ORIGINAL ARTICLE

Orbital Frontal and Amygdala Volume Reductions in Obsessive-compulsive Disorder

Philip R. Szeszko, PhD; Delbert Robinson, MD; Jose Ma. J. Alvir, DrPH; Robert M. Bilder, PhD; Todd Lencz, PhD; Manzar Ashtari, PhD; Houwei Wu, MD; Bernhard Bogerts, MD

Background: Functional neuroimaging studies have implicated the frontal lobes and the hippocampus-amygdala complex in the pathophysiology of obsessive-compulsive disorder (OCD). These brain regions have not been well investigated in patients with OCD, however, using magnetic resonance imaging.

Methods: Volumes of the superior frontal gyrus, anterior cingulate gyrus, orbital frontal region, hippocampus, and amygdala were computed from contiguous magnetic resonance images in a sample of 26 patients with OCD and 26 healthy comparison subjects.

Results: Patients with OCD had significantly reduced bilateral orbital frontal and amygdala volumes compared with healthy comparison subjects and lacked the normal hemispheric asymmetry of the hippocampus-amygdala complex. Neither brain structure volumes nor asymmetry indices were significantly correlated with total illness duration or length of current OCD episode.

Conclusions: Findings of reduced orbital frontal and amygdala volumes in patients implicate a structural abnormality of these brain regions in the pathophysiology of OCD. Absence of the normal hemispheric asymmetry of the hippocampus-amygdala complex in patients is consistent with an anomalous neurodevelopmental process.

Arch Gen Psychiatry. 1999;56:913-919

From the Department of Psychiatry Research, Hillside Hospital, North-Shore Long Island Jewish Health System, Glen Oaks, NY (Drs Szeszko, Robinson, Alvir, Bilder, Lencz, and Wu), Albert Einstein College of Medicine, Bronx, NY (Drs Szeszko, Robinson, Alvir, Bilder, and Wu); Nathan S. Kline Institute for Psychiatric Research, Orangeburg, NY (Dr Bilder); Department of Radiology, North-Shore Long Island Jewish Health System, New Hyde Park, NY (Dr Ashtari); and the Department of Psychiatry, University of Magdeburg, Magdeburg, Germany (Dr Bogerts).

CURRENT HYPOTHESES regarding the pathophysiology of obsessive-compulsive disorder (OCD) have emphasized abnormalities in cortical-striatal-thalamic-cortical circuits,[1-4] and within these circuits the frontal lobes have been regarded as an important area for investigation. In particular, orbital frontal and anterior cingulate regions have been hypothesized to play an important role in producing the symptoms associated with the disorder.[3,5-9] Neuropsychological studies have supported the hypothesis of abnormal orbital frontal[10,11] and anterior cingulate[12] functioning in OCD. The strongest evidence for dysfunction of these brain regions, however, comes from functional imaging studies, which have identified hypermetabolism during baseline conditions[13-16] and symptom provocation[9,17,18] as well as reduced metabolic activity with treatment.[19-21] In contrast to orbital frontal and anterior cingulate regions, the evidence for abnormalities in other parts of the frontal lobes has been much less compelling, although some functional imaging studies have also implicated dysfunction of lateral (including superior, middle, and/or inferior) frontal gyri.[17,22,23]

Abnormalities in the mesiotemporal lobe may also be important in understanding the repetitive thoughts and behaviors associated with OCD. Amygdalocentric models of OCD[24] are particularly relevant given the amygdala's involvement in the emotional appraisal of external stimuli[25-27] and the acquisition and consolidation of conditioned fear and anxiety responses.[28,29] Moreover, medications that are efficacious in the treatment of OCD (eg, serotonergic reuptake inhibitors) and in alleviating the concomitant anxiety associated with the disorder (eg, benzodiazepines) have been shown in animal studies to exert their effects on receptors in various amygdaloid nuclei.[30-33] Consistent with these notions are the results from several functional imaging studies that have implicated amygdala pathology in OCD.[17,34] Abnormalities in other parts of the mesiotemporal lobe, such as the hippocampus, have also been implicated in the pathophysiology of OCD.[18,35] Moreover, the cybernetic models proposed by Gray[36] and Pitman[37,38] both posit that the hippocampus plays important, albeit different roles, in compulsive behavior.

SUBJECTS AND METHODS

SAMPLE SELECTION

This study included the same subjects as our previous MRI study of patients with OCD and healthy comparison subjects[43]; detailed inclusion and exclusion criteria are available from that report. Criteria relevant to this study are described briefly. All patients with OCD had a *DSM-III-R* diagnosis of OCD by the Structured Clinical Interview for *DSM-III-R*, Patient Version (SCID-P), part 1,[45] but were excluded if they met current or past (1) *DSM-III-R*–defined alcohol or psychoactive substance abuse or dependence; (2) dementia, delirium, schizophrenia, schizoaffective disorder, delusional disorder, brief reactive psychosis, or psychotic disorder not otherwise specified; or (3) mental retardation (based on IQ testing of patients with suspected mental retardation, clinical interview, and psychosocial history). In the first 10 comparison subjects, absence of any history of psychiatric disorders was determined by a screening questionnaire and clinical interview. Subsequent comparison subjects were assessed using a SCID-P interview. Written informed consent for the study was obtained using the guidelines of the Long Island Jewish Institutional Review Board.

