ORIGINAL ARTICLE ASIAN JOURNAL OF MEDICAL SCIENCES

Morphological development of sulci in fetal brain: An anatomical study

Sarbani Das[1], Kana Bal[2], Swapan Bhattachrjee[3]

[1]Demostrator, [2]Associate Professor, Department of Anatomy, N.R.S Medical College, Kolkata, [3]Professor, Department of Anatomy, Santiniketan Medical College, Bolpur, West Bengal, India

Submission: 09-12-2022 Revision: 05-03-2022 Publication: 01-04-2022

ABSTRACT

Background: The surface of the developing human brain undergoes morphological changes with the formation of different sulci during the fetal period. During the first and second-trimester fetal brain surface remain smooth, and between the 28th and 30th weeks of gestation, new gyri and sulci appear due to rapid growth of the fetal brain. **Aims and Objectives:** To study the time of appearance of sulci in different surfaces of the fetal brain, which will help estimate the gestational age of the fetus from the specimen of the fetal brain. **Materials and Methods:** About 108 cerebral hemispheres from 54 fetal brains were examined in the Department of Anatomy, Medical College, Kolkata, West Bengal, in 1 year from December 2016 to December 2017. Among 54 fetal brains, 21 were museum specimens of the Department of Anatomy and Forensic Medicine of Medical College, Kolkata, and the rest were fetal cadavers. For brains from fetal cadavers, after brain removal, it was fixed in 10% formalin. Fetal brains were divided into two groups – a) brains from fetuses with bodyweight up to 1000 g with a weight gap of 100 g among the groups. b) brains from fetuses with body weight >1001 g with a weight gap of 250 g among the groups. Sulci in the superolateral, medial, and inferior surfaces of the fetal brain were noted carefully. **Results:** Comparing the findings of our study with the previous anatomical studies, it is found that we studied a large number of sulci in detail. When we compared the anatomical findings with the findings of USG or MRI it was found that there was 2–4 weeks delay between anatomical appearance and visualization of the same sulcus in fetal brain by imaging (USG and MRI). The development of cerebral sulci was proportional to the bodyweight of the fetus. **Conclusion:** Embryological appearance of sulci is a crucial important in the Anatomy and radiological study of brain and micro neurosurgery. The study is essential for estimation of the gestational age of the fetus also.

Key words: Anatomy; Fetal brain; Gestational age; Morphology; Sulci

Access this article online

Website: http://nepjol.info/index.php/AJMS

DOI: 10.3126/ajms.v13i4.41468

E-ISSN: 2091-0576

P-ISSN: 2467-9100

INTRODUCTION

The surface of the developing human brain undergoes morphological changes during the fetal period. Foldings of the cerebral cortex allow the human brain to accommodate in the limited space of the skull. Formation of sulci of the human brain is especially the result of an evolutionary infolding process[1,2] that is repeated throughout embryological and fetal development.[3-5] During the first and second trimesters of pregnancy, the surface of the brain is smooth. Between the 28th and 30th weeks of gestation, the brain undergoes rapid growth, which results in the appearance and the development of new gyri and sulci.[3,6] After complete development of different sulcus in the fetal and postnatal period surface of the fetal brain looks like an adult brain. Modern microsurgery has made the sulci and fissures the prominent landmarks of the brain surface and also has made them microsurgical corridors into the depth.[7-9] Histology has been a dominant modality and remains an essential method to study the detailed neural structures of brain development.[10] Studies were conducted to describe gyration of the brain in time in a small group of population with the help of ultrasonographic features[11] and the standard regular ultrasonographic features of cortical sulcal development in human fetuses between 18 and 41 weeks of gestation in

