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Study of development of sulci and gyri in fetal cerebrum

[1]Dr. Chitra Pandian, Assistant professor, Department of Anatomy, Terna Medical College, Nerul, Navi Mumbai

[2]Dr. Anjali Sabnis, Professor and head, Department of Anatomy, MGM Medical College, Navi Mumbai

[3]Dr. Gautam A. Shroff, Professor and head, Department of Anatomy, MGM Medical College, Aurangabad

Corresponding Author: Dr. Anjali Sabnis, Professor and head, Department of Anatomy, MGM Medical College, Navi Mumbai

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Introduction

The development of nervous system in fetus is a continuous, programmed and organized process which begins in third week of gestation. Multiple events of cell proliferation and cell differentiation lead to appearance of cerebral hemisphere in 5th week of development as an evagination in the lateral wall of prosencephalon. Rapid growth in cerebral hemisphere marches ahead to form large number of convolutions or elevations called gyri which are separated by depressions called sulci. Gyrification is a fascinating and poorly understood developmental process that refers to the development of the folding surface patterns on the brain [1]. Appearance of various sulci and gyri on supero-lateral, medial and inferior surface of cerebrum reflects sign of growth and development and it is co-related to the gestational age.During the third trimester of fetal life, when the brain is undergoing considerable growth, the brain develops from a relatively smooth, Lissencephaly structure to a brain that more closely resembles the morphology of the adult brain [1]. With appearance of fetal cerebral sulcus and or gyrus, gestational age can be judged. Prenatal brain development is being studied by modalities like Ultrasonography and MRI.Major fissures are present at 18th week when first ultrasonography is done do study brain development [2]. Very little information is available regarding the sonographic appearance of the fetal cortex in utero [3-6]. Anatomical studies showed appearance of parieto-occipital fissure, calcarine sulcus and cingulate sulcus on medial surface by 16–19 weeks and sulci on superolateral surface by 20–24 weeks [6, 7]. While MRI study showed sulci on medial surface by 18–20 weeks and on superolateral surface by 24-27 weeks [8, 9].The ultrasound literature suggests that the prenatal ultrasound diagnosis of Lissencephaly is not possible until 27–28 weeks [10-12]. The anatomical appearance of sulci and gyri is earlier [2].The study was carried out to note the appearance of different sulci and gyri on superolateral, medial and inferior surface of both surfaces of cerebral hemispheres of fetal brain from 17th to 40th week.

Materials and methods

In the observational study, hundred cerebral hemispheres obtained from 50 fetal brainsto evaluate the appearance of various sulci and gyri on

superolateral, inferior and medial surface of cerebral hemisphere. These brains were obtained from spontaneous abortions ranging from 17th week to 40th week. Fetal brains with congenital anomalies, macerated brains and brains with distorted anatomical structures were excluded from study.The study was authorized by the Ethical Committee for Analysis of Research Projects. The fetuses collected from the hospital were preserved in 10% formalin solution. Then we injected concentrated formalin without adding distal water in the fetal cerebrum using syringe through the scalp and fontanelles. The solution was changed weekly. The brain was removed by using a typical autopsy technique after a week.The scalp was opened by giving median incision from root of the nose to external occipital protuberance and a coronal incision between both mastoid processes. The scalp was reflected in four flaps. Brain was carefully removed from anterior to posterior by cutting the cranial nerves, and spinal cord. Meninges were removed and brain was kept 10% formalin solution for a period of 1 month for fixation. The arachnoid membrane and superficial vessels of the cerebral hemispheres were removed to simplify the identification of the sulci on the superolateral, medial and inferior brain surfaces. Photographs of anatomical dissections were obtained using a digital camera. Complete and clear depressions or invaginations were considered as sulci and elevations separating sulci are considered as gyri. Brains with congenital malformations and or structural damage were excluded.

Result

The longitudinal fissure was observed during removal of all the fetal brain. There was no smoothness on the cerebrum from 17th week onwards.

Depression of central, lateral and circular insular appeared on the superolateral surface callosal, hippocampal, calcarine and parieto-occipital were observed on the medial aspectof both the cerebral hemispheres.

The cuneus was the first gyrus which appeared at 17th week.

The appearance of sulci and gyri according to their age group are as follows in (Table- 1, 2).

