Progressive Cortical Change During Adolescence in Childhood-Onset Schizophrenia

A Longitudinal Magnetic Resonance Imaging Study

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Background: Adolescence provides a window to examine regional and disease-specific late abnormal brain development in schizophrenia. Because previous data showed progressive brain ventricular enlargement for a group of adolescents with childhood-onset schizophrenia at 2-year follow-up, with no significant changes for healthy controls, we hypothesized that there would be a progressive decrease in volume in other brain tissue in these patients during adolescence.

Methods: To examine cortical change, we used anatomical brain magnetic resonance imaging scans for 15 patients with childhood-onset schizophrenia (defined as onset of psychosis by age 12 years) and 34 temporally yoked, healthy adolescents at a mean (SD) age of 13.17 (2.73) years at initial baseline scan and 17.46 (2.96) years at follow-up scan. Cortical gray and white matter volumes were obtained with an automated analysis system that classifies brain tissue into gray matter, white matter, and cerebrospinal fluid and separates the cortex into anatomically defined lobar regions.

Results: A significant decrease in cortical gray matter volume was seen for healthy controls in the frontal (2.6%) and parietal (4.1%) regions. For the childhood-onset schizophrenia group, there was a decrease in volume in these regions (10.9% and 8.5%, respectively) as well as a 7% decrease in volume in the temporal gray matter. Thus, the childhood-onset schizophrenia group showed a distinctive disease-specific pattern (multivariate analysis of variance for change region diagnosis: F, 3.68; \( P = .004 \)), with the frontal and temporal regions showing the greatest between-group differences. Changes in white matter volume did not differ significantly between the 2 groups.

Conclusions: Patients with very early-onset schizophrenia had both a 4-fold greater decrease in cortical gray matter volume during adolescence and a disease-specific pattern of change. Etiologic models for these patients’ illness, which seem clinically and neurobiologically continuous with later-onset schizophrenia, must take into account both early and late disruptions of brain development.

Arch Gen Psychiatry. 1999;56:649-654

The neurodevelopmental hypothesis of schizophrenia suggests that a brain “lesion” is present early in life but does not manifest itself until late adolescence or early adulthood. Compelling clinical support for this model comes from numerous demonstrations of subtle but consistent abnormalities in cognitive and behavioral development noted years before the onset of psychosis. In addition, the postmortem neuropathological findings in schizophrenia can be viewed as consistent with an early nonprogressive event. The lack of progressive change in longitudinal brain imaging studies of patients with adult-onset schizophrenia is also cited as support for the “fixed lesion” neurodevelopmental hypothesis. Of the 5 prospective longitudinal anatomical brain magnetic resonance imaging (MRI) studies of adult-onset schizophrenia that compared patients with temporally yoked controls, only 2 found greater progression for their schizophrenic group as a whole. Others found either no progression or evidence of progression for only a subgroup.

Childhood-onset schizophrenia (COS) (defined as onset of psychosis by age 12 years) is a rare, usually severe manifestation of the disorder that has been shown to be continuous with the adult-onset disorder with respect to clinical and neurological characteristics, including brain MRI pattern. There is also continuity in the pattern of associated risk factors, such as early developmental language and speech abnormalities years before the onset of psychosis, cytogenetic abnormalities, and various psychopath-
SUBJECTS AND METHODS

Subjects included 15 children and adolescents who had been recruited to the National Institute of Mental Health study of COS. Recruiting and diagnostic methods have been described elsewhere. Briefly, children were sought via national recruiting who met unmodified DSM-III-R criteria for schizophrenia, with onset of psychotic symptoms by age 12 years. From more than 1000 referrals, approximately 250 patients and their families were screened in person, using both clinical examination and structured interviews over a daylong evaluation. The clinical diagnosis of schizophrenia for this group showed good reliability. Fifty-four patients received the diagnosis of COS; 47 had participated in the study at the time of this report. As patients were also participating in a clozapine treatment trial, they were refractory to treatment with typical neuroleptics.