Address for Correspondence:
Dr. Kana Bal, 8/2 T. N. Biswas Road, Sarada Apartment, P. O. Alambazar, Kolkata - 700 035, West Bengal, India.
Mobile: 9674000094/9230627013. **E-mail:** drkana.basu@gmail.com

a large group of Chinese population.[12] Sulci have a well-defined general organization.[1] However, they are usually tricky challenging to identify by different neuroimaging techniques, in fixed anatomical specimens, and during the neurosurgical,procedures, even with neuronavigation systems. The sulci are difficult to identify not only due to their arachnoidal and occasional vascular coverings but also more particularly due to their common interruptions and anatomical variations.[1] For these reasons, neuroradiologists and neurosurgeons required a better understanding of the anatomical features of different sulci of the brain and their time of appearance (gestational age) in the fetal brain. Nishikuni and Ribas conducted a study in 2013 to find reliable morphological criteria sulci for each gestational age and observed the development of cerebral development sulci is gradual and proportional to the increasing bodyweight of the fetus.[13] However, after that, there was a research gap on the morphological features of developing sulci of the fetal brain. A small number of descriptive anatomical studies were conducted on this topic. Still, the study of the embryological appearance of sulci is not only crucial for understanding the Anatomy but also for estimation of gestational age, the radiological examination of brain, and micro neurosurgery.

Aims and objectives

To study the time of appearance of sulci in different surfaces of the fetal brain, which will help estimate the gestational age of the fetus from the specimen of the fetal brain.

MATERIALS AND METHODS

About 108 cerebral hemispheres from 54 fetal brains were examined in the Department of Anatomy, Medical College, Kolkata, West Bengal in 1 year from December 2016 to December 2017. Among all specimens, 21 brain specimens were observed from the collection in the departmental museum of Anatomy and FMT of Medical College, Kolkata, and rest were collected from fetal cadavers. After taking informed consent from the mother for a post-mortem examination of CNS. The study was approved by the Ethical Committee of the Institution with Memo no: MC/KOL/IEC/NON-SPON/113/10-2015. Brains were removed by standard autopsy method, and specimens were fixed in 10% formalin solution for 1 month. For removal of brain median, posterior or transverse posterior parietal incision was given (Royal college pathologist suggested this type of incision, June 2017)[14] which was convenient and practical to remove intact brain and. We considered removal underwater. The immersion technique described by Parthlow et al.,[15] helps to retain the shape and integrity of the fetal brain after removal. By removing the brain while the head and body are totally immersed in water, the brain was easy to remove and had no chance of destroying the delicate brain tissue.

Table 1: Development of sulci in the fetal brain about fetal body weights and estimated gestational age of the collected specimens

Fetal body weight group (grams)	Sulci	Gestational age (weeks)
30–100 g	Callosal sulcus and Hippocampal sulcus were formed in 100% specimens	12–15 weeks
101–200 g	The appearance of lateral and olfactory sulci in 90% specimens and calcarine and parietooccipital sulci in more than 50% of specimens	17 weeks
201–300 g	The presence of cingulate sulcus in more than 80% specimens and lateral sulcus was developed in 100% of specimens	19 weeks
301–400 g	Central sulcus was present in 75% of specimens	21 weeks
401–500 g	Collateral and orbital sulci in 67% specimens and lunate sulcus was present in all specimens	22–26 weeks
501–600 g	The appearance of superior frontal sulcus, central and calcarine sulcus present in 100% specimens, and rhinal sulcus was detected in 50% specimens.	25–27 weeks
601–700 g	Precentral, postcentral and superior temporal sulci were detected, and parietoocipital sulcus present in 100% of specimens	26–29 weeks
701–800 g	Transverse occipital sulcus was visible	30–32 weeks
801–900 g	The intraparietal sulcus appears, precentral and cingulate sulci were fully formed.	32 weeks+
901–1000 g	Inferior frontal and transverse occipital sulci in superolateral surface, a marginal branch of the cingulate sulcus, and paracentral sulcus in medial surface detected.	33 weeks
1001–1250 g	Inferior temporal sulcus was found in 50% of specimens	34 weeks
1251–1500 g	All the central sulci of the brain were present in more than 50% of specimens. Transverse temporal sulcus was detected in 75% of specimens.	35–36 weeks

