

Development And Maturation Of Sulci And Gyri Of Cerebral Cortex In Developing Human Foetuses.

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Abstract

Introduction: The surface of the developing fetal brain undergoes significant morphological changes during fetal growth. The most characteristic feature of the forebrain is its presence of gyri and sulci on its surface and it can easily be differentiated from midbrain and hindbrain. Different major functional areas of the forebrain are demarcated by gyri and sulci.

Aims: To study the development and maturation of gyri and sulci of the cerebral in human foetuses.

Objective: To delineate the development of gyri and sulci and maturation of cortical lobules up to term.

Material and Methods: Formalin fixed 85 foetal brains (M- 40, F- 45) were dissected at Deptt. of Anatomy, RIMS, Imphal, after getting formal permission from Institutional Ethics Committee, RIMS, Imphal from the age group of 12 weeks to 40 weeks and. The results are categorized into five groups: Group I (12- <18weeks), Group II (19- <24weeks), Group III (24-<30weeks), Group IV (30- <36 weeks) and Group V (36- 40 weeks).

Results: A few chronology of sulcul and gyri development during 12 weeks to 40 weeks were summarized. Before 12 weeks few sulci were present. Measurement of different growth rates linearly increased with GA but no sexual dimorphism or cerebral asymmetry were detected.

Conclusion: In the youngest specimen of the present study i.e. 12th week of gestation, the external surfaces of cerebral hemispheres were observed smooth i.e. Lissencephalic. Features of the right cerebral hemisphere are seen more developed than left.

Key Words: Sulci, Gyri, Development, Foetus, Brain.

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I. Introduction

Developmentally the cerebral hemispheres are derived from the forebrain vesicle which is the most cranial part of neural tube.[1,2] The surface of each cerebral hemisphere is convoluted into a complex pattern of ridges or gyri which are separated by furrows of varying depths known as fissure or sulci. The cerebral cortex thickness varies from 1.5-4.5mm, thinnest in the sensory area and thickest in the motor and association area.[3, 4]

In the early weeks of gestation, the surfaces of the cerebral hemispheres are lissencephalic. During the 6th and 7th months, the surfaces of the hemispheres grow rapidly and develop convolutions separated by fissures. As a result of such surface folds, two thirds of the cerebral cortex becomes buried in the walls and floor of the sulci. Foetal sulci appear in an orderly sequence: the phylogenetically older sulci appear first, and more recently acquired sulci appear last.[5]

II. Materials & Methods

Cross-sectional Study done in the Department of Anatomy, Regional Institute of Medical Sciences, Imphal, Manipur for 2 years [October 2011 to September 2013]. Aborted normal human foetuses of different gestational were included, Gross congenital anomalies were excluded, 85 in numbers, Gestational ages, sex, crown-rump length and weight of foetuses were observed. Observation of cerebral cortex: weight, height, anteroposterior and transverse diameter, sulci and gyri were observed. Informed consent from the respective parent was taken after fully explaining the purpose of the research work. Fresh 85 foetuses of different

gestational ages which were products of MTP, under MTP act of India 1971, and still births were collected from the Department of Obstetrics & Gynaecology, RIMS, Imphal.

III. Results And Observation

The results are categorized into five groups: Group I (12 - <18weeks), Group II (18- <24weeks), Group III (24-<30weeks), Group IV (30- <36 weeks) and Group V (36- 40 weeks). The results of the present study based on findings of 40 males (47%) and 45 females (53%)

Parameters	Male	Female	t stat	p value(<.05)
GA (weeks)	25.10 ±7.86	24.80 ±7.24	0.1 83	0.855 (>.05)
AP (mm)	63.90 ±21.46	62.91 ± 18.72	0.2 27	0.821 (>.05)
Tr (mm)	57.92 ±17.15	58.13 ±16.18	0.2 27	0.954 (>.05)
CH.Wt (gm)	120.05 ±92.11	112.58± 80.09	0.4 00	0.690 (>.05)
Height (mm)	44.42± 14.54	43.74±1 3.53	0.2 22	0.618(>.05)

Table1. Showing comparison of average/mean GA, Cerebral Hemispheres (CH) Weight, Height, Antero-posterior (AP), Transverse (Tr) dimensions between male and female foetuses

Parameters	AP	Tr	CH.Wt	height
GA(Weeks)	r=0.9 66	r=0.9 29	r=0.9 39	r=0.8 80
	P=0.0 00	p=0.0 00	p=0.0 00	p= 0.00 0

Table 2: Showing Correlation of Antero-posterior diameter (AP), Transverse diameter (Tr), cerebral hemispheres Weight (CH.W), Height with Gestational Age (GA)

There are highly statistically significant differences in all these parameters with increasing GA with AP (r=0.966), Tr (r=0.929), BW (r=0.939) by Pearson correlation bivariate test (p=0.000).

Group I (12 - <18 weeks)

In the earliest specimen of the series (i.e. 12 weeks), the developing cerebral hemisphere is oblong along its anteroposterior extent with smooth superolateral surface with frontal and occipital pole. The anteroposterior dimension is more than its height. The temporal lobe is seen as the downward continuation of the posterior part of hemispheres. (Fig. 1). Two cerebral hemispheres are partially separated by longitudinal cleft. In the frontal and occipital region it is completely separated by longitudinal cleft but in the central region the fissures extend up to the intervening hemispheric commissure.

At 12 weeks foetuses, its weight is 15 gm, antero-posterior (AP) dimension is 25.5 mm, transverse (Tr) diameter is 24.5 mm and height is 21 mm. AP dimension is more than Tr diameters. The dimension of all the antero-posterior, transverse and height are increasing with the increasing gestational ages. The ratio of anteroposterior dimension to height is 1.23:1.

