Original article

Sulcogyral pattern of orbitofrontal cortex in human brain and its clinical implications

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Abstract

Introduction- The orbitofrontal cortex (OFC) has been proposed to be involved in sensory integration, in representing the affective value of reinforcers, and in decision making and expectation. Abnormalities in the structure and function of the OFC have been observed in many psychiatric disorders. Considering the clinical importance, the present study aims to observe the sulcogyral pattern of OFC.

Methods- Ninety-four formalin fixed adult cadaveric cerebral hemispheres were examined. Arachnoid membrane was removed from the brain surface and the sulci and gyri of the orbital surface of the frontal lobe were studied.

Observation- The orbital surface contains two main sulci: the olfactory sulcus, and an H-shaped orbital sulcus complex which can be classified into four subtypes- Type I, Type II, Type III and Type IV; based on the continuity of medial and lateral orbital sulci in the rostrocaudal direction.

Results- Olfactory sulcus- Olfactory sulcus was absent on one side and hypolastic in the other side in one brain. Orbital sulcus pattern - Type-I was most common (55.32%) followed by Type-II (17.02%), Type-III (12.77%) and Type-IV (10.63%). In 2 cases non-specific pattern was found in the left cerebral hemisphere. A single intermediate orbital sulcus was present in majority of cases (72.34%). Posterior orbital sulcus was absent in 25.53% cases.

Conclusion- Orbitofrontal cortex is associated with many psychiatric disorders. Better anatomical and functional characterization of the orbitofrontal cortex will improve our knowledge about these diseases. Functional neurosurgery procedures aiming to improve alterations in the orbitofrontal pathways can be an important option to treat these diseases.

Key Words- Cerebral cortex, Frontal lobe, Orbital surface, olfactory sulcus, Orbital sulcus

INTRODUCTION

The frontal lobe of cerebral hemisphere has four surfaces: a lateral, a medial, a basal and a sylvian surface.[1] The basal surface is in contact with the orbital roof, is called the orbitofrontal surface. Orbitofrontal cortex (OFC) is important for sensory-visceromotor multimodal integration[2] , as well as for emotional processing and hedonic experience[3]. It is

also likely important in the affective evaluation of reinforcers, expectation, motivation, decision making and goal directed behaviour[4]. One notable feature of OFC is its enormous individual variability at both the level of cytoarchitecture[2] and gross anatomy (sulcogyral pattern) [5] , and individual variability in OFC may be associated with individual differences in personality traits, emotional processing and behavior.

Inter individual variability of the human orbitofrontal sulci has been systemically described in several works. Apart from the olfactory sulcus in the medial orbitofrontal cortex , the morphology of other orbitofrontal sulci is highly complex and variable, and some sulci may not be consistently present. The "H-shaped" orbital sulcus refers to a configuration of multiple components namely: - the medial orbital sulcus (MOS), lateral orbital sulcus (LOS) and transverse orbital sulcus (TOS). In a previous study by Chiavaras and Petrides[5], the H-shaped sulcus has been classified into three major subtypes (Type -I, II, III) based on the continuity of the MOS and LOS. A subsequent study by Chakirova et al.[6] reported an additional subtype (type-IV) that was found in 3-6% of the neurotypical population. Other orbitofrontal sulci have also been described, including the posterior orbital sulcus (POS) and the intermediate orbital sulcus (IOS) located in the posterior and anterior orbitofrontal gyri[5].

The development of sulcogyral convolution is thought to reflect critical neurodevelopmental events, such as neuronal migration and local neuronal connection[7,8] strongly regulated by genetic factors[9,10]. Therefore, sulcogyral patterns may be significantly altered in neurodevelopmental disorders. Previous studies have identified series of critical events like cortical folding patterns, cortical growth[11] and tension from white matter[12] during early neural development to play central roles for development of psychiatric disorders.