All subjects returned at regular intervals, at which time clinical reevaluation and MRI follow-up scans were carried out. Of the 47 subjects studied to date, valid baseline scans could not be obtained for 2. Of the remaining 45, 28 had returned for at least 1 follow-up scan; 18 were rescanned after 3 to 5 years while they were still in adolescence, and 3 of these 18 had 1 scan each that could not be processed by the automated system. Most of the remaining subjects who had not been rescanned were not yet due for their 4-year (approximate) follow-up scan. Thus, only 3 eligible cases were truly unavailable to our team for MRI reevaluation. The 15 cases in the present study did not differ significantly with respect to any clinical or demographic measure from the remainder of the sample.

A temporally yoked, age- and sex-matched healthy control group of 46 adolescents was selected by a systematic evaluation process; 34 with processable scans served as the contrast group for this report. Controls were free of lifetime medical or psychiatric disorders as determined by clinical examination and standardized interview. Psychiatric illness in a first-degree relative was also exclusionary. The combined groups had a mean (SD) age of 13.17 (2.73) years at the time of initial scan, and returned after 4.28 (0.63) years for follow-up scans. Characteristics of patients and control subjects at baseline and follow-up scan are shown in Table 1.

As shown in Table 1, patients were severely ill, with a mean ± SD age of onset of psychotic symptoms at 10.3 ± 2.0 years. The patient group received a considerable amount of medication prior to initial scan, and at follow-up, all but 2 were taking medication. The scan intervals did not differ for the 2 groups. Moreover, while at first scan, the medications were primarily typical neuroleptics, at follow-up, 11 of the 15 patients were receiving atypical neuroleptics, with 2 receiving both a typical and an atypical agent. All met the criteria for schizophrenia (4 were in remission while taking clozapine) at the follow-up scan. None of these young subjects had a history of substance abuse. Thus, while patients were matched for age, sex, and time of scan, they differed significantly with respect to ethnicity, socioeconomic status, IQ score, exposure to medication, and weight at follow-up scan.

The study was approved by the National Institute of Mental Health Institutional Review Board. Parents gave written consent, and minor volunteers and patients gave verbal assent for this study.

MRI ACQUISITION AND ANALYSIS

All images were acquired on the same 1.5-T Signa scanner (General Electric, Milwaukee, Wis) located at the National Institutes of Health Clinical Center, Bethesda, Md. A 3-dimensional spoiled gradient-recalled echo in the steady-state sequence designed to optimize discrimination between gray matter, white matter, and cerebrospinal fluid was used to acquire 124 contiguous 1.5-mm-thick slices.

logic conditions, including schizophrenia and/or "spectrum" disorders, smooth-pursuit eye movement abnormalities, and/or cognitive abnormalities in the close relatives of the COS patients.

An ongoing National Institute of Mental Health study of COS included brain MRI rescans at regular intervals as part of the follow-up examination. A previous report documented an increase in brain ventricular volume between mean ages 14 and 16 years for this group that was more striking and consistent than that reported for adult-onset cases. The study also found a trend for differential decrease in total brain volume for adolescents with schizophrenia, but regional cortical volumes were not examined.

The present report is of regional cortical gray and white matter volumes for a group of patients with COS scanned at initial contact (mean age, 13.9 years) and at 3- to 5-year follow-up (mean age, 18.1 years). To carry out this examination, an automated segmentation system developed at the Montreal Neurological Institute, Montreal, Quebec, was used. Because of our earlier brain ventricular data and the smaller total brain and temporal lobe volumes with greater loss of gray matter characteristic of adults with schizophrenia, we hypothesized that there would be commensurate differential changes in other brain tissue, including cortical gray matter, with patients with COS showing a greater and more regionally selective decline than seen for healthy controls.

RESULTS

Both absolute baseline and follow-up scan values and percentage change for total and regional gray and white volumes are shown in Table 2 for COS patients and healthy controls.

WITHIN-GROUP CHANGE

For the 34 healthy controls, there was a significant (1.3%) decrease in total cerebral volume that was accounted for by a decrease in gray matter volume (1.98%) (t = 2.12, P = .04). As seen in Table 2, the regional gray matter changes also showed a statistically significant selective regional pattern (MANOVA Wilks λ: F, 19.1; P < .001), with the greatest change in the frontal and parietal gray matter and the smallest change in the occipital and temporal gray matter regions.
For the 15 COS patients, there was a significant (5.5%) decrease in total cerebral volume that was accounted for by a decrease in gray matter (8.0%). The regional gray matter change also differed selectively for COS patients (MANOVA Wilks \( \lambda \): F, 3.72; \( P = .001 \)), with 7% to 10% decreases for frontal, parietal, and temporal gray matter volume and no significant change in the occipital region.