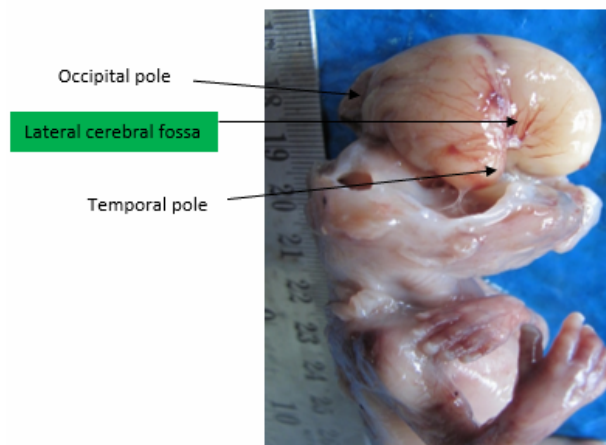


Fig. 1: Photograph of 12 weeks foetus showing brain (superolateral surface) in situ

Superolateral surface:

The cerebral hemispheres at this stage are seen as gently convex on the superolateral surface with a smooth upper border and slightly irregular inferior border. On the superolateral surface, just in front of middle point, towards its inferior part there is a depression, which is more vascular as compared to the rest of superolateral surface. The depressed area is the anlage of insular cortex. At this stage no visible sulci and gyri are seen. On the entire superolateral surface, the vascular strands radiating from the lateral cerebral fossa towards the superolateral surface at various directions. The temporal pole is just identifiable as a protuberance just behind the cerebral fossa. (Fig. 2)

At 13 weeks the visible cleft appears between the temporal and occipital pole. Rest of the sulci and gyri appearance are same except increase in length and depth of the sulci and gyri. On the superolateral surface, temporal lobe is present like a tongue shaped lobe which is seen as a continuation of the posterior part of the cerebral hemispheres downwards and forwards. There is a triangular fossa between the frontal lobe and temporal lobe. This represents the site of future lobe, insular cortex.

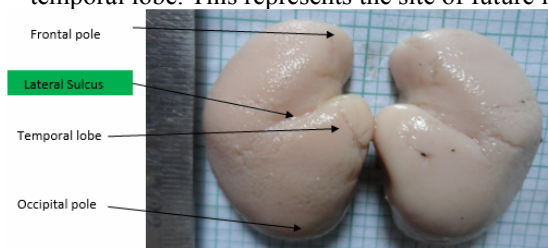


Fig. 2: Photograph of 13 weeks foetus showing Lateral sulcus with elongated frontal and temporal pole

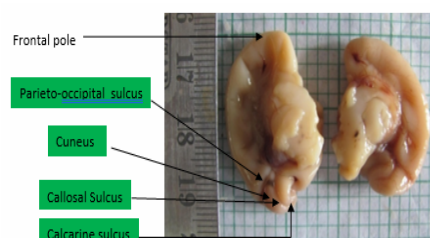


Fig. 3: Photograph of 12 weeks foetus showing medial surface of right and left cerebral hemispheres

Medial surface:

At 12 weeks, it is flattened and its upper half is the continuation of cerebral cortex, its lower part shows development of corpus callosum just above the thalamus. Irregular mild elevation and depressions are apparent just above the corpus callosum. Calcarine sulci (Calc. S) and parieto-occipital sulci (POS) are distinctly discernible at this stage towards its posterior part. Early sign of callosal sulcus just above the corpus callosum is observed. Two sulci appear on the posterior aspect of medial surface. One faint and the other distinct sulci are seen on this surface, deeper part cutting the sulci. Calc. S extends few mm in front of occipital pole. Parieto-occipital sulci and Calc. S are more developed as compared to the left side. Others sulci are not visible as yet. (Fig.3)

At 13 weeks, the medial surface is flattened with irregular elevation and depression. The parieto-occipital sulcus is discernible at this stage separating the most posterior part of the cerebral cortex running obliquely from the posterior end of the corpus callosum upwards and backwards. Another faint groove i.e the calcarine sulcus is also identifiable at right angle to parieto-occipital sulcus. At this stage supracallosal sulcus is also apparent just above the posterior half of the corpus callosum. Dentate gyrus appears deeply buried into the

temporal lobe. Hippocampal sulcus is just observed on the medial surface of the temporal lobe, but anterior two third of medial surface do not exhibit any sulci at 13 weeks of gestation. (Fig.3)

Inferior surface

Least extensive is smooth at this stage and olfactory bulb is just identifiable towards the medial side. Toward its anterior part olfactory sulcus covered by olfactory bulb is just apparent. Medial to the olfactory sulci, gyrus recti are discernible.

Group II(18-<24 Weeks)

At 18 weeks the cerebral hemisphere is more extensive posteriorly, a groove run from anterior to posterior at the junction of upper 2/3 and lower 1/3 lobes are demarcated. The poles are now better defined and developing cerebral hemisphere is seen covered by thin transparent arachnoid membrane along with the developing blood vessels on the superolateral surface. Vascular strands coming from lateral sulcus radiating towards superolateral surface. Downward prolongations of the cerebral hemispheres are observed.

At 19 weeks the developing cerebral hemisphere measures 37.5 gm of weight and Anteroposterior, Transverse and Height diamensions are 45.75 mm, 42 mm and 30 mm respectively. The anteroposterior to height ratio is 1.6:1.

Its superolateral surface is gently convex just a little in front of its centre; there is a faint groove, which is the earliest sign of central sulcus. A slight indentation of CS is seen in front of the midpoint of frontal and occipital poles of each CH. The distance of central sulcus from the frontal pole is 18 mm and the ratio of distance of central sulcus from frontal pole to anteroposterior diameter is 0.45:1. Lateral sulci (LS) and cerebral fossa remains same in appearance but mean lengths of the are sulci slightly increased on both sides. The temporal pole is just identifiable as a tongue shaped process below and in front of cerebral fossa. (Fig-4,5)

Around 23 weeks, the sulci and gyri are more elaborated and better defined than previous age groups. Lobes and poles are well appreciated. The shape of cerebral hemispheres is more or less spherical or ovoid shape

At 23 weeks, with growth and expansion of the surrounding lobes, the lateral cerebral fossa is gradually overlapped by frontal and temporal opercula and changed its shape into triangular cleft. It becomes narrow forming more deep and prominent lateral sulci. Increasing length and depth of CS are seen in front of midpoint between occipital and frontal poles extending from the supero-medial border of the hemispheres and ending just above the lateral sulci. Distance of CS from frontal pole is 31.5 mm and the ratio of anteroposterior and height is 0.47:1. In both CH, Superior frontal sulcus (SFS) in each cerebral hemisphere are observed appearing as a groove running parallel to the longitudinal cerebral fissure, just in front of CS and extend towards the frontal pole. SFS divides the frontal lobe into superior frontal and inferior frontal lobule. Slight indentations of Precentral sulci (PrCS) are also observed appearing near the longitudinal cerebral fissure in both the cerebral hemispheres. Another sulci namely postcentral sulci (PtCS) running parallel to the central sulci and ending just above the lateral sulci, in between the central and precentral sulci forming the precentral gyri (PrCG) and in between CS and Postcentral sulcus, forms the Postcentral gyri (ptCG). In this week, it is observed that postcentral gyrus is sharper and distinct than precentral gyrus. (Fig. 4,5,6)

Medial surface:

At 20 weeks of foetuses, medial surface exhibits a sharp sulcus; supracallosal sulcus is seen as a 'C' shaped structure just above the corpus callosum and found continuing towards the temporal lobe i.e early part of hippocampal sulcus. A faint sulcus is also visible just above the anterior half of developing cingulate gyrus. A deeper sulcus is seen just in front of posterior pole separating most develop part of cerebral hemispheres, early sign of POS which is more deeper than rest of the sulci above the anterior half developing cingulate gyrus.