The above table (Table 1) In 1501–1750 g fetal weight, there is the complete formation of superior, inferior frontal, postcentral, intraparietal, inferior and transverse temporal, collateral, orbital, marginal cingulate sulci in all specimens. Formation of occipitotemporal, paraolfactory, and sub parietal sulci were complete, and all the central sulci were detected in 100% collected specimens in 2001–2250 g fetal body weight. In 2251–2500 g fetal body weight Secondary sulci were present in more than 50% of specimens. In>3250 g, all the primary and secondary sulci were fully formed.

Inclusion criteria

All the fetal brains with no congenital brain anomalies and without any structural damage the damage were included in the study.

Exclusion criteria

Fetal brains with congenital malformations and structural damage were excluded from the study. We excluded one fetal brain with encephalocele and one where brain structure was damaged during removal at the initial phase of the study during our research study. A total of 56 brain specimens were examined, and 54 were included in the study. Arachnoid membranes and superficial vessels were removed from the cerebral hemisphere by dissection to correctly identify brain sulci. Sulci in the superolateral, medial, and inferior surfaces of the fetal brain were noted carefully. When the sulcus is absent, cerebral surface is smooth. In the developing stage, points and grooves of the sulci formation were detected, and when sulci were completely formed, clear and complete depression for the particular sulcus was seen.

For the proper evaluation of the result of the study, fetal brains were divided into two groups according to the bodyweight of the fetus. We divided the collected specimens as per the study of Nishikuni and Ribas (2013).[13]

1) Brains from fetuses with bodyweight up to 1000 g with a weight gap among the groups of 100 g.Thirty-one fetal brain specimens were included in this group.
2) Brains from fetuses with a bodyweight more than 1001 g with a weight gap among the groups of 250 g.Twenty-three fetal brain specimens were included in this group.

Because fetal body weight correlates with gestational age[16] when specimens of the fetal brain show a sulcus is formed, we considered that particular gestational age to be related to the formation of that specific sulcus.

RESULTS

About 54 specimens of fetal brains were collected. During the brain removal, it was found that median longitudinal fissure of the brain was already formed in all brain specimens (was present from 30–100 gm fetal weight group in 12 weeks of gestational age). The appearance of all other sulci was noted for a particular specimen. Fetal body weight was from 30 to 3500 g. In Table 1 all the findings are listed according to the fetal body weight groups.

Chart 1 shows that <100 g fetal body weight brain specimens were 2, 101–200 g body weight specimens were 6, 201–300 g specimens were 5, 301–400 g body weight specimens were 8, 401–500 g bodyweight it were 3.501–600 g bodyweight brain specimens were 2, 601–700 g bodyweight brain specimens was 1, 701–800 g body weight brain specimens were 2, 801–900 g bodyweight brain specimens was 1, 901–1000 g body weight brain specimens was 1. A Total number of brain specimens were 31 up to fetal body weight of 1000 g.

Chart 2 shows that 1001–1250 g fetal body weight brain specimens were 2, 1251–1500 g fetal body weight brain specimens were 4, 1501–1750 g fetal body weight brain specimens were 2, 1751–2000 g fetal body weight brain specimens were 2, 2001–2250 g fetal body weight brain specimens were 2, 2251–2500 g fetal body weight brain specimens was 1, 2501–2750 g fetal body weight brain specimens was 1, 2751–3000 g fetal body weight brain specimenswas1,3001–3250gfetalbodyweightbrainspecimenswas 1, 3251–3500 g fetal body weight brain specimens were 7. A total number of brain specimens were 23 with fetal body weight >1001 g.

