphometric knowledge of sulci and gyri assist the neurosurgeon 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.

Materials 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. The depth of central sulcus was 3.12 ±0.53cm on the right side and 2.12 ±0.66 cm on the left side.

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.

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.Anterior ascending and anterior horizontal rami of lateral sulcus invade the inferior frontal gyrus. The motor, premotor, frontal eye field, prefrontal area, and speech area are located in the frontal lobe on the superolateral surface and are closely related to these sulci[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

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of the lateral sulcus is of great clinical significance in surgical treatment of temporal lobe epilepsy or insular cortex lesion[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 Superior frontal sulcus is a horizontally located sulcus of the frontal lobe extending between the superior precentral sulcus and frontal pole. It separates the Broadmann area 6,8,9 on the superior frontal gyrus from the middle frontal gyrus. Researchers have concluded that the posterior part of the superior frontal sulcus is actively involved in cognitive attentional selection of eye movements .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].

During the second half of the twentieth century, surgeons were using sulci as an access to intrinsic lesions; hence, sulci was considered as a gateway for neurosurgery. Literature shows numerous studies on the sulci and gyri of the brain using radiological methods, as identifying these structures is easier with MRI. However, due to anatomical variations, it can be difficult to locate during surgical interventions[9]. Anatomical knowledge of brain sulci is crucial for neurosurgeons and radiologists. 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, aim of the present study is an attempt to learn the morphometry of major sulci on superolateral surface of the cerebral hemispheres and to investigate their interhemispheric asymmetry.

Materials and Method

A total of 70 Cerebral hemispheres (35 right and 35 left)fixed in formalin solution for dissection purposes were obtained from the Department of Anatomy MVJ Medical College and Research Hospital, Bangalore, used for the present cross-sectional study. Convenience non probability sampling method was used in sample collection. Only adult embalmed hemispheres were included. Cerebral hemispheres with damage or intracranial lesions and infant and fetal brains were excluded from the study. The arachnoid mater and blood vessels were removed to locate the cerebral sulci precisely. Sulci are identified as per standard textbook explanations.

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 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).

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

The following parameters were measured .

- Length of central sulcus - from superomedial border to termination just above the posterior ramus of lateral sulcus.(Figure N^{O}.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.