Discussion

During the development of brain multiple events of cellular differentiation, organization and proliferation set in to form well organized and well-structured cerebral hemisphere. The thickness of cortex increases to accommodate more number of neurons which reasons to create sulci and gyri. Human brain sulci developed mainly due to an evolutionary in folding process that caused a progressive increase in the cerebral cortical surface without a proportional increase in brain volume [13-16]. In the present study, appearance of various 34 sulci and 35 gyri are studied on each cerebral hemisphere of fetal brain of 17th to 40th week. After going through multiple research articles it was observed that approximately 30 different sulci and 25 different gyri of fetal cerebrum were studied [1, 2, 6, 17].

Phylogenetically, the first hemispheric sulcus to appear was the hippocampal sulcus, which separates the archicortex (dentate gyri of the hippocampus) from its paleocortical surrounding structures [15]. In the present study the first sulci to appear in Superolateral surface was longitudinal cerebral fissure, lateral, central, and circular insula. (Fig. 1A, B). The longitudinal cerebral fissure, lateral and circular insular sulci were observed at 10 - 17th week [1, 6, 17]. In the present study the appearance of sulci in 22nd week was lunate. The

central sulci were observed at 18th - 22nd week and the superior temporal and parahippocampal gyri were observed at 23rd week [1, 6, 17]. In the present study the appearance of sulci in 24th week was superior frontal.The superior temporal, precentral and lunate sulci were observed at 23rd - 24th week [6, 17]. In the present study the appearance of sulci in 25th week was pre-central, post-central and superior temporal (Fig. 1C, D). The superior frontal and postcentral sulci were observed at 25th week [6, 17]. In the present study the appearance of sulci in 27th week was intraparietal and gyrus was precentral, postcentral, superior parietal lobule, inferior parietal lobule. The intraparietal and superior temporal sulci and gyri precentral, middle temporal, postcentral, superior frontal, middle frontal and inferior occipital gyri were observed at 27th week [1, 6, 17]. In the present study the appearance of sulci in 28th week was inferior frontal, inferior temporal and lateral occipital and gyri was superior frontal, middle frontal, inferior frontal, superior temporal, middle temporal, inferior temporal, superior occipital and inferior occipital.The inferior frontals sulci and inferior temporal gyri were observed at 28th week [1, 6. 17]. In the present study the appearance of sulci in 29th week was central insular. The central insular sulci were observed at 29th week [6, 17]. In the present study the appearance of sulci in 31st week was posterior, horizontal, ascending ramus of lateral, transverse occipital and transverse temporal and gyri was pars orbitalis, pars triangular, pars opercularis, short insular, long insular, supra marginal, angular, arcus, transverse temporal (Fig. 2 A,B,C). The transverse occipital, inferior temporal and transverse temporal sulci and angular and supra marginal gyri were observed at 31st week [1, 6, 17]. In the present study Secondary sulci developed by 34th – 40th week (Table- 1). Secondary sulci were observed at 36th- 40thweek [6, 17]. Comparing the timings of the appearance of cerebral sulci between anatomical and neuroimaging studies is shown in (Table- 4).

In the present study the first gyri to appear on medial surface was callosal, calcarine and Parieto-occipital and gyri was cuneus at 17th week (Fig. 1A,B). The callosal, calcarine and parieto-occipital sulci and the cingulate gyri were observed at 17th week [1, 6, 17]. In the present study the appearance of sulci in 22nd week (Table-2). The cingulate sulci were observed at 18th - 19nd week [6, 17]. In the present study the appearance of gyri in 25th week was cingulate. The cuneus and lingual were observed at 25th week [1]. In the present study the appearance of sulci in 27th week was paraolfactory and gyrus was paracentral and medial frontal .The paraolfactory sulci were observed at 29th week [6, 17]. In the present study the appearance of sulci in 29th week was marginal branch of cingulate and paracentral and gyrus was precuneus (Table -3). The marginal branches of cingulate and paracentral sulci were observed at 30th week [17]. In the present study the appearance of sulci in 31st week was suprasplenial and subparietal and gyri was paraterminal (Fig. 2 A,B,C). The subparietal sulci were observed at 31st week [17]. Developments of sulci and gyri according to its gestational age are described in (Table-3).