**BETWEEN-GROUP COMPARISONS**

As shown in Table 2, the percentage change differed strikingly between the groups for gray matter, with the COS group showing an exaggerated and unique pattern (MANOVA Wilks \( \lambda \): F, 3.72; \( P = .002 \) overall; F, 3.68; \( P = .004 \) for regional \( \times \) diagnosis interaction). The diagnostic differences were most striking for temporal (\( P < .001 \)) and frontal (\( P = .001 \)) gray matter volumes. There was no significant difference between the groups with respect to white matter change.

The disease-specific change in brain development is seen most clearly in the Figure, showing the difference in the percentage and pattern of decline between the COS and healthy control groups.

**CLINICAL AND DEMOGRAPHIC RELATIONSHIPS**

Boys had more robust decreases in gray matter than did girls (\( P = .05 \)), and this difference was more pronounced for the COS group (ANOVA: F, 4.09; \( P = .05 \) for diagnosis \( \times \) sex). For the healthy controls, there was no significant relationship between full-scale IQ score, socioeconomic status, or ethnicity and slope of change for any region. For the COS group, those with higher baseline Brief Psychiatric Rating Scale scores had a greater rate of volume decrease for temporal, parietal, and frontal gray matter (\( t, 2.6-3.5; P < .01 \)). There was no significant relationship between weight gain or drug exposure and slope for any region. Further clinically relevant analyses were precluded by missing data and small sample size.

**COMMENT**

Within a 4-year mid-adolescent period, a significant decline in cortical gray matter volume was seen for the healthy controls. The frontal gray and white matter and parietal gray matter volumes decreased, while white matter volumes in the parietal temporal and occipital regions increased. These data support previous cross-
sectional studies of clinically referred children and adolescents and healthy prescreened controls, which found age-related decreases in cortical gray matter. Most recently, Sowell et al. found similar and striking age-related decreases in frontal and parietal gray matter for 35 healthy children and adolescents for whom statistical mapping of subtraction images was carried out. Brain regions do not normally mature in parallel, and the regional changes seen here are more robust than generally seen in young adults.

These longitudinal data for middle and late adolescence show that frontocortical gray matter volume is decreasing. While it is tempting to ascribe these developmental brain changes to peripubertal events, this is clearly not the case. Evidence from cross-sectional studies, shows that the trend for decrease in gray mat-

Table 1. Demographic Data for Patients With Childhood-Onset Schizophrenia and Healthy Controls

<table>
<thead>
<tr>
<th>Region</th>
<th>Patients (n = 15)</th>
<th>Controls (n = 34)</th>
<th>Diagnosis at Baseline, F Test</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y (range)</td>
<td>13.9 ± 2.3 (9.2-17.9)</td>
<td>18.1 ± 2.7 (13.3-23.3)</td>
<td>17.2 ± 2.9 (18.2-21.7)</td>
<td>1.66</td>
</tr>
<tr>
<td>Male/female, No.</td>
<td>6/9</td>
<td>30/41</td>
<td></td>
<td></td>
</tr>
<tr>
<td>White/black/other, No.</td>
<td>5/7/3</td>
<td>33/0/1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height, cm†</td>
<td>180.8 ± 8.6</td>
<td>167.9 ± 8.1</td>
<td>156.9 ± 16.8</td>
<td>169.2 ± 11.1</td>
</tr>
<tr>
<td>Weight, kg†</td>
<td>58.0 ± 14.3</td>
<td>81.3 ± 21.5</td>
<td>62.2 ± 11.7</td>
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</tr>
<tr>
<td>Right-handed/lefthanded/mixed, No.</td>
<td>11/3/1</td>
<td>30/4/0</td>
<td>3.04</td>
<td>.22</td>
</tr>
</tbody>
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* SES indicates socioeconomic status; WISC, Wechsler Intelligence Scale for Children; BPRS, Brief Psychiatric Rating Scale; SANS, Scale for Assessment of Negative Symptoms; and SAPS, Scale for Assessment of Positive Symptoms.
† Values are mean ± SD.
‡ x² analysis.
§ Rated using the Hollingshead 2-factor index.
¶ The estimated full-scale IQ score for 26 subjects was used; IQ scores were not available for 5 patients.
† Two additional patients were given both typical and atypical neuroleptics.
# Follow-up BPRS, SANS, and SAPS scores were missing for 2 patients.