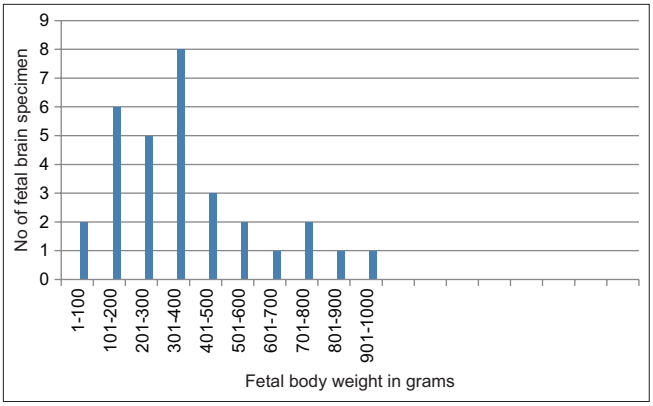

Chart 1: Bar diagram showing the relation between fetal body weight with a number of fetal brain specimens collected (up to 1000 g fetal body weight with a weight gap of 100 g)

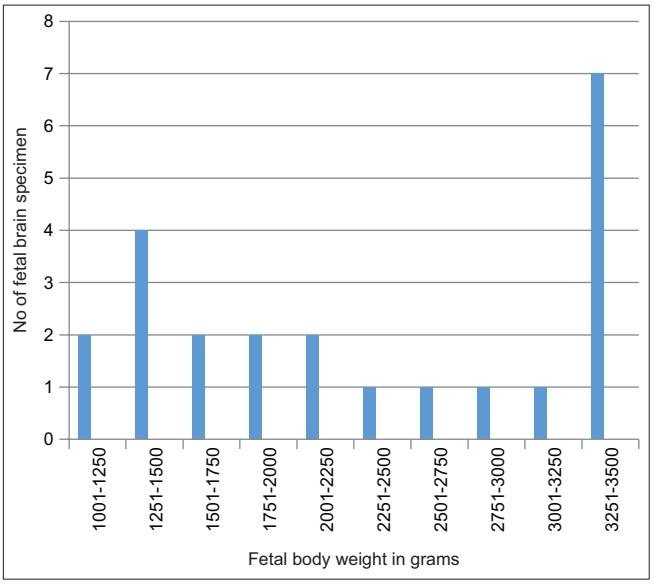

Chart 2: Bar diagram showing the relation between fetal body weight and the number of fetal brain specimens collected. (fetal body weight > 1001 g with a weight gap of 250 g)

DISCUSSION

Human brain sulci developed mainly due to an evolutionary infolding process that caused a progressive increase in the cerebral cortical surface without a proportional increase in brain volume.[17,18] Cerebral cortex sulcation influences the functional organization of the brain.[19,20] Embryological development of the sulci occurs according to the phylogeny, and hierarchy among man. Their formation begins with the appearance of fissure followed by sulci related to eloquent areas of the brain and finally with the secondary and tertiary cortical area sulci.[3,21-23] Several articles reported using ultrasonography and other neuroimaging techniques to describe developmental changes in the fetal brain in premature and normal fetuses.[24,25] Embryological development of brain sulci in fetuses has been only scarcely studied in a few descriptive anatomical studies. Still, it is currently of significant interest and practical to calculate the fetus's gestational age.[6,26]

As described in the previous studies in our study also it was detected that median longitudinal fissure is the first fissure to appear and was observed in the smallest fetus examined. In the superolateral surface of fetal brain, the lateral sulcus (Sylvian fissure) first appears as superficial shallow depression (Figure 1), then gradually it becomes deeper and more prominent (Figure 2). Chen et al., in their study (2017) on ultrasonographic characteristics of cortical sulcus development stated that Sylvian fissure could be visible in all fetuses from 22 weeks onwards.[27] In our study initially, the central sulcus was detected as a point or groove in the parasagittal region (Figure 3). Then gradually, it extends obliquely, inferiorly, and anteriorly until it reaches the lateral sulcus, and then grows superiorly and reaches the median longitudinal fissure. The precentral sulcus develops anterior and parallel to the central sulcus (Figure 2). We observed that there is an interruption in the precentral sulcus as observed in the previous study (Ono et al.).[4] Post central sulcus develops in the same time period. The superior frontal sulcus first appears in the frontal pole and gradually extends posteriorly. The intraparietal sulcus develops almost parallel to the medial longitudinal fissure. Transverse occipital sulcus was present at the posterior end of intraparietal sulcus. The superior temporal sulcus was parallel to the lateral sulcus (Figure 3).