In the present study the first sulci to appear on the inferior surface was hippocampal at 17th week (Fig. 1A, B). The hippocampal and olfactory sulci were observed at 17th week [6, 17]. In the present study the appearance of sulci in 23rd week was collateral and olfactory and gyri were parahippocampal. The olfactory and collateral sulci and parahippocampal gyri were observed at 22nd - 23rd week [1, 6, 17]. In the present

study the appearance of sulci in 25th week was rhinal and gyrus was uncus (Fig. 1C, D).The rhinal sulci were observed at 25th week. [17]In the present study the appearance of sulci in 28th week was occipitotemporal and orbital (Fig. 2 A,B,C).The occipitotemporal sulci were observed at 30st week and orbital sulci appeared at 22nd week [6, 17]. In the present study appearance of gyri in 31st week was medial occipitotemporal, lateral occipitotemporal, orbital (ant, post, med, & lat) and gyrus rectus (Fig. 3).The orbital gyri were observed at 29th week and occipitotemporal gyri were observed at 31st week [1].

Conclusions

The development of the cerebral sulci and gyri is gradual and proportional to the increasing gestational age of the fetus. By 31 st week of gestational age all the primary sulci and gyri are formed and secondary sulci then develop. There were no Lissencephaly (Abnormal smooth brain with few sulci and gyri.) found in our fetal cerebrum. Number of sulci and gyri are increasing in number and size on superolateral, medial and inferior surface of fetal brain as the gestational age increase