At 23 weeks, position of hippocampus within the temporal lobe remained unchanged, dentate gyri are clearly visible. The surface shows increase in length and depth of Calc. S and POS which is more clearly visible. The Calc. S emerges behind the splenium of the corpus callosum arching towards the occipital pole. Shallow Cing. S are observed more developed emerges behind the frontal pole which is not continuous on the left side, one of the branch of Cing. S, marginal branches of these sulci turned off at right angle toward the dorsal margin of the hemispheres, ends near the superomedial border of the hemispheres. It is observed more developed on right than left side. It is more extensive reaching the posterior part of corpus callosum. Cingulate gyri are better pronounced just dorsal to the corpus callosum. Callosal sulcus is formed rostrally near the corpus callosum which is continuous with the hippocampal fissure. (Fig. 4,5)

Inferior surface:

In this group, the olfactory bulb along with tract appears more developed and prominent than previous groups. Lateral olfactory tract extends towards the lateral cerebral fossa forming the lateral olfactory stria.

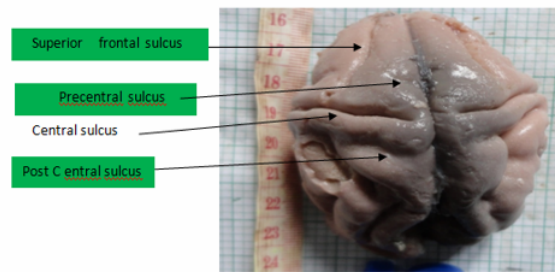


Fig.4: Photograph of 23 weeks foetus showing superolateral surface

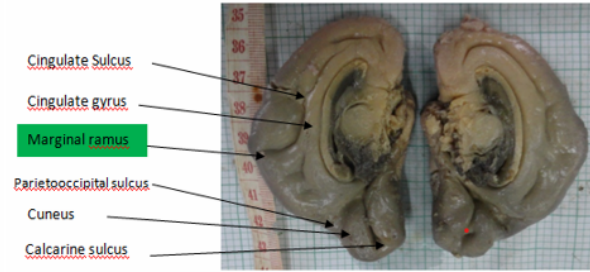


Fig.5: Photograph of 23 weeks foetus showing medial surface

Group III (24 - <30 weeks)

There is increased in size of the each hemisphere with overall gain in convexity and its cortical thickness, less glistening. The frontal pole is still smooth and blunt whilst the occipital pole more pointed (Fig.29). In the cerebral hemispheres, some convoluted gyri are identified on the superolateral surface such as precentral and postcentral gyri, demarcated from the frontal lobe and parietal lobes by precentral and postcentral sulci respectively. (Fig. 7)

The developing cerebral hemisphere of 25 weeks measures 103.75 gm of weight and anteroposterior, transverse and height dimensions are 64.5 mm, 61.75 mm, 47 mm respectively. The anteroposterior to height ratio is 1.32:1.

Superolateral surface:

The surface are of this surface is more extensive than previous age group due to overall growth of the different lobes. In both hemispheres, the Superior temporal sulci (STS) are observed appearing at 25 weeks of gestation (Fig. 29). It is observed as running parallel to the lateral sulcus, curving towards the superolateral surface dividing the temporal lobe into superior temporal gyri (STG) and inferior temporal gyri (ITG). Uprturned end of superior temporal sulcus forms the angular gyrus. Posterior ramus of LS are more or less straight running parallel to the longitudinal fissure ending at right angle to STS, short ascending ramus of lateral sulcus in front of PrCS runs above the frontal lobe. Uprturned end of lateral sulcus in parietal lobe, supramarginal gyrus is seen from 25 weeks onward. Increasing depth of central sulcus is observed on both CH extending near the superomedial border of the hemispheres and ends around one finger breadth above the lateral sulci. Distance of central sulcus from frontal pole is 30 mm. The ratio between the distance of central sulcus from the frontal pole and anteroposterior dimension is 0.47:1. PrCS and PtCS are also observed running parallel to the CS. That PtCS is deeper than PrCS ending before the CS ends. Anlage of lunate sulcus is seen just in front of occipital pole as a deep 'C' shaped curved Most part of insula is covered by temporal and parietal opercula; exposed insula appears as a quadrangular in shape on both hemispheres.

At 27 weeks more developed lateral fissure observes in this group. All the sulci and gyri remains same except increase in length and width, and the intraparietal sulci are observed, as a shallow groove just posterior to the postcentral sulcus anterior to occipital pole, dividing the parietal lobe into superior and inferior parietal lobule. Irregular depression and folding are visible in that lobule. A finger breadth in front of CS, SFS demarcating the lobule from rest of the frontal lobe. Another small depression are seen in front of CS, but SFS is most obvious and deeper. Now PrCG are well developed and clearly distinguished. The uncovered exposed Insula is reduced as compared to previous groups. (Fig. 6, 7)

At 28 weeks, well defined central sulcus is observed. Lateral sulcus is extending towards the anteroinferior part of parietal lobe. The ascending ramus of the lateral sulcus is shallow but it is found that lateral sulcus is deeper anteriorly. Early parts of Broca's area are now formed. In inferior frontal lobule another sulci appears at right angle to the CS, Inferior Frontal Sulci (IFS) are observed. In Insula, 3 opercula are seen approaching each other, but the distance between the frontal and temporal pole are slightly more as compared to the previous weeks. Linear sulci appear on the surface.

Temporal lobe: Tongue shaped temporal pole covers the posterosuperior part of insula; STS are seen as a 'Y' shaped sulci on left side where two limbs are present posteriorly and stem anteriorly. On the right side, STS directing downwards is gently curved and parallel to the posterior limb of lateral sulcus. Inferior Temporal Sulci (ITS) are observed in this week. The shallow ITS begin just behind the temporal pole, running parallel to the STS and ends on the superolateral surface of the right hemispheres. ITS on the left is shorter and ends on the temporal lobe. STS and ITS now divide the temporal lobe into superior, middle and inferior temporal gyri. Superior and inferior temporal gyri (STG and ITG) are in continuity.