On the inferior cerebral surface, the olfactory sulcus appears initially as a superficial depression on the medial aspect of the orbital surface. After that, it develops parallel to the longitudinal cerebral fissure under the olfactory bulb and tract, limiting the gyrus recti, was our study found that hippocampal sulcus formed at about 15–16 weeks of gestation and rhinal sulcus at about 25 weeks of gestation.

On the medial surface of the fetal brain specimens, we found that callosal sulcus was already formed in the lowest body weight fetus (Figure 4 showing callosal sulcus in the brain specimen of 18 weeks fetus). We have found that callosal sulcus was already formed in the lowest body weight fetus (Figure 4 showing callosal sulcus in the brain specimen of

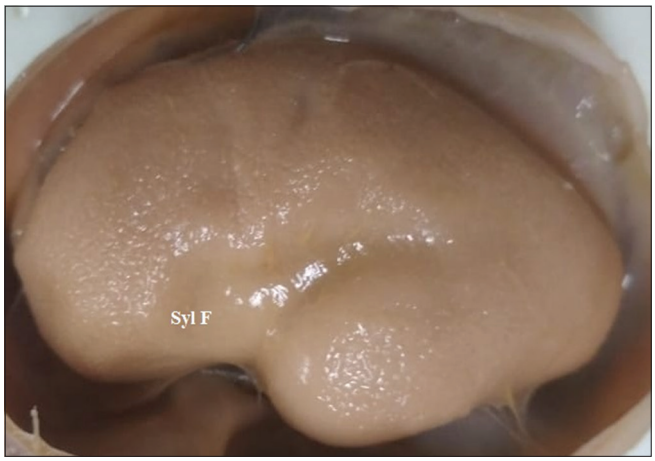

Figure 1: Superolateral surface of cerebral hemisphere of 18 weeks IUL fetus (CR Length: 18.5 cm) showing developing Sylvian Fissure (Syl F)

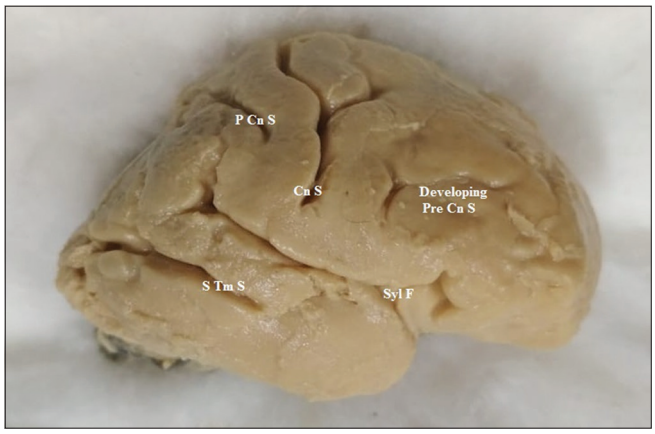

Figure 2: The superolateral surface of Cerebral Hemisphere of 30 weeks (IUL) fetus showing Central Sulcus (Cn S), Post-central Sulcus (P Cn S), Superior temporal Sulcus (S Tm S), Sylvian Fissure (Syl F), and developing Precentral sulcus (Pre Cn S)