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Legend Table and Figure

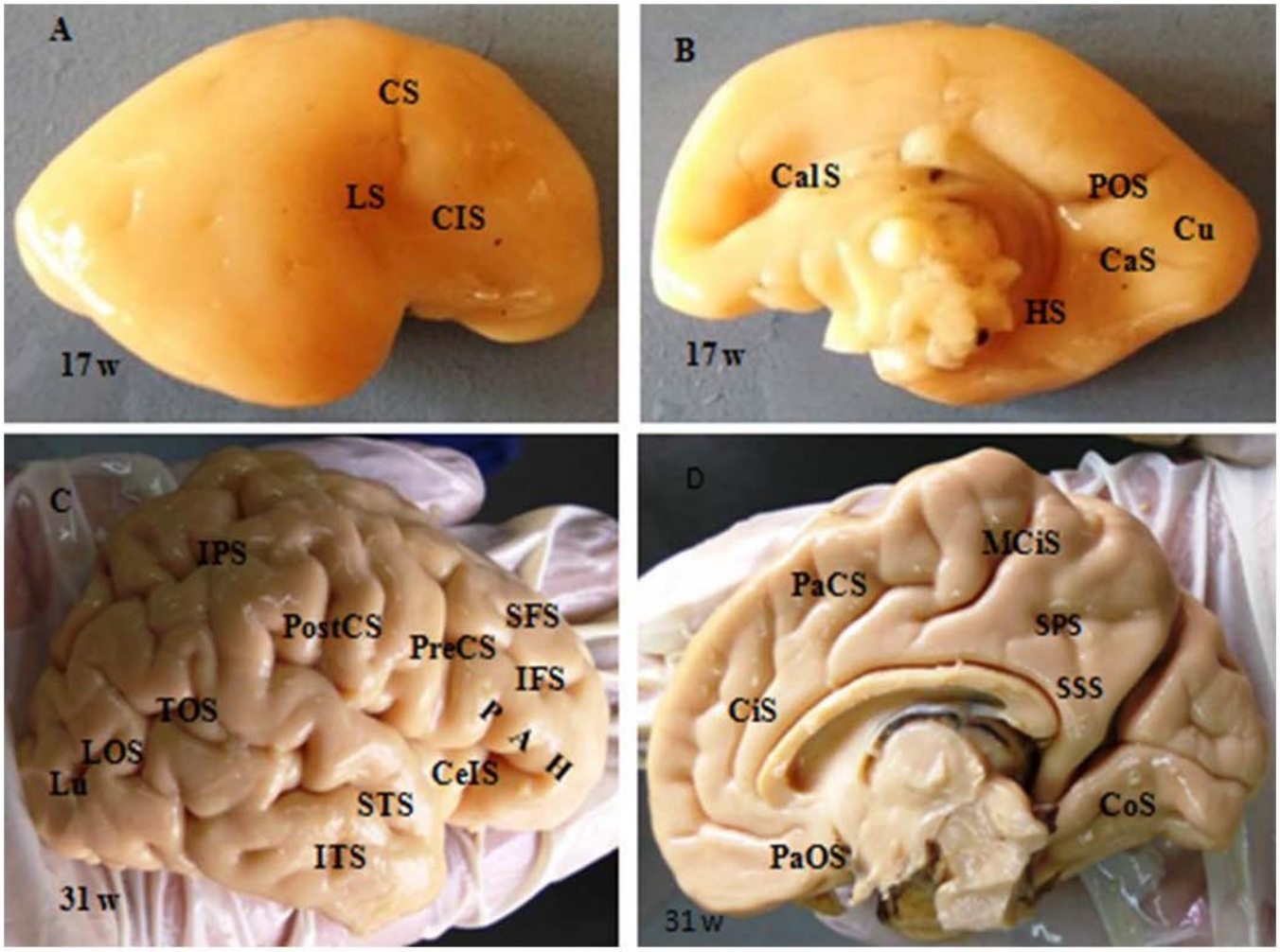

Fig 1: Sulci of fetal cerebrum. A 17th week. CS- central; LS- lateral and CIS- Circular Insular. **B** 17th week CalS- Callosal; Po S- Parieto-occipital; Ca S- Calcarine; Cu- cuneus and HS- hippocampal. **C**; PrCS- Precentral; PoCS- postcentral; IPS- Intraparietal; SFS- Superior frontal; IFS- Inferior frontal; STS- Superior Temporal; ITS- Inferior Temporal; Lu- lunate; LOS- Lateral occipital; TOS- Transverse occipital; CeIS- Central insular; PAH- posterior, ascending, horizontal; **D** CiS- Cingulate; PaCS- paracentral; MCiS- marginal cingulate; SPS- subparietal; SSS- suprasplenium; CoS- collateral and PaOS- Paraolfactory. S- sulcus.

