THE MORPHOLOGY OF THE CLAUSTRUM WITH COMPUTER-AIDED THREE-DIMENSIONAL (3D) RECONSTRUCTION IN MAN

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SUMMARY

Purpose : *The main purpose of this study was to demonstrate the three-dimensional (3D) appearance of the claustrum from serial sections taken from a human cadaver.* ***Methods :*** *The 3D reconstruction of the the claustrum was performed by using serial macroscopic anatomic sections taken from a cadaver. Sectional photographs were scanned and they were transferred into a computer. The contours of the claustrum were traced manually and the traces obtained were transformed into a 3D reconstruction program. At first, the wire-frame reconstruction and then the rendered form of this wire-frame reconstruction from different view angles was obtained.* ***Results and Conclusion :*** *When the reconstruction of the claustrum was examined, it was found that the claustrum was oval in shape. The medial part of this structure was concave, whereas the lateral part had a convex appearance. Additionally, irregularities were found on the convex lateral surface of the claustrum. The claustrum had a superior and an inferior pole, and the inferior pole of the claustrum continued towards the amygdala and prepiriform cortex. In some of the serial sections, grey matter extensions were observed between the insular cortex and the claustrum. Moreover in this study, the dimensions of the claustrum were also reported. In conclusion, this is the first study reporting the three-dimensional reconstruction and the exact dimensions of the claustrum of the human brain. We believe that this study will be of great value to future studies concerning the claustrum and its neighborhood relations.*

Key Words: *Claustrum, Three-Dimensional (3-D) Reconstruction, Human Brain.*

INTRODUCTION

The claustrum is a thin sheet of grey matter coextensive with the insula and putamen, from which it is separated by the external capsule (1). In the examination of the horizontal section of the claustrum, thin sheets of neurons are found which are reciprocally and topographically connected with the cerebral cortex (2). The connections and

This study has been dedicated to the honor of our Emeritus Professor Dr. Doğan Taner.

functional significance of the claustrum are unknown in the human brain (1). Additionally, the three-dimensional reconstruction of the claustrum has not been reported previously. Therefore, we aimed to obtain the computer aided three-dimensional appearance and the dimensions of the claustrum by using serial sections taken from the brain of a 50-year-old human male cadaver.

MATERIAL AND METHODS

The three-dimensional (3D) reconstruction of the claustrum was performed by using serial macroscopic anatomic sections, taken from the left cerebral hemisphere of a 50-year-old formalin-fixed male cadaver. This cerebral hemisphere was placed into a deep freezer (-20°C) for 48 hours. Then, the serial sections of the human brain were obtained by cryosectioning the left cerebral hemisphere through the horizontal plane in 600 µm increments on a macrotome (Reicheirt, Austria).

The landmarks were put into the trimming system apparatus in the X-axis and in the Y-axis, in order to remove the rotation and shifts of the serial sections.

After each trimming procedure, the obtained sections were photographed with close-up lenses. These photographs were scanned by a UMAX Astra 1200S scanner and they were transferred into an Apple Power Macintosh 4400/200 computer. The contours of the claustrum (Fig.1) were traced by a manual method (Adobe Photoshop 3.0 for Macintosh) and the obtained traces were transformed into a 3D reconstruction program (Adobe Dimension 2.0 for Macintosh). The thickness of each serial section (100 µm) and the distance between two consequetive serial sections (500 µm) were taken into consideration during the 3D reconstruction process. At first, the wire-frame reconstruction (Fig. 2) and then the rendered form of this wire-frame reconstruction from different view angles (Figs. 3a, b, c, d, e) were obtained. The obtained images were transformed into hard-copies by a Xerox Docu Color 40 (Fiery 525) printer.

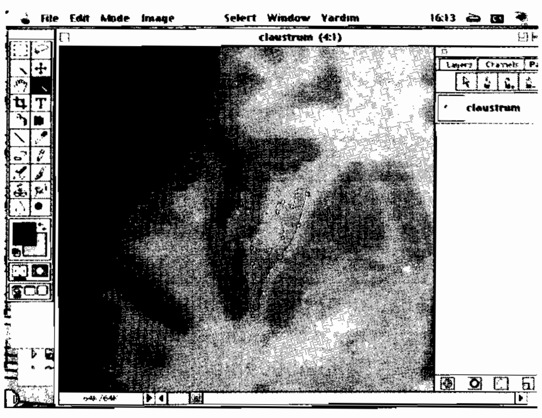

Fig. 1 : A sample section from serial sections. The claustrum had been traced by a manual method.

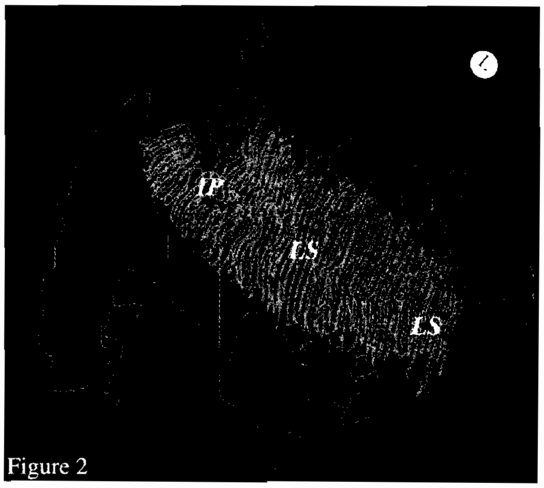

Fig. 2 : The wire-frame image of the human left hemispheric claustrum. (antero-supero-lateral view) IP inferior pole of the claustrum, LS lateral surface of the claustrum, M medial, L lateral, I inferior, and S superior.