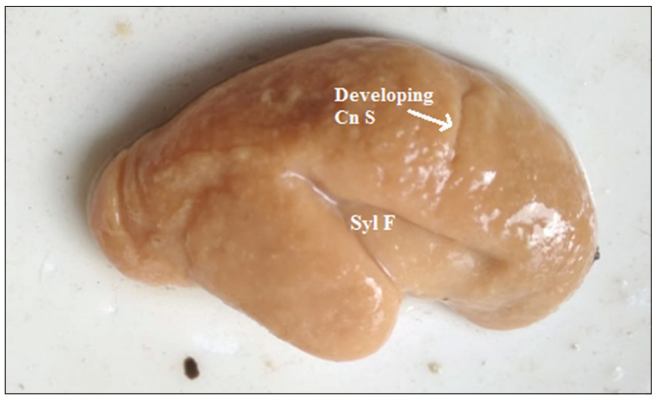

Figure 3: The superolateral surface of Cerebral Hemisphere of 21 weeks IUL fetus (CR Length: 20cm) showing Developing Central Sulcus (Cn S), and Sylvian Fissure (Syl F)

18 weeks fetus), so it was considered the first sulcus appears on the medial surface. The cingulate sulcus develops parallel to the callosal sulcus (Figures 5 and 6). The ascending part of the cingulate sulcus forms the marginal branch of the cingulate sulcus, which delineates the paracentral lobule posteriorly. The cingulate sulcus is delineated anteriorly by the paracentral sulcus (Figure 6), which develops during the same period of the marginal branch of the cingulate sulcus. Parietooccipital sulcus separates precuneus of parietal lobe from cuneus of the occipital lobe (Figure 6). We observed that the calcarine sulcus appears almost simultaneously with the parietooccipital sulcus (Figures 4-6).

Figure 4: Medial surface of developing cerebral hemisphere of a 18 weeks fetus showing growing Parieto-occipital sulcus (POS), Callosal Sulcus (Call S) and Corpus Callosum (CC)

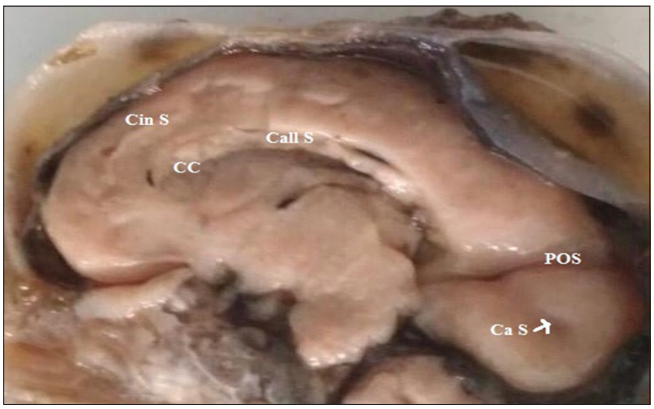

Figure 5: Medial surface of developing cerebral hemisphere of 19 weeks fetus showing growing Calcarine sulcus (Ca S), Parieto-occipital sulcus (POS), Callosal Sulcus (Call S) and Cingulate Sulcus (Cin S)

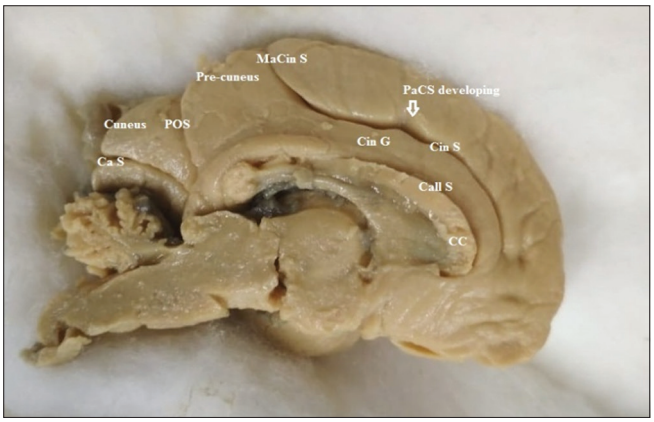

Figure 6: Medial surface of developing cerebral hemisphere of the fetus at 30 weeks of IUL showing Calcarine sulcus (Cal S), Parieto-occipital sulcus (POS), Callosal Sulcus (Call S), Cingulate Sulcus (Cin S), Marginal branch of the Cingulate Sulcus (Marin S) has formed completely and Para central sulcus (PACs) is developing

Comparing the findings of our study with the previous anatomical studies, it is found that we studied a large number of sulci in detail. When we compared the time of appearance of sulci between anatomical and neuroimaging techniques, it was found that 2–4 weeks delay between anatomical findings and visualization of the same sulcus by USG or MRI.