In last few years, many studies have showed the relationship between altered orbitofrontal cortical pattern and psychiatric disorders. Nakamura et al.[13] were the first to report the variations of the subtypes of the H-shaped sulcus in schizophrenia, with an increased occurrence of the disease amongst Type-III subtype in the right hemisphere. Type-III expression of the orbital sulcus was also associated with more severe psychotic symptoms. Similar alteration was also observed by Chakirova et al.[6] in individuals at high risk of developing schizophrenia. Watanabe et al.[14] reported an increased occurrence of Type-III pattern of orbital sulcus in both hemisphere in patients with ASD (Autism Spectrum Disorders). They also found an association of absence of posterior orbital sulcus in right hemisphere with ASD. Lavoi et al[15] found a protective effect of possessing a Type-I pattern in right cerebral hemisphere in developing psychosis in ultra high risk individuals.

Considering the clinical importance of orbitofrontal cortex, we have done an anatomical study to see the sulcogyral pattern of OFC.

AIMS AND OBJECTIVES

The aim of the present study is to evaluate the sulcogyral pattern of orbitofrontal cortex of adult human brain, knowledge of which will give better understanding of psychiatric disorders aiming to possible neurosurgical treatments. Our study involves pattern and distribution of the olfactory sulcus, the orbital sulcus and the other gyri present in the orbital surface of the frontal lobe.

MATERIALS AND METHODS

The present study was conducted in the Department of Anatomy, KPC Medical College, Kolkata over a

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period of one year where 94 formalin fixed cerebral hemispheres from human cadavers collected irrespective of age and sex. There were 48 specimens of right hemisphere and 46 of the left side. The arachnoid membrane was removed from the brain surface and the sulci and gyri of the orbital surface of the frontal lobe were studied and the findings were recorded in a tabulated manner. Photograph of the orbital surface was taken. Statistical analysis (TABLE **I, II AND III)** and graphical representations were also made. **(FIGURE IV)**

OBSERVATIONS AND RESULTS

The orbital surface contains two main sulci: the olfactory sulcus, and an H-shaped orbital sulcus complex which is made up of a medial orbital sulcus (MOS), a lateral orbital sulcus (LOS) and a transverse orbital sulcus (TOS). **(FIGURE IA)**

The olfactory sulcus, the most medial of the orbitofrontal sulcus accommodate the olfactory bulb and its tract. Its anterior end can bend medially, can touch the division between orbital and medial surface, can go beyond achieving the margin between them into the medial surface or restricted into the orbital surface almost straight forward. The posterior end of the olfactory sulcus after touching the olfactory trigone can bend laterally in a hook like shape, can merge with the caudal part of the medial orbital sulcus, or may not be deviated to any side.

The H -shaped orbital sulcus can be classified into different subtypes based on the continuity of medial and lateral orbital sulci in the rostrocaudal direction. In Type I, rostral and caudal portions of the MOS were clearly interrupted, whereas the LOS was continuous throughout the entire length. In Type II, rostral and caudal portions of the MOS and LOS were continuous without interruption connected by the TOS makes a configuration of perfect H. in Type III, rostral and caudal portions of both MOS and LOS were interrupted. In Type IV, the rostral and caudal portions of the LOS were interrupted in presence of a continuous MOS just opposite of Type I**. (FIGURE IB AND II)**

The elongated area medial to the olfactory sulcus is called gyrus rectus. Rest of the orbital surface is divided by the H- shaped orbital sulcus into four orbital gyri- anterior, posterior, medial and lateral. The anterior orbital gyrus is situated anterior to the TOS and between the rostral portions of the medial and lateral orbital sulcus and contains one or more intermediate orbital sulcus. The posterior orbital gyrus is situated posterior to the TOS and between the caudal portions of the MOS and LOS and contains one or more posterior orbital sulcus, anterior end of which may or may not be connected with the TOS. Sulcus fragmentosus may be present in the medial orbital gyrus.