Medial surface:

Deeper parieto-occipital and calcarine sulcus is seen at 27 weeks of gestation. Marginal ramus of cingulate sulcus is seen on the medial surfaces of both cerebral hemispheres.

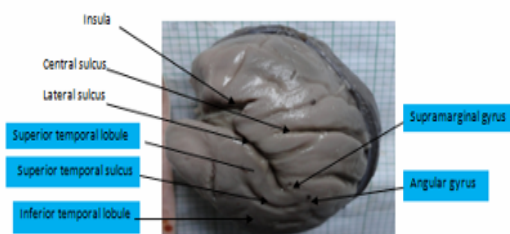


Fig. 6: Photograph of 25 weeks foetus showing lunate sulcus in occipital lobe

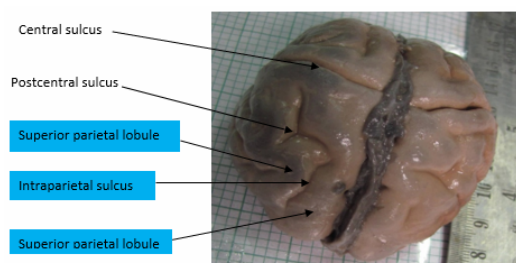


Fig. 7: Photograph of 27 weeks foetus showing superolateral surface

Inferior surface:

On the orbital surface of frontal lobe, an incomplete linear olfactory sulci are clearly visible. Small strip of gyrus recti are seen on both hemispheres. A shallow well defined but irregular collateral sulci are observed appearing on the tentorial surface of CH at 27 weeks of gestation, it emerges behind the temporal pole running longitudinally and ends just in front of the occipital pole. It divides the inferior surface into medial and lateral folding area. The medial folding area corresponds to parahippocampal gyrus.

Group IV (30- <36 weeks)

At 32 weeks, foetal specimen shows more convoluted gyri. Lobes are divided into lobules. (Fig. 8)
 Mean weight of the cerebral hemisphere is 200 gms, Antero-posterior, transverse and height are 84 mm, 80 mm, 57.33 mm respectively. The ratio of anteroposterior to height is 1.48:1.
 In the occipital lobe, small indentation of Transverse occipital sulci are seen extending from the superomedial border around the parietooccipital sulcus to the superolateral surface.
 The developing cerebral hemispheres at 33 weeks is significantly bigger in size than previous weeks. The cerebral hemisphere at this stage gains in weight as well as in dimension from side to side and from above downwards.

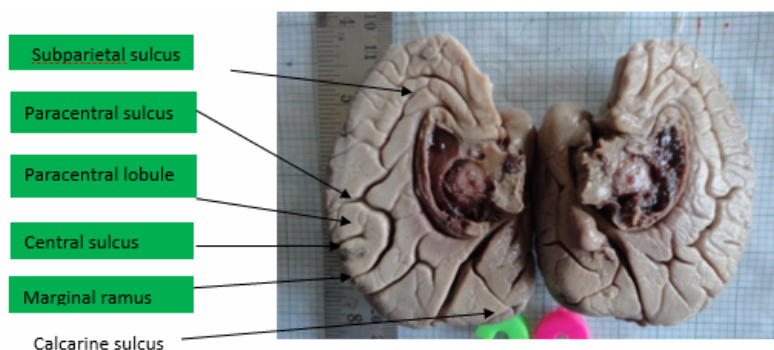


Fig. 8: Photograph of 32 weeks foetus showing medial surface of both CH

Superolateral surface:

At 33 weeks, the Central sulcus begins from the medial surface and extend downwards and forwards behind the midpoint of frontal and occipital poles and ends just above the lateral sulcus. Distance of central sulcus from the frontal pole is 51 mm and the ratio of central sulcus distance to anteroposterior dimension is 0.59:1. Lateral sulcus begins on the basal surface of the brain as a deep cleft lateral to the anterior perforated substance, like in adult, upturned end of this sulcus forms the supramarginal gyrus. Preoccipital notch are well identified. Irregular deep continuous superior temporal sulcus is extending parallel to the lateral sulcus forming the better differentiated angular gyrus than earlier preceding age group. Occipital lobe Lateral occipital sulci are seen in front of the occipital pole dividing the occipital lobe into superior and inferior lobe. It is observed more developed on the right side as compared to left. Around the parieto-occipital sulcus, arcus parieto-occipitalis is observed.

Insula: Almost all parts of insula is covered by opercula leaving small uncovered area behind with reduction in distance between frontal and temporal pole.

Medial surface:

At 32 weeks, central sulcus is seen on the medial surface of the hemisphere. Cingulate sulcus terminates by dividing into marginal ramus and subparietal sulcus. Another branch near the splenium of corpus callosum, subparietal sulcus. In between, paracentral and subparietal sulcus, paracentral lobule is seen.

Numerous gyri and sulci are seen on the medial surface. It is covered by thin transparent arachnoid mater along with blood vessels. Cingulate sulcus follows a curved course parallel to the upper convex margin, the corpus callosum. Most of the sulci mainly the cingulate sulci, start branching and form the secondary type of sulci namely marginal and paracentral sulci. In between the formed sulci the paracentral lobules are identified. Well defined and more extensive, corpus callosum are seen The calcarine sulcus extends forwards beyond its junction and ends a little below the splenium of corpus callosum. The small area separating the splenium from calcarine sulcus, isthmus is clearly seen. Just in front of lamina terminalis, paraterminal gyrus is observed (Fig-8)

Inferior surface:

Better developed olfactory sulci are seen at 32 weeks extending towards the frontal pole. Occipitotemporal sulci (OTS) are observed on the midpoint of the tentorial surface of inferior surface, running parallel to the collateral sulci which are deeper and increase in length than previous group. OTS divides the surface into medial and lateral occipitotemporal gyri (OTG), it is continuous with the inferior temporal gyri. Parahippocampal gyri are observed more convoluted and uniform in shape. Numerous unnamed sulci are also observed.

Closed to the medial border of the orbital surface, olfactory sulci is observed in an anteroposterior direction. Collateral sulci are seen more or less continuous, deeper than occipito-temporal sulci running longitudinally in an anteroposterior direction extending behind the temporal pole and ends in front of occipital pole. Posterior end of collateral sulci are parallel to the calcarine sulcus. In between the calcarine and cingulate sulcus, lingual gyrus is observed which is continuous with the parahippocampal gyrus. The anterior end of the parahippocampal gyrus is cut off from the curved temporal pole of the hemispheres by rhinal sulcus. This part of parahippocampal gyrus forms a hook like structure which is called uncus is observed. Posteriorly the parahippocampal gyrus is continuous with the lingual gyrus by isthmus. Medial and lateral part of occipitotemporal gyrus are seen which is continuous with the inferior temporal gyrus.