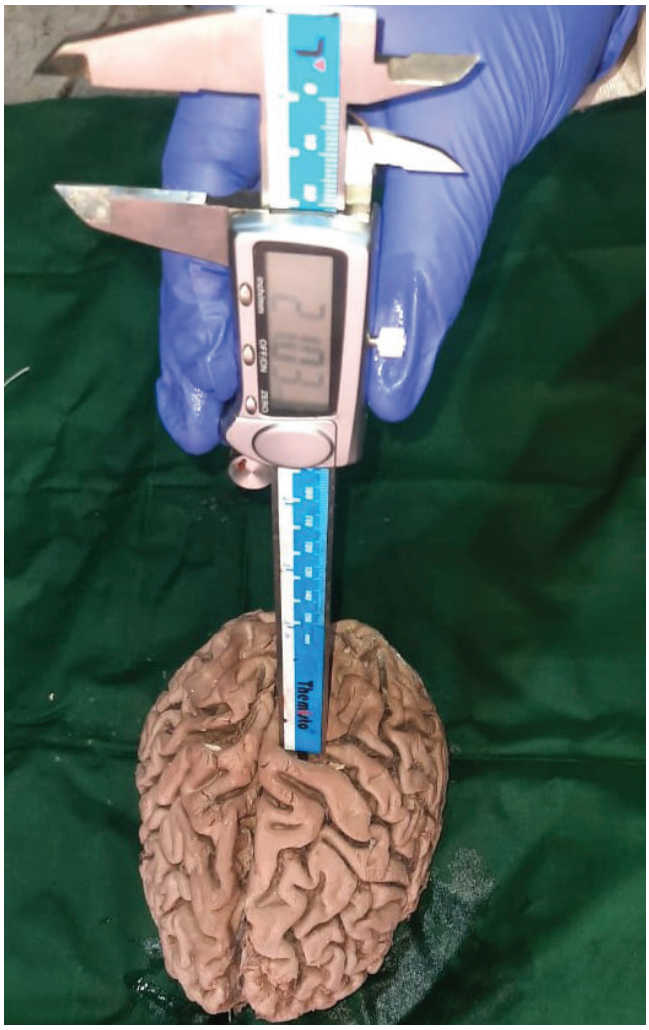

Figure 2B. Specimen showing the measurement of depth of central sulcus.

• 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.

Result

he frontal lobe on the superolateral surface of the brain was demarcated as per Cunningham's manual of Practical anatomy Volume 3[10] and the length of all major sulci on the superolateral surface of brain, namely central sulcus , precentral sulcus, superior frontal, inferior frontal, anterior ascending, anterior horizontal and posterior ramus of lateral sulcus were measured. Distance of central sulcus from frontal lobe as well as depth of central sulcus was measured.

Discussion

During the fetal period, around the 28th-30th week of gestation, the surface of the cerebral cortex shows morphological changes in the form of foldings to allow the brain to accommodate the limited space of the skull[11]. 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. This phenomenon of asymmetry between the hemispheres

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

is called as Yakovlevian torque,where the right side of brain is warped forward, and the left side of the brain is warped backward[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 mean length of the central sulcus was more on the left side when compared to the right. The survey conducted by Sun *et al* on 18 cadaveric brain specimens concluded that the length of the central sulcus averaged 9.32 cm on the left side and 8.45 cm on the right side[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 9.47 cm and 9.60 cm 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±1.8 cm 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 parameter 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] .Surgeries of aneurysms of the middle cerebral artery and basilar artery can be accessed through the lateral sulcus[18]. Broca's and Wernicke's areas are closely associated with the lateral sulcus, 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].

A study by Valli S *et al.* 2022 showed that the mean length of the anterior ascending ramus was 2.7±0.3 cm on the right side and 3.13±0.3 cm on the left side, anterior horizontal ramus was 2.34± 0.37 cm on the right side and 2.55±0.4 cm on the left side. The posterior ramus of the lateral sulcus on the right side measured 5.6±0.65 cm and 6.1±0.3 cm on the left[12]. Results of current closely correlates 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. The superior frontal sulcus first appears in the frontal pole and extends posteriorly. The superior frontal sulcus is associated with frontal lobe epilepsy along with focal cortical dysplasia. 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].

In a study by Vijayalaxmi *et al* the length of the precentral sulcus on the right side is 9.2 cm, and the left side is 9.1 cm, and the superior frontal sulcus length on the right side and left side are 9.7cm and 8.6 cm respectively. The length of the inferior frontal sulcus was 8.8 cm on the right side and 8.6cm on the left

side. In our study, the length of the precentral sulcus on the right side is 8.23±0.74 cm and on the left side 8.24±0.83 cm and the length of the superior frontal sulcus is 9.18±1.15 cm on the right side and 9.45±1.2 cm on the left side. The length of the inferior frontal sulcus on the right side is 7.81±0.68 cm and on the left side is 7.83±0.76 cm[19]. In the present study inferior frontal sulcus was discontinuous in 11 specimens (5 Right and 6 left). It shows high variations due to its late appearance during development[19].

Conclusion

In the current study, the mean length of central sulcus, precentral sulcus, lateral sulcus and its rami ,superior and inferior frontal sulcus was more on the left cerebral hemisphere as compared to right concluding the asymmetry between the cerebral hemispheres. 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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Ethics statement

"The authors state that every effort was made to follow all local and international ethical guidelines and laws that pertain to the use of human cadaveric donors in anatomical research".

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Mini Curriculum and Author's Contribution

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