Limitations of the study

In this topic we studied the morphological appearance of the sulci in fetal brain, there were a less number of study on this topic previously. It will be more informative if in future more number of fetal brain can be studied to set the criteria to estimate gestational age from fetal brain sample. The study will be more conclusive if morphological appearance of sulci in fetal brain can be compared with ultra-sonographic appearance in the same study.

CONCLUSION

The study aimed to find the morphological features of cerebral sulci in developing fetal brain and to determine morphological criteria of brain sulci for each gestational age. It was observed that cerebral sulci develop gradually, and development is proportional to the bodyweight of the fetus. At the initial stage of development fetal brain remains smooth. Then, furrows appear which deepens and produce brain sulci. Hence, morphological study of the fetal brain surface using knowledge of anatomy must help us to clarify the features of the development of cerebral sulci—this anatomical knowledge of the development of brain sulci is also helpful in neurosurgery and neuroimaging.

ACKNOWLEDGMENT

We acknowledge the contribution of the mothers who gave their consent for the study, the cadaver handlers of Medical College, Kolkata and museum caretaker of Medical College,Kolkata.

REFERENCES

1. Ribas GC. The cerebral sulci and gyri. Neurosurg Focus. 2010;28(2):E2.

https://doi.org/10.3171/2009.11.FOCUS09245

2. Sarnat HB and Netsky MG. Evolution of the Nervous System. 2nd ed. New York: Oxford University Press; 1981.
3. Chi JG, Dooling EC and Gilles FH. Gyral development of the human brain. Ann Neurol. 1977;1(1):86-93.
   https://doi.org/10.1002/ana.410010109
4. Ono M, Kubik S and Abernathey CD. Atlas of the Cerebral Sulci. New York: Thieme; 1990.
5. Williams PL, Warwick R, editors. Gray's Anatomy. 36th ed. Philadelphia, PA: Saunders; 1980.
6. Dorovini-Zis K and Dolman CL. Gestational development of brain. Arch Pathol Lab Med. 1977;101(4):192-195.
7. Yasargil MG. Microneurosurgery. Vol. 4. Stuttgart: Thieme; 1994.
8. Yasargil MG, Cravens GF and Roth P. Surgical approaches to in-accessible brain tumors. Clin Neurosurg. 1998;34:42-110.
9. Yasargil MG, Kasdaglis K, Jain KK and Weber HP. Anatomical observations of the subarachnoid cisterns of the brain during surgery. J Neurosurg. 1976;44(3):298-302.
   https://doi.org/10.3171/jns.1976.44.3.0298
10. Afif A, Trouillas J and Mertens P. Development of the sensorimotor cortex in the human fetus: A morphological description. Surg Radiol Anat. 2015;37(2):153-160.
    https://doi.org/10.1007/s00276-014-1332-4
11. Alosono I, Borenstein M, Grant G, Narbona I and Azumendi G. Depth of brain fissures by perinatal ultrasound between 19 and 30 weeks of gestation. Ultrasound Obstet Gynecol. 2010;36(6):693-699.
    https://doi.org/10.1002/uog.7660
12. Quarello E,Stirnemann J,Ville Y,Guibaud L.assessment of fetal sylvian fissure operculization between 22 and 32 weeks: A subjective approach.Ultrasound Obstet gynaecol.2008;32:44-9
13. Nishikuni K and Ribas GC. Study of fetal and postnatal morphological development of the brain sulci. J Neurosurg Paediatr. 2013;11(1):1-11.
    https://doi.org/10.3171/2012.9.PEDS12122