MRI AND MEASUREMENT METHODS

Magnetic resonance images were acquired in the coronal plane using a 3-dimensional gradient echo FLASH (fast low-angle shots) sequence with a 50° flip angle, 40-millisecond repetition time, and 15-millisecond echo time on a 1.0-T whole-body superconducting imaging system (Siemens, Magnetom, Erlangen, Germany). This sequence produced 63 contiguous coronal slices (slice thickness, 3.1 mm) through the whole head in about 11 minutes, with in-plane resolution of 1.17 × 1.17 mm in a 256 × 256 matrix. All scans were reviewed by a neuroradiologist for clinical pathologic characteristics. Prior to all measurements, scans of patients with OCD and healthy comparison subjects were randomly mixed together and flipped. All measurements were thus completed by an operator (P.R.S.) unaware of group membership and hemisphere.

Measurement of mesiotemporal lobe structures was based on criteria operationalized from postmortem histological work[46] using a semi-automated, computerized mensuration system.[47] The anatomic regions used for measurement are illustrated elsewhere[48] and have been used in prior MRI research.[48,49] Two contiguous portions of the hippocampus-amygdala complex in each hemisphere were analyzed, which included the hippocampus and the amygdaloid complex. The hippocampus was measured from the level where the ascending fornix (ie, surrounding pulvinar) was interrupted to the slice posterior to the mammillary bodies. Measurement of the hippocampal formation included all CA segments (CA1, CA2, CA3, CA4), dentate gyrus, alveus, and the subicular region, which could not be separated in the scans. The amygdaloid complex was measured from the slice at the level of the mammillary bodies to its anterior boundary including the uncus. Additional details regarding these delineation criteria are available on request. Intraclass correlations between 2 operators for volumes of these structures in the right and left hemispheres ranged from 0.80 to 0.97 in 10 cases.

For measurement of the frontal lobe subregions, a modified version of Analysis of Functional NeuroImages[50] was used to resample images in the 3 orthogonal planes using 1.5-mm isotropic voxels, align all cases along the anterior and posterior commissures space, and to manually delineate the subregions on a slice-by-slice, voxel-by-voxel basis. In-house programming modifications to Analysis

Despite evidence for functional abnormalities in different parts of the frontal lobes and in mesiotemporal-limbic structures of patients with OCD, these regions have not been well investigated using magnetic resonance imaging (MRI). Several MRI studies reported no significant differences between patients with OCD and healthy comparison subjects in either frontal or mesiotemporal lobe brain structure volumes.[39-41] In contrast, one study identified increased anterior cingulate gyrus volume in neuroleptic-naive pediatric patients with OCD compared with healthy control subjects.[42]

Given the importance of frontal lobe and mesiotemporal-limbic regions to pathophysiologic hypotheses of OCD, we investigated whether patients with OCD had volumetric abnormalities of these brain structures using MRI scans obtained from our previous study.[43] In that study, we found that patients with OCD had reduced volume of the caudate nucleus compared with healthy subjects. The methods for measuring the frontal lobe subregions were developed recently in our laboratory[44] and were therefore unavailable at the time of our original study. We also examined the relationship between frontal and mesiotemporal-limbic structure volumes and measures of illness duration.

RESULTS

SUBJECTS

The demographic characteristics for the 26 patients and 26 healthy comparison subjects were described previously[43] and information relevant to this study is summarized. Patients with OCD (14 men, 12 women) had a mean age of 32.2 ± 8.0 years (range, 19-44 years). Healthy comparison subjects (16 men, 10 women) had a mean age of 29.8 ± 6.3 years (age range, 20-45 years). Twenty-two patients with OCD and 22 of the healthy comparison subjects were right-handed as assessed by a modified 20-item Edinburgh Inventory.[53] Handedness was not determined for 1 healthy comparison subject. Patients with OCD had been ill an extended time (mean onset of illness prior to the scans was 13.8 ± 6.2 years; range, 3-28 years) and their symptoms were of moderate severity (mean total of the 10 items for obsessions and compulsions on the Yale-Brown Obsessive Compulsive Scale[54] was 22.4 ± 6.9; range, 8-37). Most patients (n = 20) had received prior treatment for their disorder, including selective serotonin reuptake inhibitors or clomipramine hydrochloride, for 4 or more weeks. The mean Hamilton

of Functional NeuroImages allowed operators to "paint" a sulcus in the plane where it was optimally visible and have it appear simultaneously in the other 2 planes, thereby facilitating identification of sulci for measurement of frontal lobe subregions.

Methods for measuring the frontal lobe subregions were adapted from Rademacher et al[51] with several modifications for use in our magnetic resonance images.[44] An illustration of the frontal lobe subregions with their corresponding boundaries is provided elsewhere.[44] The boundaries of the superior frontal gyrus were (anterior, posterior, lateral, medial) tip of the cingulate sulcus, connection of the superior and precentral sulci, superior frontal sulcus, and cingulate sulcus. The boundaries of the anterior cingulate gyrus were (anterior, posterior, ventral, dorsal) tip of the cingulate sulcus, connection of the superior and precentral sulci, callosal sulcus, and cingulate sulcus. The boundaries of the orbital frontal region were (anterior, posterior, lateral, and medial) last appearance of the anterior horizontal ramus, last appearance of the olfactory sulcus, anterior horizontal ramus or circular sulcus of insula, and the olfactory sulcus. All frontal lobe subregions included gray and white matter. Intraclass correlations between 2 operators for volumes of the frontal lobe subregions ranged from 0.84 to 0.98 in 12 cases. Because one of the limiting sulci required for measurement of the orbital frontal region (ie, the anterior horizontal ramus) was not present in every hemisphere, total orbital frontal volumes were not computed for 2 patients with OCD and 4 healthy comparison subjects.