'H' shaped sulci along with orbital gyri are observed on the orbital surface of frontal lobe which are more developed on the right than the left. 'V' shaped sulcus is seen in front of anterior orbital gyrus on the inferior surface of left hemisphere. (Fig-9)

Group V (36- 40 Weeks)

The cerebral hemisphere, cortex is more or less assumed the miniature adult brain, although smaller in size. The surface convoluted gyri and sulci are more pronounced and distinct than earlier age group.

The developing cerebral hemispheres is significantly bigger in size than previous weeks and weigh 260 gms, Antero-posterodiamension and transverse diamension, height are 100 mm, 79 mm, 69 mm respectively. The ratio of anteroposterior by height is 1.45:1.

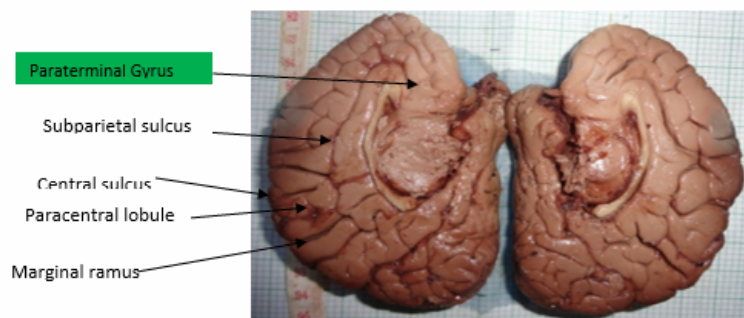


Fig. 9: Photograph of 40 weeks foetus showing inferior surface of both CH

Superolateral surface:

More lobules are identifiable at this stage and more branching sulci are seen on the convex superolateral surfaces. Central sulcus is relatively displaced behind the midpoint of frontal and occipital pole. Distance of central sulcus from the frontal pole is 73 mm and the ratio is 0.73:1. Lateral sulcus appears almost like adult i.e insular cortex is now closed by the developing lower border of frontal cortex and upper border of temporal lobe. Sulcus centralis, some faint sulci and convoluted gyri are observed on the surface of insula. Uprturned end of posterior ramus of lateral sulcus is seen forming the more convoluted supramarginal gyrus. Anterior horizontal and ascending rami of lateral sulci are clearly seen extending on the inferior frontal lobule.

Medial surface:

Cingulate sulcus on the posterior aspect turns upwards to reach the superolateral surface of the hemispheres a little behind the central sulcus, which is seen as continuous branching and tortuous. Medial frontal gyrus and paracentral lobules are more organized and distinct. In medial frontal gyrus another sulci running parallel to cingulate sulcus are also observed. In front of lamina terminalis, paraterminal and parolfactory gyri are

observed which is separated by anterior and posterior parolfactory sulci. Calcarine sulcus begins as a deep fissure, a little below the splenium of corpus callosum with a convexity upwards to the pole extend up to the superolateral surface. Deeper parieto-occipital sulcus is also seen at the midpoint of calcarine sulcus extends up to the superolateral surface. More convoluted cuneus is observed.

Inferior surface:

Close to the medial border the olfactory sulci are seen extending towards the frontal pole. Near the medial border gyrus rectus are seen. H-shaped sulci with more convoluted orbital gyri are seen more distinctly. More convolution of Parahippocampal gyri are seen medial to the collateral sulci. Lateral occipitotemporal gyri are observed more convoluted than medial occipitotemporal gyri.

IV. Discussion

Embryologically, the sulci developed according to a sequence that reflected their phylogeny and a hierarchy that existed among them. Their formation began with the appearance of the fissures, followed by sulci at eloquent areas of the brain, and finally the secondary and tertiary sulci in cortical area.[1]

Morphology

According to Chi JG et al [6], there was no difference between male and female brain sulcation. In our study, we found that statistically there is no significant sex difference in sulcation of developing brain. Hence, we are in agreement with that reported by the above mentioned authors.

Zhang Z et al [7] stated that measurement of fetal brains with different growth rate increased linearly with GA. Fetal brain sexual dimorphisms and asymmetries might arise and develop during the 3rd trimester.

In the present work, we noticed a gradual change in the size of the brain. There are linear increases of cerebral hemispheres weight, height, anteroposterior, and transverse diameter as age advanced.

Hill J et al [8] reported that several sulci appeared earlier on the right than left and According to Chi JG [6] stated that the right cerebral hemisphere shows gyral complexity earlier than the left. Squir L et al [8] stated that during the first year, growth is more advanced on the right side, but by 6-8 years of age, the maturation of distal dendrites on the left exceeds that of right.

In our study, we observed that almost all sulci and gyri are developed earlier on right side, as well as an increase in length and depth on the right side than left side.

Longitudinal cerebral fissure:

It is the first fissure to appear and is observed at 12 weeks of gestation; which is similar with the findings of Chi JG et al [6] and Nishukini K et al [9]. However, according to Garel C et al [10], longitudinal cerebral fissure appears at 22 weeks GA.

Callosal Sulcus:

The callosal sulcus separates the corpus callosum from the cingulate gyrus above. The callosal sulcus developed from anterior to posterior direction, concomitantly with the development of the callosal body. According to Chi JG et al [6] and Monteagudo A et al [11] on ultrasound studies found at 14 weeks of gestation. Bernard C et al [12] on ultrasound studies found at 21 weeks, Garel C et al [10] on MRI at 22-23 weeks of gestation.

The present study shows the appearance of the callosal sulcus on the medial surface of the brain at 12 weeks of gestation.

Hence, in this study callosal sulcus appeared earlier than the above studies.

Parieto-occipital sulcus:

According to Chi JG et al [6] and Dorovini- Zis K et al [13], parieto-occipital sulcus developed around 16 and 22 weeks of gestation. Zhang Z et al [14], Garel C et al [10], Ruoss K et al [15] on MRI studies found at 18-19 weeks, 20 weeks, 22-23 weeks, 26 weeks, 30-33 weeks respectively. On ultrasound studies, Monteagudo A et al [11], Bernard C et al [12] observed at 18 weeks, 18.5-20.5 weeks and 25 weeks respectively.

However in the present study, it is observed at 12 weeks of gestation in majority of cases but in some foetuses parieto-occipital sulcus is not yet seen until 15 weeks.