The contours of the major related structures were added to the 3-D reconstruction once for every ten claustrum serial section in order to facilitate the understanding of the relations of the claustrum (Figs. 3a, b, c, d, e).

Statistical analysis was performed by using the Apple Macintosh Colour Classic computer with InStat for Mac and StatView II softwares.

RESULTS

The serial sections of the claustrum were 100 µm in thickness. The distance between two consequtive serial sections used in 3D reconstruction of the claustrum was 500 µm with this method, 55 serial sections were obtained and

Fig. 3 : The rendered image of the human left hemispheric claustrum. (A) Antero-supero-lateral view. (B) Supero-lateral view. (C) Infero-lateral view. The red asterisks indicate the insular extensions of the claustrum. (D) Antero-medial view. (E) Antero-infero-medial view. CN caudate nucleus, CI cisterna interpedincularis, CC cerebral cortex, CAJ claustro-amygdaloid junction, IC insular cortex, SP superior pole, T thalamus, LN lentiform nucleus, U uncus, A amygdala, M medial, L lateral, I inferior and S superior.

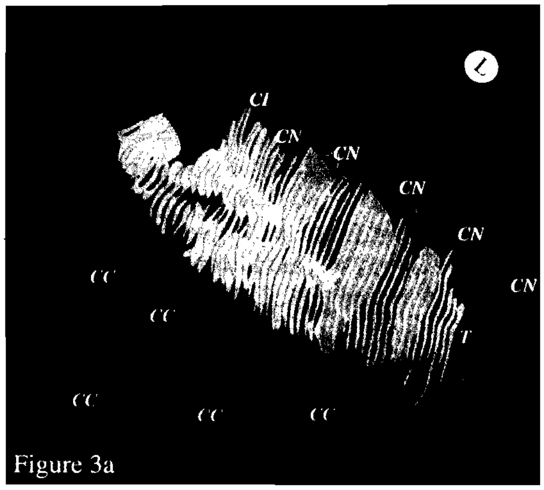

Figure 3a

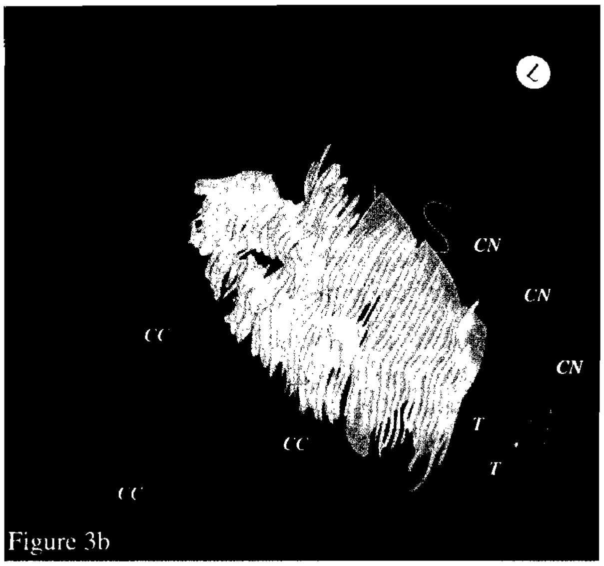

Figure 3b

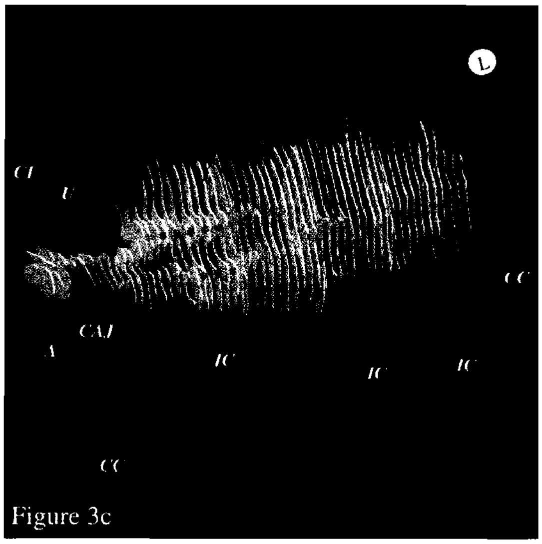

Figure 3c

Figure 3d

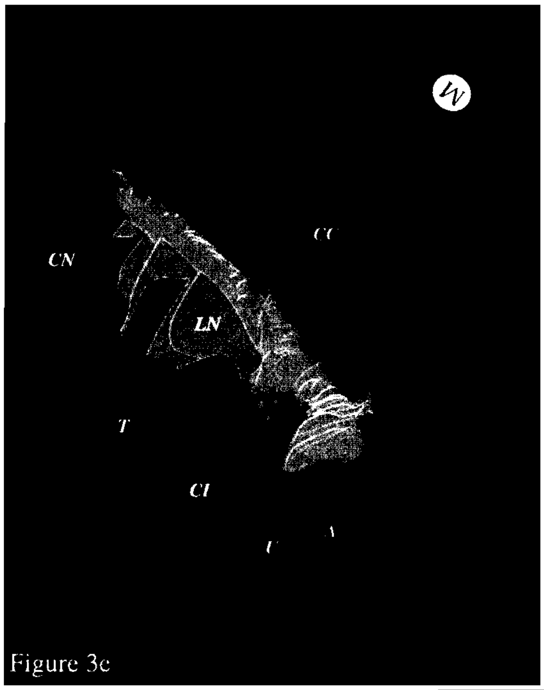

Figure 3e

therefore, the vertical dimension of the claustrum was 32.5 mm ([55x[100+500]]-500 μm).

Examination of the wire-frame reconstruction of the claustrum showed that it had the form of the skeleton of a fish (Fig. 2). On the other hand, when we examined the rendered form of this wire-frame reconstruction, we found that the claustrum was oval in shape. The medial part of this structure was concave whereas its lateral part had a convex appearance. Additionally, irregularities were detected on the convex surface of the claustrum. The claustrum had a superior and an inferior pole, and the inferior pole of the claustrum continued towards the amygdala and prepiriform cortex (Figs. 3a, c, e). We suggest that this continuation can be termed as the claustro-amygdaloid junction.

In some of the serial sections, the grey matter extensions were observed between the insular cortex and the claustrum. As a second suggestion, these may be termed as the claustro-insular extensions.

The relative antero-posterior diameters (C1) of the serial sections of the claustrum were measured from the augmented rendered images and this data was transformed into real diameters (C2) by means of a constant value (0.14908). This constant value had been calculated by using the relative (218 mm) and the real (32.5 mm) values of the supero-inferior lengths of the serial sections. A statistical analysis of these measurements was also made. The results showed that the minimum antero-posterior diameter of the claustrum was 1.94 mm (in the connection point of the claustrum, prepiriform and amygdaloid cortex), the maximum antero-posterior diameter was 20.28 mm and the average antero-posterior diameter was 14.07± 1.89 mm (SD: 5.53) (Table 1).