STATISTICAL PROCEDURES

Mixed-models analyses from SAS-PC (version 6.12; SAS Institute, Cary, NC) were used to compare the brain structure volumes between the OCD and healthy comparison groups. Brain structures were examined separately because of their functional and neuroanatomical heterogeneity and the possibility that OCD may involve structural pathology in a single frontal or mesiotemporal lobe brain region. Group (OCD patients vs healthy comparison subjects) and sex were between-subjects factors and hemisphere (right vs left) was a within-subjects factor. To examine possible group differences in brain asymmetry, we computed asymmetry indices according to the following formula: $[(\text{right} - \text{left}) / (\text{right} + \text{left})] \times 100$.[52] Thus, when the right hemisphere volume is larger than the left, the asymmetry index is positive, and when the left is larger than the right, the asymmetry index is negative. Group and sex served as between-subjects factors for analyses investigating asymmetry. Asymmetry indices were examined for the entire sample and then subsequently for right-handed individuals only because asymmetry may be influenced by handedness.[52] Pearson product moment correlations were used to investigate brain structure volumes and asymmetry indices in relationship to measures of illness duration.

All analyses were 2 tailed and α was set at .05. Although whole brain volume was comparable between patients with OCD (mean volume = 1321 cm^3) and healthy comparison subjects (mean volume = 1324 cm^3), we included it as a covariate in analyses investigating brain structure volumes because it explained part of the variance in these volumes. Because of the age differences between groups and the finding that age explained some variance in brain structure volumes, it also was included as a covariate. We considered the possibility that educational level might also be a suitable covariate; however, because it did not correlate with any brain structure volume in either the patient or comparison group, it was not included as a covariate. Additional analyses subdivided the OCD patient group by history of depression and prior psychotropic medication use to investigate the potential effects of these variables on significant findings. Mean values are given with SDs.

Depression Rating Scale[55] score (17 items minus the obsessive-compulsive item) for patients was 7.3 ± 4.9, indicating that they were not depressed, although 8 patients did have a history of major depression.

BRAIN MEASURES

Unadjusted frontal lobe and hippocampus-amygdala volumes are presented in **Table 1** along with the 95% confidence intervals for the difference between group means after adjustment for age and total brain volume (healthy comparison group – OCD patient group).

Mixed-models analyses revealed significant main effects of group for orbital frontal ($F_{1,47} = 5.64$, $P = .02$) and amygdala ($F_{1,47} = 6.60$, $P = .01$) volumes, such that patients with OCD had reduced overall volumes of these structures. The interaction of group and hemisphere was statistically significant for amygdala volume ($F_{1,50} = 4.18$, $P = .046$) such that patients with OCD had significantly reduced right amygdala volume compared with healthy comparison subjects ($t_{1,50} = 3.27$, $P = .002$; Table 1). Other results included a significant main effect of hemisphere for anterior cingulate ($F_{1,50} = 12.43$, $P < .001$), amygdala ($F_{1,50} = 12.39$, $P < .001$), and orbital frontal ($F_{1,44} = 7.94$, $P = .007$) volumes, with larger anterior cingulate and amygdala volumes in the right hemisphere and larger orbital frontal volume in the left hemisphere in patients with OCD and healthy comparison subjects. There was also a significant main effect of sex for superior frontal gyrus ($F_{1,47} = 10.0$, $P = .003$) and amygdala ($F_{1,47} = 8.92$, $P = .005$) volumes, such that women had larger superior frontal gyrus volume and men had larger amygdala volume. None of the group × sex interactions was statistically significant for any of the brain structure volumes. The distributions of the unadjusted total orbital frontal and amygdala volumes are presented in **Figure 1** and **Figure 2**, respectively.

Unadjusted asymmetry indices for the frontal and mesiotemporal lobe structures are presented in **Table 2** along with the 95% confidence intervals for the difference between group means after adjustment for age (healthy comparison group – OCD patient group). These analyses revealed that compared with healthy comparison subjects, patients with OCD had significantly less asymmetry in amygdala volume ($F_{1,48} = 7.61$, $P = .008$) with a trend for less asymmetry in hippocampus volume ($F_{1,48} = 3.25$, $P = .08$). When analyses were restricted to right-handed individuals, results indicated that patients

Table 1. Mean Brain Volumes*

Region	Mean (SD) Brain Volume, mm³		
	Patients With OCD (n = 26)	Healthy Comparison Subjects (n = 26)	Adjusted† 95% CI of Difference Between Groups
Superior frontal gyrus total	53 234 (9515)	53 304 (8717)	−3543 to 4055
Superior frontal gyrus right	26 616 (5208)	26 437 (4458)	−2122 to 1951
Superior frontal gyrus left	26 619 (4858)	26 868 (4635)	−1695 to 2378
Anterior cingulate gyrus total	11 166 (2328)	11 567 (3203)	−1154 to 1873
Anterior cingulate gyrus right	6213 (1481)	6309 (2024)	−864 to 1014
Anterior cingulate gyrus left	4953 (1511)	5258 (1846)	−654 to 1223
Orbital frontal region total‡	15 559 (2726)	17 193 (2519)	113 to 3348¶
Orbital frontal region right§	7387 (1946)	7979 (1420)	−352 to 1676
Orbital frontal region left‖	8169 (1553)	9164 (2084)	31 to 2076¶
Hippocampus total	3701 (733)	3685 (536)	−341 to 350
Hippocampus right	1831 (329)	1750 (300)	−260 to 120
Hippocampus left	1871 (457)	1935 (316)	−115 to 265
Amygdala total	3865 (576)	4215 (877)	4 to 700¶
Amygdala right	1982 (364)	2295 (505)	121 to 506#
Amygdala left	1883 (294)	1920 (424)	−155 to 231

*OCD indicates obsessive-compulsive disorder; CI, confidence interval.
†Adjusted for age and total brain volume.
‡Sample sizes (n) were 24 and 22, respectively.
§Sample sizes were 24 and 25, respectively.
‖Sample sizes were 26 and 23, respectively.
¶P<.05.
#P<.005.