Hence, our observation on the parieto-occipital sulcus is earlier than reported by the above mentioned authors.

Calcarine sulcus

The calcarine sulcus appears concomitantly with the parieto-occipital sulcus. Chi JG et al [6], Dorovini- Zis K et al [13] found at 16 and 22 weeks of gestation. But Ruoss K et al [15], Garel C et al [10] on MRI studies found at 29-38 weeks, 24-25 weeks, 22-23 weeks, 18-19 weeks of gestation respectively. On

ultrasound studies Bernard C et al [12], Monteagudo A et al [11], Toi A [16] observed at 25 weeks, 18 weeks, 18.5-21.9 weeks of gestation respectively.

In the present study, the calcarine sulcus is apparent as early as at 12 weeks of gestation.

Therefore, our observation on the calcarine sulcus is earlier than reported by the previous authors.

Cuneus

Crossman AR [1], Fitzgearald MJT et al [4] described that triangular lobule cuneus is formed on each hemisphere below by the calcarine sulcus, in front by the parieto-occipital sulcus and above by the superomedial margin.

In the present study, we found triangular or wedge shaped cuneus is seen on each hemisphere from 12 weeks of gestation.

Olfactory sulcus

According to Chi JG et al [6] the olfactory sulcus was developed in each brain that contains the olfactory bulb and tract and was absent when the olfactory bulb and tract did not develop, which denoted an interesting developmental interrelationship between those structures and that sulcal space. Nishukini K et al, [9] Zhang Z et al [7], Garel C et al [10] reported at 17 weeks, 20 weeks and 25 weeks of gestation respectively. But the olfactory sulci become well defined by 25 weeks of gestation as stated by Naidich TP et al [17].

The olfactory sulcus appears initially as a superficial depression on the medial aspect of the cerebral orbital surface. It develops parallel to the longitudinal cerebral fissure, underneath the olfactory bulb and tract, extends delimiting the rectal gyrus laterally.

In the present study, olfactory bulb is first discernible at 12 weeks of gestation making the shallow olfactory sulcus. Olfactory bulbs with olfactory tract are clearly seen from 19 weeks onward. Medial to the olfactory sulci, gyrus recti are clearly discernible from 19th weeks onwards.

Hippocampal fissure:

Chi JG et al [6] observed that the hippocampal sulcus gradually narrowed while the medial portion of the temporal lobe developed and Nishukini K et al [9] stated that the hippocampal sulcus was formed in foetuses at approximately 15th week of gestation. But Garel C et al [10] found, on MRI studies, at 22-23 weeks gestational period.

In the present study, hippocampal sulcus is observed at 13 weeks of gestation.

Hence, our study observed earlier than above mentioned authors.

Lateral sulcus

According to Nishukini K et al [9] it was observed at 17 weeks of gestation. Zhang Z et al [7] stated that lateral sulcus was the 1st to be distinguished and the most obvious of all of the sulci, during 12-22 weeks GA. LS became deeper and wider with the opercula insulae approaching each other. Opercula insula did not fold till 22 weeks.

In our study, the lateral sulcus (Sylvain fissure) is the first to appear at 13 weeks of gestation on the superolateral surface. The lateral sulcus is seen at first as a superficial depression in the lateral surface of the hemispheres that gradually became deeper, at the same time as the frontal, parietal and temporal opercula also rapidly grows to conceal it. Before becoming linear lateral sulcus above the temporal lobe, it represented as cerebral fossa which changed into triangular cleft with the base of triangular area forward and apex behind. Ascending ramus and horizontal ramus of lateral sulcus is seen at 28 weeks of gestation forming the Broca's area.

Central sulcus

Nishukini K et al, [9] Chi JG et al [6] observed at 21 weeks, 20 weeks, and 24 weeks of gestation respectively. On MRI studies Ruoss K et al [15], Garel C et al [10] found at 20 weeks, 24-26 weeks, 24.5-32 weeks, 27 weeks and 26-27 weeks of gestation respectively.

The present study observed the central sulcus at 19 weeks of gestation extending obliquely, inferiorly and anteriorly. At first it is seen in front of midpoint between frontal and occipital pole. But from the 30th weeks of gestation onwards it is observed behind the midpoint of frontal and occipital lobe.

Hence, the study observed the central sulcus earlier than the above mentioned authors.

Cingulate sulcus and cingulate gyrus:

Crossman AR [1] also stated that during the 5th month of IUL, the cingulate sulcus appears on the medial aspect of the hemispheres. Nishukini K et al, [9] Dorovini –Zis K et al [13] observed the first appearance of cingulate sulcus at 18 weeks, 19 weeks, and 24 weeks of gestation respectively. On MRI studies, Garel C et al, [10] found the cingulate sulcus at 24- 25 weeks whereas Ruoss K et al [15] observed at 28-33 weeks

respectively. Ultrasound studies by Toi A et al, [16] observed the cingulate sulcus at 18 weeks, 23.2-24.3 weeks, and 26 weeks.

By ultrasound studies, Monteagudo A et al [11] stated that in the median plane and on the medial surface of the hemisphere, the cingulate sulcus first appeared as a small indentation. Later it became a better defined linear echo paralleling the corpus callosum at 27-34 weeks and lastly, it developed several secondary branches at 30-40 weeks. The cingulate gyrus was identified between the corpus callosum and cingulate sulcus.

In our study, it is observed at 20 weeks of gestation, later it starts giving branches from the age of 23 weeks of gestation. In between the cingulate sulcus and corpus callosum forms the cingulate gyrus. Then from 32 weeks to till term, marginal ramus, paracentral sulcus and sub parietal sulcus which are the branches of cingulate sulcus are seen. In between the paracentral and marginal ramus forms the paracentral lobule which is clearly discernible at 32 weeks of gestation.

Therefore, in the present study, the cingulate sulcus and gyrus are seen earlier than the above mentioned authors but Toi A et al [16] found 1(One) week earlier than the present study. A secondary branch of cingulate sulcus appears almost similar or 1-2 weeks later than reported by Monteagudo A et al [11].

Superior frontal sulcus and frontal lobule:

Chi JG et al [6], Nishukini K et al [9], Garel C et al [10] on MRI studies, observed the superior frontal sulcus at 25 weeks, 25±2 weeks, at 29 weeks. Squire L et al [8] stated that superior, middle frontal gyri become well defined between 26-28 weeks of gestation.

In the present study, it is observed at 23 weeks of gestation. Superior frontal sulci divide the frontal lobe into superior and inferior frontal lobule at 23 weeks of gestation.