However, due to the irregular shape of the contours of the claustrum, the thickness of this structure could not be measured properly.

DISCUSSION

The claustrum is regarded by some as belonging to the corpus striatum and by others as a detached part of the insular cortex. However, detailed studies suggest that it may have at least two structurally and functionally distinct zones, the 'insular' claustrum and the 'temporal' or 'prepiriform' claustrum (1). The claustrum receives fibres from the entire cortex (3-5) and in addition there is a reciprocal projection from the claustrum to the cortex (1, 6-9).

Pearson and co-workers (10) studied the organization of the connections between the cortex and the claustrum in the monkey.

Table 1 : The antero-posterior relative and real diameters of the claustrum. (C1 and C2 columns respectively). CV constant value, Max maximum, Min minimum and Average diameters.

Section	C1(mm)	C2(mm)	Section	C1(mm)	C2(mm)	Section	C1(mm)	C2(mm)
1	71	10.58	21	128	19.08	41	92	13.72
2	68	10.14	22	132	19.68	42	74	11.03
3	101	15.06	23	132	19.68	43	62	9.24
4	85	12.67	24	127	18.93	44	57	8.50
5	98	14.61	25	125	18.64	45	45	6.71
6	110	16.40	26	127	18.93	46	45	6.71
7	93	13.86	27	136	20.28	47	25	3.73
8	85	12.67	28	125	18.64	48	27	4.03
9	102	15.21	29	124	18.49	49	22	3.28
10	99	14.76	30	124	18.49	50	19	2.83
11	110	16.40	31	100	14.91	51	16	2.39
12	132	19.68	32	123	18.34	52	13	1.94
13	124	18.49	33	122	18.19	53	50	7.45
14	113	16.85	34	121	18.04	54	45	6.71
15	126	18.78	35	118	17.59	55	39	5.81
16	109	16.25	36	119	17.74		**C1**	**C2**
17	118	17.59	37	118	17.59	**CV**	1	0.14908
18	120	17.89	38	110	16.40	**Max**	50	20.28
19	125	18.64	39	116	17.29	**Min**	45	1.94
20	134	19.98	40	109	16.25	**Average**	39	14.07

According to them, the frontal and parietal lobes are related to the anterior and posterior halves of the claustrum respectively, and the occipital and temporal cortex to the posterior and inferior margins of this structure.

As mentioned previously, there is only sparse data related to the claustrum of the human brain in the literature. Additionally, the computer aided 3D reconstruction of the claustrum and the measurements regarding the dimensions of this structure have not been reported previously. Therefore, we believe that this study will be of great help to future studies concerning the claustrum and the relations of the claustrum.

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