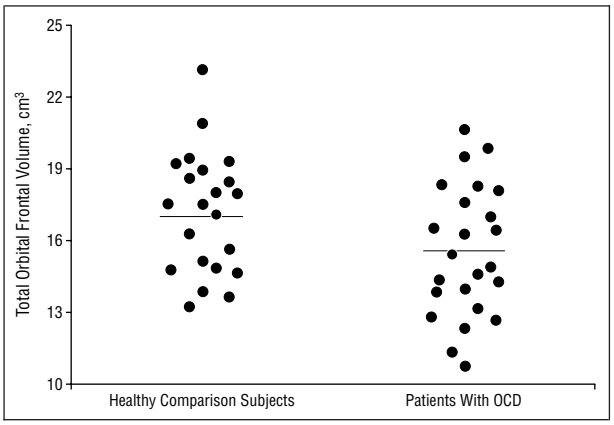

Figure 1. *Total orbital frontal volume data for obsessive-compulsive disorder (OCD) and healthy comparison groups. Horizontal lines represent mean values.*

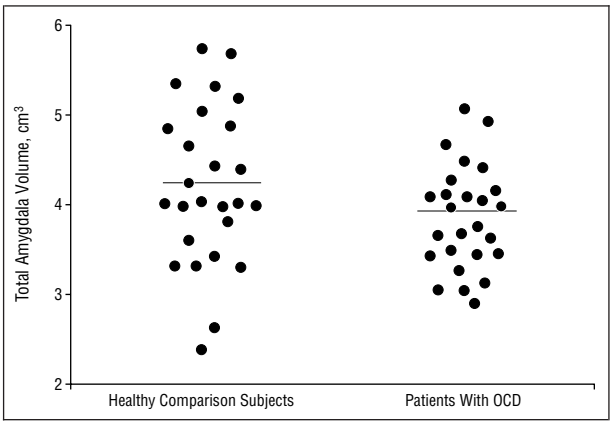

Figure 2. *Total amygdala volume data for obsessive-compulsive disorder (OCD) and healthy comparison groups. Horizontal lines represent mean values.*

with OCD had significantly less asymmetry in amygdala ($F_{1,40} = 10.11$, $P = .003$) and hippocampus ($F_{1,40} = 5.38$, $P = .02$) volume compared with healthy comparison subjects.

We investigated the effects of having a history of major depression and prior exposure to psychotropic medications on (1) orbital frontal and amygdala volumes and (2) hippocampus and amygdala asymmetry indices (for the total sample and for right-handed subjects only). Although we found no evidence for an effect of these variables on orbital frontal and amygdala volumes, patients with OCD (including the left-handed individuals) without a history of major depression had significantly less asymmetry of the amygdala compared with OCD patients with a history of major depression ($F_{1,22} = 6.91$, $P = .02$).

We also investigated total orbital frontal and total amygdala volumes and hippocampus and amygdala asymmetry indices (again for the total sample and then restricted to right-handed individuals) in relation to duration of current OCD episode and total illness duration, but none of these correlations was statistically significant.

COMMENT

Using parcellation methods based on sulcal anatomy, these findings provide the first MRI evidence to our knowledge of reduced orbital frontal volume in patients with OCD compared with healthy comparison subjects. It is noteworthy that reduced orbital frontal volume was identified in this sample of patients without associated struc-

tural compromise of other frontal lobe subregions including the anterior cingulate and superior frontal gyri. Investigation of mesiotemporal-limbic structures revealed that patients with OCD had reduced amygdala volume as well as an absence in the normal hemispheric asymmetry of the hippocampus-amygdala complex. Although these findings were unrelated to prior medication treatment, less asymmetry of the amygdala was more characteristic of OCD patients without a history of major depression.

There have been relatively few MRI investigations in OCD; thus, it is difficult to compare our results with prior studies. Grachev et al[39] reported no volume differences in the orbital frontal region between 10 female patients with OCD and 10 healthy female comparison subjects. An important difference between their study and our study, however, is that Grachev et al[39] used methods for neocortical parcellation and thus their measure included cortical gray matter alone whereas our measure included both gray and white matter. In another MRI study, Jenike et al[41] reported no group differences in amygdala volume using the same OCD and healthy comparison groups as the study by Grachev et al.[39] As noted by these authors, however, the small sample size may have limited statistical power. There is also the possibility, however, that OCD may be a heterogeneous disorder and that our study and their studies used different subgroups of patients. It is unlikely that different findings between the studies were due to the inclusion of male patients with OCD in our sample because there was no significant interaction of group and sex for any of the brain structure volumes.