14. Osbom M, Cox P, Hargital B and Marton T. Royal College Pathologist. Guidelines on Autopsy Practice: Fetal Autopsy; 2017.
15. Parthlow J, Ross KF, Salzberger L, Lott EG, Guileyardo JM and Barnard JJ. Immersion technique of brain removal in perinatal autopsies. J Forensic Sci. 1998;43(5):1056-1060.
16. Stocker JT and Dehner LP, editors. Pediatric Pathology. 2nd ed., Vol. 2. Philadelphia, PA: Lippincott Williams and Wilkins; 2001.
17. Ribas GC. Considerations about the nervous system phylogenetic evolution, behavior, and the emergence of consciousness. Rev Bras Psiquiatr. 2006;28(4):326-338.
    https://doi.org/10.1590/S1516-44462006000400015
18. Tamraz JC and Comair YG. Atlas of Regional Anatomy of the Brain Using MRI. Berlin: Springer; 20004.
19. Li Y, Sescousse G, Amiez C and Dreher JC. Local morphology predicts functional organization of experienced value signals in the human orbitofrontal cortex. J Neurosci. 2015;35(4):1648-1658.
    https://doi.org/10.1523/JNEUROSCI.3058-14.2015
20. Lopez-Persem A, Verhagen L, Amiez C, Petrides M and Sallet J. The human ventromedial prefrontal cortex: Sulcal morphology and its influence on functional organization. J Neurosci. 2019;39(19):3627-3639.
    https://doi.org/10.1523/JNEUROSCI.2060-18.2019
21. Broca P. Sur, et al. Topographic crânio-cerebral relation between Anatomy and Anthropology.1876;5:193-248.
22. Nishikuni K. Study of the Fetal and Post-natal Morphological Development of the Sulci of the Brain. {Thesis}] São Paulo: Faculdade de Medicina, Universidade de São Paulo; 2006.
23. Pearce JM. Louis Pierre Gratiolet (1815-1865): The cerebral lobes and fissures. Eur Neurol. 2006;56:262-264.
    https://doi.org/10.1159/000096679
24. Naidiach TP, Grant JL, Altman N, Zimmerman RA, Birchansky SB, Braffman B, et al. The developing cerebral surface, preliminary report on the patterns of sulcal and gyral maturation-anatomy, ultrasound, and magnetic resonance imaging. Neuroimaging Clin North Am. 1994;4(2):201-240.
25. Patriquin H, Fontaine S, Michaud J, Lafortune M and Boisvert J. Development of fetal brain in second trimester: An anatomic and ulrasinigraphic demonbstration. Can Assoc Radiol J. 1992;43(2):131-137.
26. Larroche JC. The development of the central nervous system during intrauterine life. In: Falkner F, editor. Human Development. Philadelphia, PA: WB Saunders; 1966. p. 257-276.
27. Chen X, Li SL, Luo GY, Norwitz ER, Ouyang SY, Wen HX, et al. Ultrasonographic characteristics of cortical sulcus development in the human fetus between 18 and 41 weeks of gestation. Chin Med J. 2017;130(8):920-928.
    https://doi.org/10.4103/0366-6999.204114

Author's Contributions:
SD- Concept of the study, specimen collection and observation, review of literature, manuscript preparation; **KB-** Specimen collection and observation, design of the study, review of literature, preparation of the manuscript, interpretation of results; **SB-** Concept of the study, helped in observation of the specimens, review of literature, revision of the manuscript

Work attributed to:
Medical College, Kolkata, West Bengal, India

ORCID ID:
Dr. Sarbani Das - https://orcid.org/0000-0002-3147-0836
Dr. Kana Bal - https://orcid.org/0000-0003-2051-8440
Dr. Swapan Bhattacharjee - https://orcid.org/0000-0002-5770-2877

Source of Funding: None, **Conflicts of Interest:** None.