Therefore the present studies of superior frontal sulcus appear earlier than the above mentioned authors.

Occipitotemporal sulcus

Chi JG et al,[6] Nishukini K et al,[9] Garel C et al [10] observed the first appearance of occipitotemporal sulcus at 30 weeks, 30 ±3 weeks, 33 weeks of gestation respectively.

In the present study, we observe the occipitotemporal sulcus to appear at 32 weeks of gestation. In between the occipito-temporal sulcus and collateral sulcus, medial and lateral occipito-temporal gyri are formed.

Hence, our observation on occipito-temporal sulcus was slightly later than Chi JG et al [6] and Nishukini K et al [9]. However, a week earlier than those reported by Garel C et al. [10]

Precentral and postcentral sulcus

Precentral sulci are observed at 24 weeks and postcentral sulci at 25 weeks of gestation by Chi JG et al [6] and by Garel C et al [10], precentral sulcus at 27 weeks and postcentral sulcus at 28 weeks of gestation.

In the present study, the precentral sulcus and postcentral sulcus is developed anteriorly and roughly parallel to the central sulcus at 23 weeks of gestation.

Hence, both sulci are seen at the same week whereas Chi JG et al [6] and Garel C et al [10] observed a week difference between the pre central and post central sulcus and are slightly later than our study.

Precentral and postcentral gyrus

Noback CR [18] observed that precentral and postcentral gyri appear on the external surface of the cerebral hemisphere at the 8th months of foetus. Squire L et al [8] stated that precentral and postcentral gyri become well defined between 26-28 weeks of gestation.

In the present study, the precentral sulcus and postcentral sulcus is developed anteriorly and roughly parallel to the central sulcus forming the precentral and postcentral gyrus at 23 weeks of gestation.

Therefore, the precentral and postcentral gyri appear earlier than the above mentioned authors. Appearances on development of gyri are 3 weeks earlier than previous author, Squire L et al [7].

Superior temporal sulcus and temporal gyri

Chi JG et al [6] and Dorovini- Zis K et al,[13] found superior temporal sulcus at 23 weeks whereas Nishukini K et al[9], Garel C et al [10] observed at 20 weeks, 26±3 weeks, 32 weeks. Squire L et al [7] stated that superior, middle temporal gyri become well defined between 26-28 weeks of gestation.

In our study, first appearance of superior temporal sulcus is seen at 25 weeks of gestation dividing the temporal lobe into superior and inferior temporal lobule. Uprturned end of superior temporal gyrus in the inferior parietal lobule forms the angular gyrus at 25 weeks of gestation.

Hence our study on the superior temporal sulcus is observed later than Chi JG et al [6] but earlier than Nishukini K et al [9], Garel C et al [10]. Superior and inferior temporal lobule appears 1-2 weeks earlier than Squire L et al[8] .

Inferior temporal sulcus

Chi JG et al [6], Nishukini K et al [9] found inferior temporal sulcus at 30 weeks 31±3 weeks, 33 weeks.

In our study, first appearance of inferior temporal sulcus is seen at 28 weeks of gestation. Superior, middle and inferior temporal gyri are formed at 28 weeks of gestation.

Therefore, the inferior temporal sulcus is seen earlier than those by the above mentioned authors.

Lunate sulcus:

Nishukini K et al [9] observed the first appearance of lunate sulcus at 24±2 weeks.

In the present study, it is first observed at 25 weeks of gestation. Hence, it is almost comparable with the above mentioned author.

Collateral sulcus: Chi JG et al [6], Nishukini K et al [9] and Garel C et al [10] found at 23 weeks, 24±2 weeks and 27 weeks of gestation. Crossman AR [1] medial to the collateral sulcus, parahippocampal gyrus is formed.

In our study, it is observed at 27 weeks of gestation along with the parahippocampal gyrus.

Appearance of collateral sulcus is similar with Garel C et al [10] but it appears 1-2 weeks earlier than the Chi JG et al [6] and Nishukini K et al [9].

Rhinal sulcus

Nishukini K et al [9] observed the first appearance of rhinal sulcus at 25±2 weeks.

In our study, the rhinal sulcus is observed at 33 week.

Hence, rhinal sulcus appears around 7 weeks later than stated by the previous authors.

Intraparietal sulcus

Chi JG et al [6], Garel C et al [10] and Nishukini K et al [9] observed first appearance of intraparietal sulcus at 26 weeks, 28 weeks at 29±2 weeks

In this study, intraparietal sulcus is observed at 27 weeks of gestation dividing the parietal lobe into superior and inferior parietal lobule. This study demonstrates that intraparietal sulcus appears 1 week later than Chi JG et al, [6] but 1- 2weeks earlier than Garel C et al [10] and Nishukini K et al [9].

Parietal lobule

Crossman AR [1], Fitzgerald MJT et al [4], Carpenter MB et al [7] described that superior parietal lobule, between the superomedial margin of the hemisphere and the intraparietal sulcus, is continuous anteriorly with the postcentral gyrus. Inferior parietal lobule, below the intraparietal sulcus and behind the lower part of the postcentral sulcus, is divided into three. The anterior part is the supramarginal gyrus, upturned end of the lateral fissure. The middle part of the inferior parietal lobule, called the angular gyrus, arches over the end of the superior temporal sulcus, it is continuous postero-inferiorly with middle temporal gyrus. The posterior part arches over the upturned end of the inferior temporal sulcus.

In the present study, we observed the superior and inferior parietal lobule from 27 weeks of gestation. Upturned end of lateral fissure, supramarginal gyrus and upturned end of superior temporal sulcus, angular gyrus are also discernible from 25 weeks of gestation but more convoluted from 27 weeks onward.

Inferior frontal sulcus

The first appearance of inferior frontal sulcus was noted by Chi JG et al, [6] Garel C et al [10] and Nishukini K et al [18] at 28 weeks, 29 weeks, 30±3weeks of gestation. Crossman AR [1], Fitzgerald MJT et al [4] stated that the area of frontal lobe anterior to the precentral sulcus is divided into superior, middle and inferior frontal gyri.

We first observed it at 28 weeks of gestation. From 28 weeks onward, the frontal lobe is divided into superior, middle and inferior frontal gyri by superior and inferior frontal sulcus.

Hence, our study is comparable with the Chi et al [6]. However, our observations are slightly earlier than Nishukini K et al [9] and Garel C et al [10].

Transverse occipital sulcus: Chi JG et al [6], Garel C et al [10] and Nishukini K et al [9] noted the first appearance of Transverse occipital sulcus at 26 weeks, at 28 weeks, 29±2 weeks it was observed.