The evolutionary cytoarchitectonic theory of cerebral cortex development proposed by Sanides[56] may provide a useful framework in which to interpret the findings of reduced orbital frontal and amygdala volumes. According to Sanides,[56] 6-layered isocortex in the frontal lobes develops from 2 primordial moieties: hippocampal ("archicortical") and olfactory ("paleocortical"). The archicortical trend includes the hippocampal formation, cingulate gyrus, and dorsal prefrontal cortices, whereas in the paleocortical trend cortical development is hypothesized to originate in the olfactory cortex and has higher phases of development in peri-insular, temporal polar (ie, amygdala), and ventral neocortices (ie, orbital frontal cortex). Results of Sanides' early studies have since been supported by modern cytoarchitectonic data, including anatomical studies of both long- and short-range connectivity patterns, and by patterns of laminar organization.[57,58] Thus, the amygdala and orbital frontal cortex together can be considered part of a trend in brain development deriving from an olfactory (ie, paleocortical) moiety.[7,8,56,59] The findings from this study would therefore be consistent with a pathophysiologic process involving paleocortical, but not archicortical brain regions in OCD.

Although the nonsignificant group differences in anterior cingulate gyrus volume may be difficult to reconcile with functional imaging studies that have implicated abnormalities of this region in OCD,[9,14,21] this finding was consistent with previous MRI investigations in adults with OCD, which have also yielded negative findings.[39,40] One possible explanation for our negative finding could be related to the lack of sensitivity of our MRI measure for detecting subtle neuronal loss or other abnormalities specifically in the anterior cingulate as compared with other measures such as ^{1}H-magnetic resonance spectroscopy of *N*-acetylaspartate, which have identified abnormalities of this region in patients with OCD.[60]

Table 2. Mean Asymmetry Indices*

Region	Patients With OCD (n = 26)	Healthy Comparison Subjects (n = 26)	Adjusted† 95% CI of Difference Between Groups
Superior frontal gyrus	–0.2 (6.6)	–0.8 (4.9)	–3.1 to 3.2
Anterior cingulate gyrus	11.6 (15.6)	8.4 (20.0)	–13.9 to 6.7
Oribtal frontal region‡	–5.8 (15.3)	–7.2 (14.5)	–11.0 to 7.5
Hippocampus	–0.4 (9.0)	–4.9 (8.3)	–9.4 to 0.5
Amygdala	2.3 (8.2)	8.7 (8.3)	1.8 to 11.3§

**Asymmetry index, given as mean (SD), was computed using the formula: [(right – left)/(right + left)] × 100. OCD indicates obsessive-compulsive disorder; CI, confidence interval.*

†Adjusted for age.

‡Sample sizes (n) were 24 and 22, respectively.

§P<.01.

Because most patients with OCD in this study had a long duration of symptoms prior to seeking treatment, the possibility of reduced brain volumes or abnormal asymmetry reflecting a neurodegenerative process occurring sometime during the first few years of symptoms cannot be entirely ruled out. There are, however, several reasons to argue against a neurodegenerative process. In this study we found no significant association of either brain structure volumes or asymmetry indices with duration of current OCD episode or total illness duration. Moreover, because we are unaware of any evidence that brain asymmetry can be diminished by a neurodegenerative process (at least among healthy individuals), the finding of anomalous hippocampus-amygdala asymmetry is probably more consistent with an aberrant neurodevelopmental process. Although the neurodevelopmental mechanisms underlying establishment of normal brain asymmetry are not fully understood, gross asymmetries are apparent as early as week 16 of gestation[61,62] and both hormonal and genetic influences probably contribute to this effect.[63,64]

There were several limitations of the morphometric delineation criteria that preclude firm conclusions. One limitation of the hippocampus-amygdala delineation methods was that precise separation of the hippocampus from the amygdala was not possible in these FLASH images. Thus, the amygdala volume included the most rostral part of the hippocampal formation, while the hippocampal volume included the most caudal part of the amygdala. In addition, because of methodological limitations, we did not use methods for gray and white matter segmentation and thus could not determine whether reduced orbital frontal volume was specific to the gray or white matter. An assumption in measuring the frontal lobe subregions based on sulcal anatomy is that these sulci provide accurate and meaningful bound-

aries between adjacent cytoarchitectonic areas. Although this study attempted to use theoretically meaningful sulcal boundaries, it is important to acknowledge that the size of architectonic fields can vary considerably among individuals and even among hemispheres of the same individual, and that these variations may not always map neatly onto the sulcal anatomy of the cortex.[65-67]

In summary, these results complement our previous MRI investigation[43] by identifying pathological involvement of additional brain regions in OCD. Future morphometric studies in OCD should focus on the thalamus, which could not be measured in the present study because of technical limitations of the imaging protocol, and use methods for gray and white matter segmentation of pathophysiologically relevant cortical subregions. An additional goal should be to address the relationship between abnormal structure and function in the same patients.

Accepted for publication June 16, 1999.

This work was supported by a grant from the Obsessive-Compulsive Foundation, Milford, Conn (Dr Szeszko), and grant MH46663-01A2 from the National Institute of Mental Health, Rockville, Md (Dr Robinson). This study was performed in association with The Brain Morphometry and Image Analysis Center of the North-Shore Long Island Jewish Health System, Glen Oaks, NY, supported by a grant from the Helen and Irving Schneider Family.

This study was presented in part at the Meeting of the Society for Biological Psychiatry, Toronto, Ontario, May 28, 1998.

Reprints: Philip R. Szeszko, PhD, Hillside Hospital, Department of Psychiatry Research, 75-59 263rd St, Glen Oaks, NY 11004 (e-mail: szeszko@lij.edu).