Table 2. Anatomical Brain Magnetic Resonance Imaging Measures and Percentage Changes at Baseline and 3- to 5-Year Follow-up During Adolescence for Patients With Childhood-Onset Schizophrenia and Healthy Controls

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* Values are mean ± SD.
† Values are in cubic centimeters.
‡ Values were calculated as follows: (follow-up - baseline)/baseline × 100.
§ Multivariate analysis of variance was used for gray matter vs white matter: F₄₄, 6.23; P = .004.
| Post hoc results for diagnostic differences: P = .003.
| Post hoc results for diagnostic differences: P = .001.
| Post hoc results for diagnostic differences: P = .04.

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symptoms of schizophrenia. Thus, a specific pattern in frontal and temporal lobe connectivity underlie the consistent with evidence suggesting that abnormalities in the frontal and temporal areas. These data are also consistent with evidence suggesting that abnormalities in frontal and temporal lobe connectivity underlie the symptoms of schizophrenia. Thus, a specific pattern in keeping with MRI findings for adults with schizophrenia develops across the adolescent years. The presumed changes underlying this differential progression would include excessive synaptic and dendritic pruning, and probably also trophic glial and vascular decreases, compatible with the neuropathological findings of Selemon et al, Rajkowska et al, and Selem and Goldman-Rakie, showing increased neuronal density and possible trophic glial changes in the schizophrenic cortex.

Adolescence is a period of marked change in brain anatomy and metabolism. Because neuropathological observations of normal development are based on very meager data sets since death during childhood and adolescence of otherwise healthy individuals is rare, brain MRI studies provide a unique and noninvasive way to study brain development in healthy children. This study extends our earlier cross-sectional data with the first longitudinal brain MRI study of healthy adolescents; surprisingly robust changes are seen during this limited period between ages 13 and 18 years.

This study of diagnostic differences in brain development is limited by many factors. The samples are not matched for socioeconomic status, race, IQ score, or exposure to neuroleptic medication. Moreover, several COS patients were switched to therapy with newer atypical antipsychotics at follow-up. In addition, COS patients represent a severely ill, treatment-refractory population; “episodes” of illness were virtually unknown and fluctuations in clinical state were regrettably few. Thus, it might be argued that these differences in progression reflect the course of a subgroup of subjects with poor outcomes described in previous studies of patients with adult-onset schizophrenia. This seems unlikely, however, given that as our patients reach their early adult years, the rate of ventricular enlargement slows and does not differ from that of healthy controls. Thus, the lack of progression seen in most studies of adult patients was also observed in our subjects after they passed through adolescence.

In theory, the late progressive brain changes might reflect some unique interaction between adolescent brain development and the illness, including stress and drastically altered environmental exposure and/or treatments, not seen in schizophrenia at other ages. This possibility cannot be addressed by these data. An ongoing longitudinal MRI study of our patients’ siblings may shed further light on a familial genetic basis for these progressive events. It is unlikely, however, that the patients’ differential weight gain affected our findings; after age was taken into account, neither weight nor body mass index was significantly related to any brain measure or to these progressive changes.

The differential changes seen in our COS patients are not directly relevant to the issue of “triggers” for psychosis. Our patients had a mean age of onset of psychotic symptoms of 10.3 years (Table 1), while their mean age at first scan was 14 years. These data do, however, indirectly support models of schizophrenia postulating later abnormalities of brain development.

Finally, this study does not undermine the neurodevelopmental model of schizophrenia. In fact, the early developmental histories of our group show more striking impairments in language and motor development than reported for patients with adult-onset schizophrenia. However, it is already evident that genes known to influence prenatal brain development may also play a role in later maturation. These findings do indicate that etiologic models of schizophrenia, whether genetic or environmental, need to take into account both early and late neurodevelopmental events.

Accepted for publication March 30, 1999.

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REFERENCES