Out of total 94 cerebral hemispheres analyzed, 48 were of right side and 46 were of left side. The findings are as follows.-

a) Olfactory sulcus- The anterior end of the olfactory sulcus was deviated medially in 16 cases (33.33%) on right side and in 4 cases (8.69%) on left side. The posterior end of the olfactory sulcus, after touching the olfactory trigone, was deviated laterally in 4 cases (8.33%) on right side and 4 cases (8.69%) on left side. **(TABLE I)** In one brain,the olfactory sulcus was absent on the right side and hypoplastic on the left side with bilateral absence of the olfactory bulb and tract on both sides. (**FIGURE III)**

b) Orbital sulcus pattern - Type-I pattern was most common on both right (66.67%) and left (43.48%) sides. Type-II pattern was found in 8.33% cases of right side and in 26.09% cases of left side. Type-III pattern was present in 16.67% cases of right side and

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in 8.69% cases of left side. Type-IV pattern was also found in 8.33% cases of right side and 13.05% cases of left side. **(TABLE II) .** 2 cases had a non-specific pattern of left hemisphere which did not match with any of the above mentioned category.

c) In the anterior orbital gyrus, intermediate orbital sulcus was absent in 6 cases (13.05%) on left side and was present in all cases on the right side. In majority of cases (75% on right side and 69.56% on left side) a single intermediate orbital sulcus was present. Two intermediate orbital sulci were present in 20.83% cases of right side and in 13.05% cases of left side. In 2 cases three intermediate orbital sulci were found on both sides. **(TABLE III)**

d) Posterior orbital sulcus, in posterior orbital gyrus, was absent in 12 cases on both sides. A single posterior orbital sulcus was present in most of the cases (66.67% in right side and 47.83% in left side). Double posterior orbital sulci were present in8.33% cases on right side and in 26.08% cases on left side. 20% of the posterior orbital sulci of right side and 26.09% sulci of left side were connected with the transverse orbital sulcus. **(TABLE III)**

e) Sulcus fragmentosus was present in 25% cases on right side and in 26.09% cases on left side. **(TABLE III)**

DISCUSSION

The orbitofrontal cortex (OFC) is a functionally heterogeneous brain region that has been particularly implicated in contributing to different aspects of social and emotional behavior (Kringelbach and Rolls, 2004)[16]. Neuroimaging studies provide evidence that structural aspects of the OFC are important for mediating these functions. There are marked individual differences in the pattern of cortical (sulcogyral) folding in the orbitofrontal cortex (OFC), and there is a growing literature suggesting that these individual differences are associated with risk for psychotic disorders. The main objective of this study is to characterize, the orbitofrontal surface according to its sulcal and gyrus anatomy. This sort of anatomical characterization is quite important to a real knowledge of the orbital part of frontal lobe. There already are many studies that classify the orbitofrontal sulcus and gyrus based on magnetic resonance images or by dissection method and our results were very similar to theirs results.The intermediate orbital sulcus was present in all cases according to other studies [5,14,16] but the present study showed absence of that in 6.38% cases. In our study, the posterior orbital sulcus was present in 74.47% cases, whereas it was present in 77%, 78% and 70.24% cases in the studies of Chiavaras and Petrides, Watanabe et al, and Rodrigues et al. respectively. Chiavaras and Petrides observed sulcus fragmentosus in 10% of the cerebral hemispheres, but the present study showed the presence of sulcus fragmentosis in a higher percentage of cases (25.53%). A comparison of the different studies along with the present study is shown in **TABLE IV.**

The olfactory sulcus was absent on right side and hypoplastic on left side along with absent olfactory bulb and tract in one brain in our study. (**FIGURE III).** Agenesis of the olfactory bulbs (arrhinencephaly) may occur as an isolated defect, as a component of holoprosencephaly associated with other cerebral malformations, or as a component of Kallmann syndrome with endocrinopathies[18].

The anterior end of the olfactory sulcus deviated medially in 21.28% cases in our study, but the percentage was higher (33.33%) in the study of Rodrigues et al. The posterior end of the olfactory sulcus deviated laterally in 8.52% cases in our study,

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whereas it was much higher (23.81%) in previous study.

CONCLUSION

The most common pattern of orbitofrontal sulcal pattern is Type-I with a continuous lateral orbital sulcus and an interrupted medial orbital sulcus, followed by Type-II, Type-III and Type-IV respectively. Since the initial description of orbitofrontal cortex patterns, several studies have showed altered proportion of this basic pattern distribution in psychiatric disorders . Better anatomical and functional characterization of the orbitofrontal cortex and its connections will improve our knowledge about these diseases. Functional neurosurgery procedures aiming to improve alterations in the orbitofrontal pathways can be an important option to treat these diseases.