REFERENCES

1. Rapoport JL, Wise SP. Obsessive-compulsive disorder: evidence for basal ganglia dysfunction. *Psychopharmacol Bull.* 1988;24:380-384.
2. Modell JG, Mountz JM, Curtis GC, Greden JF. Neurophysiologic dysfunction in basal ganglia/limbic striatal and thalamocortical circuits as a pathogenetic mechanism of obsessive-compulsive disorder. *J Neuropsychiatry.* 1989;1:27-36.
3. Insel TR. Toward a neuroanatomy of obsessive-compulsive disorder. *Arch Gen Psychiatry.* 1992;49:739-744.
4. Cummings JL. Frontal-subcortical circuits and human behavior. *Arch Neurol.* 1993; 50:873-880.
5. Baxter LR, Schwartz JM, Bergman KS, Szuba MP, Guze BH, Mazziotta JC, Alazraki A, Selin CE, Ferng HK, Munford P, Phelps ME. Caudate glucose metabolic rate changes with both drug and behavior therapy for obsessive-compulsive disorder. *Arch Gen Psychiatry.* 1992;49:681-689.
6. Baxter LR. Positron emission tomography studies of cerebral glucose metabolism in obsessive compulsive disorder. *J Clin Psychiatry.* 1994;55(suppl):54-59.
7. Zald DH, Kim SW. Anatomy and function of the orbital frontal cortex, I: anatomy, neurocircuitry, and obsessive-compulsive disorder. *J Neuropsychiatry Clin Neurosci.* 1996;8:125-138.
8. Zald DH, Kim SW. Anatomy and function of the orbital frontal cortex, II: function and relevance to obsessive-compulsive disorder. *J Neuropsychiatry Clin Neurosci.* 1996;8:249-261.
9. Rauch SL, Jenike MA, Alpert NM, Baer L, Breiter HCR, Savage CR, Fischman AJ. Regional cerebral blood flow measured during symptom provocation in obsessive-compulsive disorder using ^{15}O-labeled CO_2 and positron emission tomography. *Arch Gen Psychiatry.* 1994;51:62-70.
10. Abbruzzese M, Bellodi L, Ferri S, Scarone S. Frontal lobe dysfunction in schizophrenia and obsessive compulsive disorder: a neuropsychological study. *Brain Cogn.* 1995;27:202-212.
11. Rosenberg DR, Averbach DH, O'Hearn KM, Seymour AB, Birmaher B, Sweeney JA. Oculomotor response inhibition abnormalities in pediatric obsessive-compulsive disorder. *Arch Gen Psychiatry.* 1997;54:831-838.
12. Schmidtke K, Schorb A, Winkelmann G, Hohagen F. Cognitive frontal lobe dysfunction in obsessive-compulsive disorder. *Biol Psychiatry.* 1998;43:666-673.
13. Nordahl TE, Benkelfat C, Semple WE, Gross M, King AC, Cohen RM. Cerebral glucose metabolic rates in obsessive-compulsive disorder. *Neuropsychopharmacology.* 1989;2:23-28.
14. Swedo SE, Schapiro MB, Grady CL, Cheslow DL, Leonard HL, Kumar A, Friedland R, Rapoport SI, Rapoport JL. Cerebral glucose metabolism in childhood-onset obsessive-compulsive disorder. *Arch Gen Psychiatry.* 1989;46:518-523.
15. Baxter LR, Phelps ME, Mazziotta JC, Guze BH, Schwartz JM, Selin CE. Local cerebral glucose metabolic rates in obsessive-compulsive disorder: a comparison with rates in unipolar depression and normal controls. *Arch Gen Psychiatry.* 1987; 44:211-218.
16. Baxter LR, Schwartz JM, Mazziotta JC, Phelps M, Pahl JJ, Guze BH, Fairbanks L. Cerebral glucose metabolic rates in nondepressed patients with obsessive-compulsive disorder. *Am J Psychiatry.* 1988;145:1560-1563.
17. Breiter HC, Rauch SL, Kwong KK, Baker JR, Weisskoff RM, Kennedy DN, Kendrick AD, Davis TL, Jiang A, Cohen MS, Stern CE, Belliveau JW, Baer L, O'Sullivan RL, Savage CR, Jenike MA, Rosen B. Functional magnetic resonance imaging of symptom provocation in obsessive-compulsive disorder. *Arch Gen Psychiatry.* 1996;53:595-606.
18. McGuire PK, Bench CJ, Frith CD, Marks IM, Frackowiak RS, Dolan RJ. Functional anatomy of obsessive-compulsive phenomena. *Br J Psychiatry.* 1994;164:459-468.