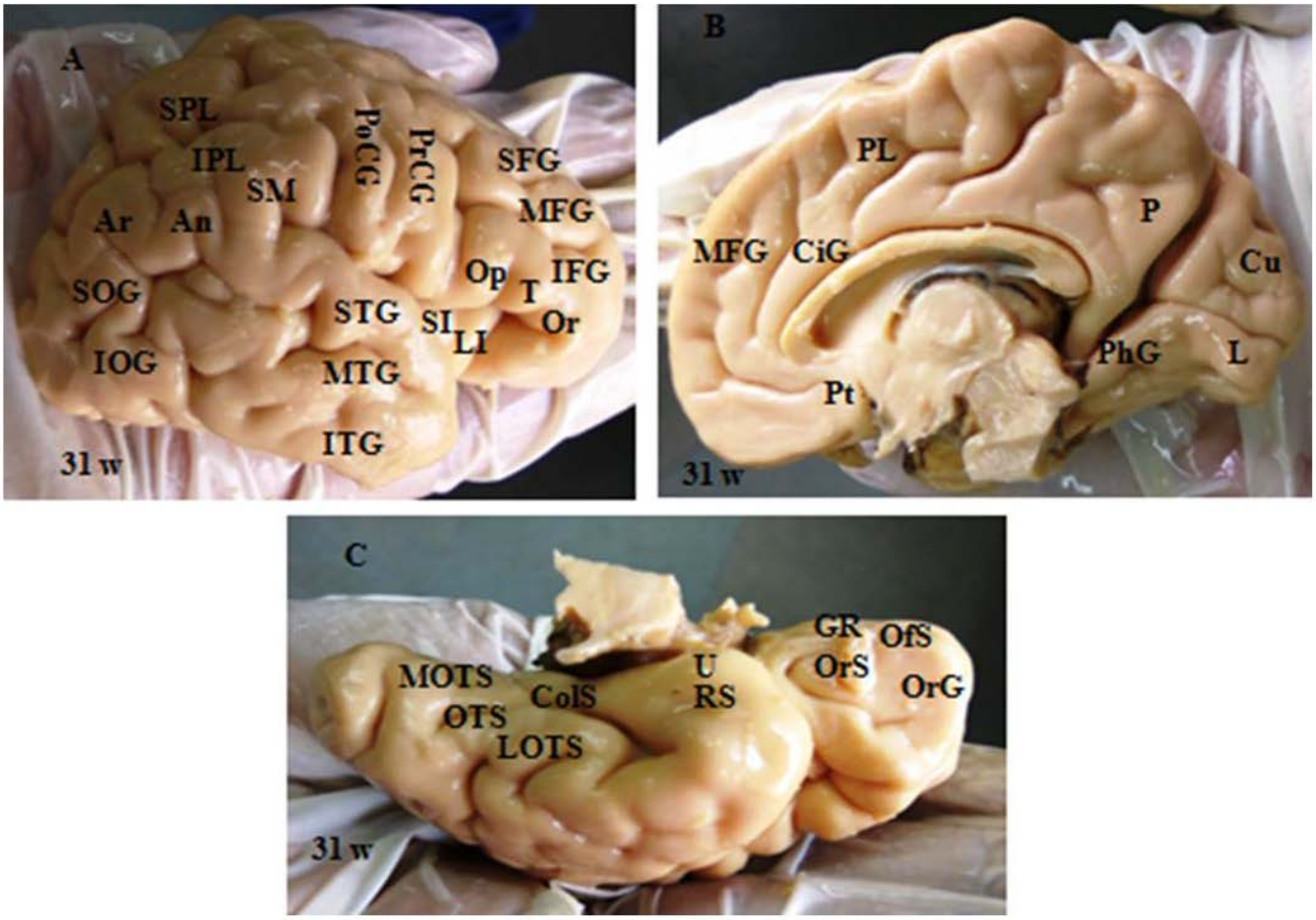

Fig 2: 31st week fetal cerebrum. **A** PrCG- precentral; PoCG- postcentral; SFG- superior frontal; MFG- middle frontal; IFG- inferior frontal; Op- opercularis; T- triangularis; Or-orbitalis; SPL-superior parietal Lobule; IPL- inferior parietal lobule; STG- superior temporal; MTG- middle temporal; ITG- inferior temporal; SOG- superior occipital; IOG- inferior occipital; SM- supramarginal; An- angular; Ar-arcus; SI- short insular; LI- long insular. **B** MFG- medial frontal; CiG- cingulate; PL- paracentral lobule; P- precuneus Cu- cuneus; L- lingual; PhG- parahippocampal and Pt- Paraterminal. **C** GR- gyrus rectus; OfS- olfactory; OrS- orbital; OrG- orbital; U- uncus; RS- rhinal; ColS- collateral; MOTG- medial occipitotemporal; OTS- occipitotemporal LOTG- lateral occipitotemporal. S- sulcus and G- gyrus.

Table 1: Time of appearance of cerebral sulci.

Gestational age of fetus in weeks	Appearance of the sulci
17th	Longitudinal cerebral fissure, callosal, Hippocampal, Lateral, Central, Circular insular, Calcarine, Parieto-occipital
22nd	Lunate, Cingulated
23rd	Collateral, Olfactory
24th	Superior frontal
25th	Pre-central, Post-central, Superior temporal, Rhinal
27th	Intraparietal, Para-olfactory

28th	Inferior frontal, Inferior temporal, Lateral occipital, Occipitotemporal, Orbital.
29th	Marginal B. of cingulate, Paracentral, Central insular
31st	Posterior, horizontal, ascending ramus of lateral, Transverse occipital, Transverse temporal, Supra-splenial, Subparietal
34th– 40th	Secondary sulci

Table 2: Time of appearance of cerebral gyri.

Gestational age of fetus in weeks	Appearance of the gyri
17th	Cuneus
23rd	Parahippocampal
25th	Cingulate, Uncus and Lingual.
27th	Precentral, Postcentral, Superior parietal lobule, Inferior parietal lobule, Paracentral and Medial frontal.
28th	Superior frontal, Middle frontal, Inferior frontal, Superior temporal, Middle temporal, Inferior temporal, Superior occipital and Inferior occipital.
29th	Precuneus
31st	Pars orbitalis, Pars triangular, Pars opercularis, Short insular, Long insular, Supra marginal, Angular, Arcus, Paraterminal, Medial occipitotemporal, Lateral occipitotemporal, Transverse temporal, Orbital (ant, post, med,& lat) andGyrus rectus.

Table 3: Developments of sulci and gyri according to its gestational age.