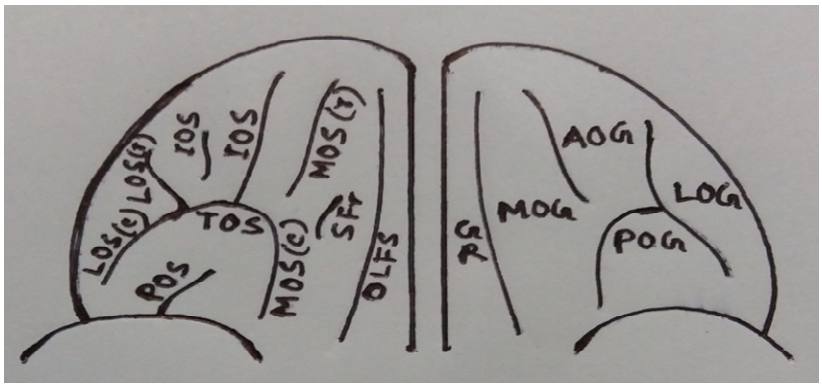

FIGURE I (A)

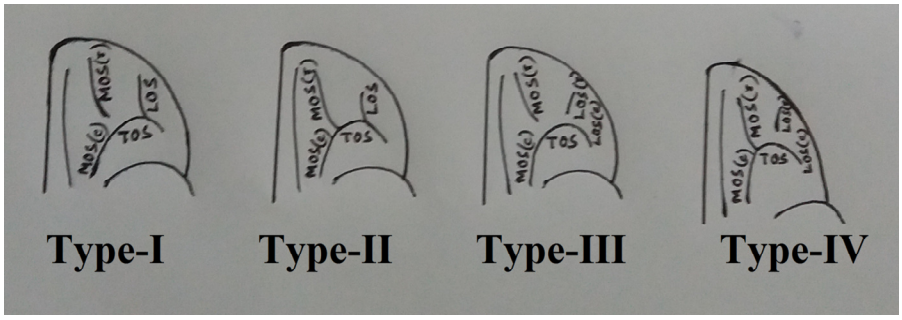

FIGURE I (B)

FIGURE I:

(A) Schematic diagram showing orbitofrontal sulci (left half) and gyri (right)

(B) Different patterns of Orbital sulcus.

FIGURE II

TYPE I

TYPE II

TYPE III

TYPE IV

FIGURE II:

Specimen showing:

(A) Type I orbital sulcus

(B)Type II orbital sulcus

(C) Type III orbital sulcus

(D)Type IV orbital sulcus

Abbreviations : MOS- medial orbital sulcus, LOS- lateral orbital sulcus, IOS- intermediate orbital sulcus, POS- posterior orbital sulcus, TOS- transverse orbital sulcus, OLFS- olfactory sulcus, (r)- rostral, (c)- caudal.

FIGURE III

Figure III:

Specimen of the orbital surface of the both cerebral hemisphere showing absent olfactory sulcus on right side and hypoplastic olfactory sulcus on left side (OLFS) along with absent olfactory bulb and tract on both sides. R- right side of specimen.

FIGURE IV

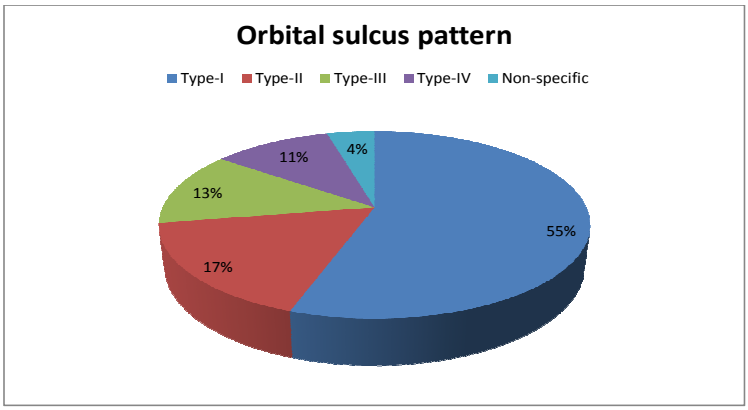

FIG IV(A)