19. Benkelfat C, Nordahl TE, Semple WE, King C, Murphy DL, Cohen RM. Local cerebral glucose metabolic rates in obsessive-compulsive disorder: patients treated with clomipramine. *Arch Gen Psychiatry.* 1990;47:840-848.
20. Swedo SE, Pietrini P, Leonard HL, Schapiro MB, Rettew DC, Goldberger EL, Rapoport SI, Rapoport JL, Grady CL. Cerebral glucose metabolism in childhood-onset obsessive-compulsive disorder: revisualization during pharmacotherapy. *Arch Gen Psychiatry.* 1992;49:690-694.
21. Perani D, Colombo C, Bressi S, Bonfanti A, Grassi F, Scarone S, Bellodi L, Smeraldi E, Fazio F. [18F]-FDG PET study in obsessive-compulsive disorder: a clinical/metabolic correlation study after treatment. *Br J Psychiatry.* 1995;166:244-250.
22. Lucey JL, Costa DC, Blanes T, Busatto GF, Pilowsky LS, Takei N, Marks IM, Ell PJ, Kerwin RW. Regional cerebral blood flow in obsessive-compulsive disordered patients at rest: differential correlations with obsessive-compulsive and anxious-avoidant dimensions. *Br J Psychiatry.* 1995;167:629-634.
23. Martinot JL, Allilaire JF, Mazoyer BM, Hantouche E, Huret JD, Legaut-Demare F, Deslauriers AG, Hardy P, Pappata S, Baron JC, Syrota A. Obsessive-compulsive disorder: a clinical, neuropsychological, and positron emission tomography study. *Acta Psychiatr Scand.* 1990;82:233-242.
24. Rauch SL, Whalen PJ, Dougherty D, Jenike MA. Neurobiological models of obsessive-compulsive disorder. In: Jenike MA, Baer L, Minichiello WE, eds. *Obsessive-Compulsive Disorders Practical Management.* St Louis, Mo: Mosby–Year Book Inc; 1998:222-253.
25. Bechara A, Tranel D, Damasio H, Adolphs R, Rockland C, Damasio, AR. Double dissociation of conditioning and declarative knowledge relative to the amygdala and hippocampus in humans. *Science.* 1995;269:1115-1118.
26. Ketter TA, Andreason PJ, George MS, Lee C, Gill DS, Parekh PI, Willis MW, Herscovitch P, Post RW. Anterior paralimbic mediation of procaine-induced emotional and psychosensory experiences. *Arch Gen Psychiatry.* 1996;53:59-69.
27. Irwin W, Davidson RJ, Lowe MJ, Mock BJ, Sorenson JA, Turski PA. Human amygdala activation detected with echo-planar functional magnetic resonance imaging. *Neuroreport.* 1996;7:1765-1769.
28. Davis M. Neurobiology of fear responses: the role of the amygdala. *J Neuropsychiatry Clin Neurosci.* 1997;9:382-402.
29. Davis M. The role of the amygdala in fear and anxiety. *Annu Rev Neurosci.* 1992; 15:353-375.
30. Nagy J, Zambo K, Decsi L. Anti-anxiety action of diazepam after intra-amygdaloid application in the rat. *Neuropharmacology.* 1979;18:573-576.
31. Hodges H, Green S, Glenn B. Evidence that the amygdala is involved in benzodiazepine and serotonergic effects on punished responding but not on discrimination. *Psychopharmacology.* 1987;92:491-504.
32. Costall B, Kelly ME, Naylor RJ, Onaivi ES, Tyers MB. Neuroanatomical sites of action of 5-HT-3 receptor agonist and antagonists for alteration of aversive behavior in the mouse. *Br J Pharmacol.* 1989;96:325-332.
33. Gonzalez LE, Andrews N, File SE. 5-HT1A and benzodiazepine receptors in the basolateral amygdala modulate anxiety in the social interaction test, but not in the elevated plus-maze. *Brain Res.* 1996;732:145-153.
34. Horwitz B, Swedo SE, Grady CL, Pietrini P, Schapiro, MB, Rapoport JL, Rapoport SI. Cerebral metabolic pattern in obsessive-compulsive disorder: altered interconnections between regional rates of glucose utilization. *Psychiatry Res Neuroimaging.* 1991;40:221-237.