Age group in weeks	No. of fetus	Depression present	No. of sulci	Sulci developed	Smoothness present	No. of gyri	Gyri developed	Presence of corpus callosum
17-21	30	Yes	8	Longitudinal cerebral fissure, Callosal, Hippocampal, Lateral, Central, Circular insular, Calcarine, Parieto-occipital	No	1	Cuneus	Yes
22-23	4	Yes	3	Lunate, Cingulated	No			Yes
23-24	3	Yes	2	Collateral, Olfactory	No	1	Parahippocampal	Yes
24-25	3	Yes	1	Superior frontal	No			Yes
25-26	2	Yes	4	Pre-central, Post-central, Superior temporal, Rhinal	No	3	Cingulate, Uncus and Lingual	Yes
27-28	1	Yes	2	Intraparietal, Para-olfactory	No	6	Precentral, Postcentral, Superior parietal lobule, Inferior parietal lobule, Paracentral and Medial frontal	Yes

28-29	2	Yes	4	Inferior frontal, Inferior temporal, Lateral occipital, Occipito-temporal, Orbital.	No	8	Superior frontal, Middle frontal, Inferior frontal, Superior temporal, Middle temporal, Inferior temporal, Superior occipital and Inferior occipital	Yes
29-30	1	Yes	3	Marginal B. of cingulate, Paracentral, Central insular	No	1	Precuneus	Yes
31-33	1	Yes	8	Posterior, horizontal, ascending ramus of lateral, Transverse occipital, Transverse temporal, Supra-splenial, Subparietal	No	14	Pars orbitalis, Pars triangular, Pars opercularis, Short insular, Long insular, Supra marginal, Angular, Arcus, Paraterminal, Medial occipitotempor al, Lateral occipitotempor	Yes

							al, Transverse temporal, Orbital (ant, post, med,& lat) andGyrus rectus	
34-40	3	Yes		Secondary sulci	No			Yes

Table 4: comparing the timings of the appearance of cerebral sulci between anatomical and neuroimaging studies

Sulcus	Ultrasonography study	MRI study	Anatomical study	Anatomical study	In present study
	Bernard et al., 1988	Levine & Barnes, 1999	Nishikuni, 2006	Chi et al., 1977	
No of fetus	70	40	107	207	50
Range of gestational age	10-37	14-38		10-44	17-40
Longitudinal cerebral fissure	10	14-15	12	10	17
Superolateral cerebral surface					
Lateral sulcus		16-17	17	14	17
Posterior ramus of lateral sulcus					31
Horizontal ramus of lateral sulcus					31
Ascending ramus of lateral sulcus					31
Circular insular sulcus		18-19	17	18	17
Central insular sulcus		32-33	29 ± 2		29
Central sulcus		26-27	21	20	17
Precentral sulcus		26-27	26 ± 3	24	25
Superior frontal sulcus			25 ± 2	25	24
Inferior frontal sulcus		30-31	30 ± 3	28	28
Postcentral sulcus		28-29	26 ± 3	25	25
Intraparietal sulcus			29 ± 2	26	27
Transverse occipital sulcus			30 ± 3		29
Lateral occipital sulcus					28
Lunate sulcus			24 ± 2		23
Superior temporal sulcus	26-28	28-29	26 ± 3	23	23
Inferior temporal sulcus		30-31	31 ± 3	30	28
Transverse temporal sulcus			33 ± 3	31	31
Inferior cerebral surface					
Olfactory sulcus			17	16	17
Orbital sulcus			22		28
Hippocampal sulcus			15	10	17

Rhinal sulcus			25 ± 2		25
Collateral sulcus	23-25		24 ± 2	23	23
Occipitotemporal sulcus			30 ± 3	30	28
Medial cerebral surface					
Callosal sulcus	19		12	14	17
Cingulate sulcus	22-24	24-25	19	18	22
Marginal branch of cingulate sulcus	30		30 ± 3		29
Paracentral sulcus			30 ± 3		29
Paraolfactory sulcus			29 ± 2		27
Subparietal sulcus			30 ± 3		31
Calcarine sulcus	23	18-19	17	16	17
Parietoccipital sulcus	23	18-19	17	16	17
Suprasplenial					31
Secondary sulci		34-35	38 ± 3	40	34