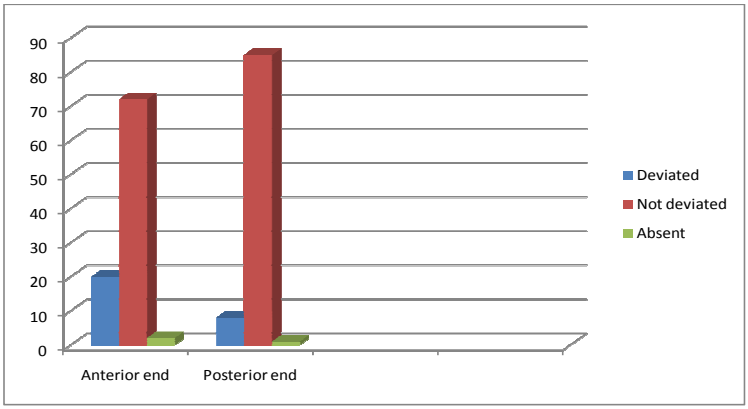

FIG IV(B)

Figure IV:

(A): Piechart diagram showing the orbital sulcal pattern distribution of both cerebral hemispheres.

(B): Bar diagram showing the characteristerics and pattern of the olfactory sulcus of both cerebral hemispheres.

TABLE I

Characteristics of the olfactory sulcus of the orbitofrontal cortex on both sides

Olfactory sulcus	Anterior end			Posterior end		
	Medially deviated	Not deviated	absent	Laterally deviated	Not deviated	absent
Right side(n=48)	16 (33.33%)	31 (64.58%)	1(2.08%)	4(8.33%)	43(89.59%)	1(2.08%)
Left side(n=46)	4 (8.69%)	41 (89.13%)	1(2.17%)	4(8.69%)	42(91.30%)	0(0%)
Total(N=94)	20(21.28%)	72(76.59%)	2(2.13%)	8(8.52%)	85(90.42%)	1(1.06%)

TABLE II

Orbital sulcus pattern and distribution in the orbitofrontal cortex of both sides

Orbital sulcus pattern	Type I	Type II	Type III	Type IV	Non specific
Right(n=48)	32(66.67%)	4(8.33%)	8(16.67%)	4(8.33%)	0(0%)
Left(n=46)	20(43.48%)	12(26.09%)	4(8.69%)	6(13.05%)	4(8.69%)
Total(N=94)	52(55.32%)	16(17.02%)	12(12.77%)	10(10.63%)	4(4.26%)

TABLE III

Presence of Intermediate Orbital sulcus, Posterior Orbital sulcus and Sulcus Fragmentosus in the orbitofrontal cortex of both sides

	Intermediate Orbital sulcus				Posterior orbital sulcus			Sulcus fragmentosus	
	Absent	One	Two	Three	Absent	One	Two	Present	absent
Right side	0 (0%)	36 (75%)	10 (20.83 %)	2 (4.17 %)	12 (25%)	32 (66.67 %)	4 (8.33%)	12 (25%)	36 (75%)
Left side	6 (13.05 %)	32 (69.56 %)	6 (13.05 %)	2 (4.34 %)	12 (26.09 %)	22 (47.83 %)	12 (26.08 %)	12 (26.09 %)	34 (73.91 %)
Total	6 (6.38%)	68 (72.34 %)	16 (17.02 %)	2 (4.26 %)	24 (25.53 %)	54 (57.45 %)	16 (17.02 %)	24 (25.53 %)	70 (74.47 %)

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TABLE IV

Comparison of orbital sulcus pattern and distribution from various studies

	Type -I	Type-II	Type-III	Type-IV	Non-specific
Chiavaras and Petrides[5]	56%	30%	14%	NA	NA
Charikova et al.[6](in healthy control gr.)	56.9%	23.6%	15.3%	4.2%	NA
Nakamura et al.[13](in healthy control gr.)	54%	32%	14%	NA	NA
Watanabe et al.[14](in healthy control gr.)	56%	29%	11%	4%	NA
Rodrigues[17] et al.	41.67%	36.90%	11.86%	3.57%	NA
Present study	55.32%	17.02%	12.77%	10.63%	4.26%

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