35. Rauch SL, Savage CR, Alpert NM, Dougherty D, Kendrick A, Curran T, Brown HD, Manzo P, Fischman AJ, Jenike MA. Probing striatal function in obsessive-compulsive disorder: a PET study of implicit sequence learning. *J Neuropsychiatry Clin Neurosci.* 1997;9:568-573.
36. Gray JA. *The Neuropsychology of Anxiety: An Enquiry Into the Functions of the Septo-Hippocampal System.* Oxford, England: Oxford University Press; 1982.
37. Pitman RK. Animal models of compulsive behavior. *Biol Psychiatry.* 1987;26: 189-198.
38. Pitman RK. A cybernetic model of obsessive-compulsive psychopathology. *Compr Psychiatry.* 1987;28:334-343.
39. Grachev ID, Breiter HC, Rauch SL, Savage CR, Baer L, Shera DM, Kennedy DN, Makris N, Caviness VS, Jenike MA. Structural abnormalities of frontal neocortex in obsessive-compulsive disorder [letter]. *Arch Gen Psychiatry.* 1998;55:181-182.
40. Kellner CH, Jolley RR, Holgate RC, Austin L, Lydiard RB, Laraia M, Ballenger JC. Brain MRI in obsessive-compulsive disorder. *Psychiatry Res.* 1991;36:45-49.
41. Jenike M, Breiter HC, Baer L, Kennedy DN, Savage CR, Olivares MJ, O'Sullivan M, Shera DM, Rauch SL, Keuthen N, Rosen BR, Caviness VS, Filipek PA. Cerebral structural abnormalities in obsessive-compulsive disorder: a quantitative morphometric magnetic resonance imaging study. *Arch Gen Psychiatry.* 1996;53: 625-632.
42. Rosenberg DR, Keshavan MS. Toward a neurodevelopmental model of obsessive-compulsive disorder. *Biol Psychiatry.* 1998;43:623-640.
43. Robinson D, Wu H, Munne RA, Ashtari M, Alvir JMaJ, Lerner G, Koreen A, Cole K, Bogerts B. Reduced caudate nucleus volume in obsessive-compulsive disorder. *Arch Gen Psychiatry.* 1995;52:393-398.
44. Szeszko PR, Bilder RM, Lencz T, Pollack S, Alvir JMaJ, Ashtari M, Wu H, Lieberman JA. Investigation of frontal lobe subregions in first-episode schizophrenia. *Psychiatry Res Neuroimaging.* 1999;90:1-16.
45. Spitzer RL, Williams JBW, Gibbon M. *Structured Clinical Interview for DSM-III-R: Patient Version: SCID-P 4/1/88.* New York: Biometrics Research Department, New York State Psychiatric Institute; 1988.
46. Bogerts B, Meertz E, Schonfeld-Bausch R. Basal ganglia and limbic system pathology in schizophrenia. *Arch Gen Psychiatry.* 1985;42:784-791.
47. Ashtari M, Zito JL, Gold BI, Lieberman JA, Borenstein M, Herman PG. Computerized volume measurement of brain structure. *Invest Radiol.* 1990;25:798-805.
48. Bogerts B, Ashtari M, Degreef G, Alvir JMaJ, Bilder RM, Lieberman JA. Reduced temporal limbic structure volumes on magnetic resonance images in first-episode schizophrenia. *Psychiatry Res Neuroimaging.* 1990;35:1-13.
49. Bogerts B, Lieberman JA, Ashtari M, Bilder RM, Degreef G, Lerner G, Johns C, Masiar S. Hippocampus-amygdala volumes and psychopathology in chronic schizophrenia. *Biol Psychiatry.* 1993;33:236-246.
50. Cox RW. *Analysis of Functional NeuroImages* [computer program]. Milwaukee: Biophysics Research Institute, Medical College of Wisconsin–Milwaukee; 1995.
51. Rademacher J, Galaburda AM, Kennedy DN, Filipek PA, Caviness VS Jr. Human cerebral cortex: localization, parcellation, and morphometry with magnetic resonance imaging. *J Cogn Neurosci.* 1992;4:352-374.
52. Bilder RM, Wu H, Bogerts B, Degreef G, Ashtari M, Alvir JMaJ, Snyder PJ, Lieberman JA. Absence of regional hemispheric volume asymmetries in first-episode schizophrenia. *Am J Psychiatry.* 1994;151:1437-1447.
53. Oldfield RC. The assessment and analysis of handedness: the Edinburgh Inventory. *Neuropsychologia.* 1971;9:97-114.
54. Goodman WK, Rasmussen SA, Price LH, Mazure C, Heninger GR, Charney DS. *Yale-Brown Obsessive Compulsive Scale (Y-BOCS).* New Haven: Clinical Neuroscience Research Unit, Connecticut Mental Health Center; 1988.
55. Hamilton M. A rating scale for depression. *J Neurol Neurosurg Psychiatry.* 1960; 23:56-62.
56. Sanides F. Comparative architectonics of the neocortex of mammals and their evolutionary interpretation. *Ann N Y Acad Sci.* 1969;167:404-423.
57. Pandya DN, Barnes CL. Architecture and connections of the frontal lobe. In: Perecman E, ed. *The Frontal Lobes Revisited.* New York, NY: IBRN Press; 1987.
58. Yeterian EH, Pandya DN. Architectonic features of the primate brain: implications for information processing and behavior. In: Markowitsch HJ, ed. *Information Processing by the Brain.* Gottingen, Germany: Hans Huber Publishers; 1988:7-37.
59. Mega MS, Cummings JL, Salloway S, Malloy P. The limbic system: an anatomic, phylogenetic, and clinical perspective. *J Neuropsychiatry Clin Neurosci.* 1997;9:315-330.
60. Ebert D, Speck O, Konig A, Berger M, Hennig J, Hohagen F. 1H-magnetic resonance spectroscopy in obsessive-compulsive disorder: evidence for neuronal loss in the cingulate gyrus and right striatum. *Psychiatry Res Neuroimaging.* 1997; 74:173-176.
61. LeMay M. Morphological cerebral asymmetries of modern man, fossil man, and nonhuman primate. *Ann N Y Acad Sci.* 1976;280:349-366.
62. Witelson SF, Pallie W. Left hemisphere specialization for language in the newborn: neuroanatomical evidence of asymmetry. *Brain.* 1973;96:641-646.
63. Geschwind N, Galaburda AM. *Cerebral Lateralization: Biological Mechanisms, Associations and Pathology.* Cambridge, Mass: MIT Press; 1987.
64. Best CT. The emergence of cerebral asymmetries in early human development: a literature review and a neuroembryological model. In: Molfese DL, Segalowitz SJ, eds. *Brain Lateralization in Children: Developmental Implications.* New York, NY: Guilford Press; 1988.
65. Galaburda AM, Sanides F, Geschwind N. Human brain: cytoarchitectonic left-right asymmetries in the temporal speech region. *Arch Neurol.* 1978;35:812-817.
66. Rajkowska G, Goldman-Rakic PS. Cytoarchitectonic definition of prefrontal areas in the normal human cortex: I, remapping of areas 9 and 46 using quantitative criteria. *Cereb Cortex.* 1995;5:307-322.
67. Rajkowska G, Goldman-Rakic PS. Cytoarchitectonic definition of prefrontal areas in the normal human cortex: II, variability in locations of areas 9 and 46 and relationship to the Talairach coordinate system. *Cereb Cortex.* 1995;5:323-337.