In our study it is observed at 32 weeks of gestation.

Hence, our observation on the transverse occipital sulcus was later than reported by the above mentioned authors.

Lateral occipital sulcus, 'H'- shaped sulcus

Garel C et al [10] noticed that 'H' shaped sulci was found at 28-31 weeks of gestation. Naidich TP [19] et al reported by 28-31 weeks, the orbital sulci develop progressively and after 36 to 39 weeks, the secondary sulci define the anterior and posterior orbital gyri.

In the present study, lateral occipital sulcus, H-shaped sulcus along with orbital gyri appeared at 33 weeks of gestation.

Therefore, in the study, it is seen later than the above mentioned authors.

Occipital gyri

Squire L et al [7] stated that superior and inferior occipital gyri become well defined between 26-28 weeks of gestation.

In the present study, we observed the superior and inferior occipital gyrus which is divided by lateral occipital sulcus at 32 weeks of gestation.

Therefore, the occipital gyri are seen 4 weeks later than above mentioned author.

Secondary and tertiary sulci

Chi JG et al [6] and Garel C et al [10] observed secondary occipital sulci at 34 weeks of gestation and Nishukini K et al [9] observed at 38±3 weeks. Squir L et al [7] stated that development of secondary and tertiary gyri occurs late in gestation, and in the last trimester the sulci become deeply enfolded.

In our study, the main sulci appear in a relatively short period, generally at the beginning of the third trimester of pregnancy and afterward the secondary sulci developed. At approximately 32 weeks of gestation, the secondary sulci begin to develop while the main sulci became deep and tertiary sulci after 37 weeks of gestation.

Insula: Crossman AR [1], Fitzgearald MJT et al [4] the surface of the hemisphere expands at a greater rate than the hemisphere as a whole. The insula is gradually buried by the adjacent cortical region and they overlap by the opercula.[1]

In our study, at first, insular area is seen as lateral cerebral fossa and the distance between frontal and occipital pole gradually increases but after 31 weeks onward, as temporal lobe grows forward, it is covered by the opercula leaving small exposed area of insula.

By 28-35 weeks, most of the insula is covered but full closure of most anterior part is not achieved until birth to 2 years.

In the present study, we observed at term insula is not fully covered by the opercula. From 25 weeks onward $\frac{3}{4}$ parts of insula are covered by the opercula posteriorly, it is observed that the most anterior part is not covered by 40 weeks of gestation.

Hence, the study is comparable with the above mentioned authors.

V. Conclusion:

In the youngest specimen of the present study i.e. 12th week of gestation, the external surfaces of cerebral hemispheres are observed smooth i.e. Lissencephalic.

There is gradual increase in weight and size of cerebral hemispheres in all dimensions as age advances. Features of the right cerebral hemisphere are seen more developed than left.

No statistically significant sex difference of anteroposterior, transverse, weight and height of cerebral hemispheres.

Highly statistically significant difference with increasing gestational age of anteroposterior, transverse, height and weight of cerebral hemispheres.

Anteroposterior dimension is more than the height throughout foetal life. At 12 weeks, the ratio of anteroposterior to height is 1.23:1 and at term it is 1.45:1.

Calcarine sulcus and parieto-occipital sulcus along with Cuneus is seen by 12 weeks of gestation.

Olfactory sulci along with ovoid olfactory bulbs are visible by 12 weeks of gestational age

Shallow hippocampal sulcus is visible by 13 weeks of gestational ages which become deeper and infolded into the temporal lobe.

Between temporal and frontal lobe a deep fossa appears in which the forerunner of lateral fissure is observed at 13 weeks of gestation in the cerebral fossa. Before becoming linear lateral sulcus above the temporal lobe, it represented as cerebral fossa which changed into triangular cleft with the base of triangular area forward and apex behind. Ascending ramus and horizontal ramus of lateral sulcus is seen at 27 weeks of gestation forming the Broca's area.

Central sulcus is seen at 19 weeks of GA. At first it is seen as slight indentation in front of midpoint between frontal and occipital pole but from the 36th weeks of gestation, it is observed behind the midpoint of frontal and occipital pole. The ratio between distance from central sulcus to frontal pole and anteroposterior diameter is 0.44:1 in group II which gradually increases and at term it is 0.73:1.

Anlage of cingulate sulcus parallel to the corpus callosum along with cingulate gyrus is observed by 20 weeks of gestation.

Precentral sulcus and postcentral sulcus is seen by 23 weeks of gestation. At this week, postcentral sulcus is sharper and distinct than precentral sulcus. Between central sulcus and precentral sulcus, precentral gyrus is formed at 23 weeks of gestation. postcentral gyrus are observed at the same week in between central sulcus and post central sulcus.

Superior frontal sulcus is seen by 23 weeks of gestation. Superior frontal sulcus divides the frontal lobe into superior and inferior frontal lobule at this week.

Superior temporal sulcus is seen as a slight curvature parallel to the lateral sulcus on the surface of temporal lobe dividing the temporal lobe into superior and inferior temporal lobule.

The anlage of lunate sulcus is seen as a 'C' shaped curve in front of occipital pole by 25 weeks of gestation. Angular gyrus is seen at 25 weeks of gestation in the inferior parietal lobule.

Upturned end of posterior ramus of lateral sulcus forms the supramarginal gyrus in the parietal lobule; it is clearly discernible from 25 weeks of onward.

Collateral, intraparietal sulci are observed on the inferior and superolateral surface of hemispheres by 27 weeks of gestation whereas inferior temporal sulcus and inferior frontal sulcus are observed by 28 weeks of gestation. At this age superior, middle and inferior temporal gyri are observed.

At 27 weeks of gestation just medial to the collateral sulcus parahippocampal gyrus is seen

Transverse occipital sulcus are observed near the superomedial border of the hemispheres at 32 weeks of gestation

First appearance of occipitotemporal sulcus is seen at 32 weeks of gestation between which the collateral and occipito-temporal sulcus forms the medial and lateral occipito-temporal gyri at this week.

Rhinal sulcus observed on the inferior surface of cerebral hemisphere at 33 weeks of gestation.

Lateral occipital sulcus and 'H'- shaped sulcus along with orbital gyri are observed by 33 weeks of gestation. Lateral occipital sulcus divides the occipital lobe into superior and inferior occipital gyri at this week.

At the 33rd week of gestation, all of the primary sulci are already formed. After 33 weeks of gestation, secondary and tertiary sulci and gyri are formed. The development of the cerebral sulci is gradual and proportionate to the increasing body weight and age of the foetus

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