Surface Area, Volume and Cortical Thickness Metrics of the Cingulate Gyrus in Schizophrenia

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Introduction

The cingulate gyrus (CG) has attracted considerable interest because of its role in deleted cognitive functions that appear to be critical for understanding schizophrenia. Abnormalities in structure and function of the cingulate gyrus have been reported in schizophrenic subjects. Automated methods of cortical analysis described here involve construction of the 3D neocortical mantle representing the positions of the gray matter connected voxels that form the highly convoluted structure, and the construction of a triangulated graph representing the 2D submanifold of the gray/white matter boundary which are linked in that the 2D submanifold, and hence its convoluted geometry, is determined by the variation, position, and density of the cortical mantle cells, manifested as gray matter at the macroscopic scale of current MRI imaging methods. Gray matter volume is necessarily the product of the surface area of the structure and its thickness. The separate measurement of surface area and thickness, especially within small subregions that are topographically distinct, may be essential when attempting to detect subtle aberrations of neuronal cytoarchitecture.

Subjects and Scans

	N (m/f)	Age (yrs)
Schizophrenia	54 (32/22)	37.2 (±12.0)
Control	68 (35/33)	39.1 (±14.4)

- Magnetom SP-4000 1.5T Siemens imaging system, standard head coil
- 3D Turbo FLASH sequence (TR=20ms, TE=5.4ms, flip angle=30º)
- 1mm section thickness, 180 slices, 256mm FOV, matrix 256x256
- Acquisitions=1, scanning time=13.5 min @ 1mm^3/voxel

Methods

Bayesian segmentation with partial volumes was used to classify tissues in MRI cingulate subvolumes as cerebrospinal fluid (CSF), Partial volume CSF/Grey (PCG), Gray Matter (GM), Partial volume Grey/White (PGW) and White Matter (WM) as follows:

$$CSF,\ PCG,\ G,\ PGW,\ W:\ \ p(I_n \mid \mu_n(h_n), \sigma_n^2(h_n)) = \prod_{n=1}^{N} \frac{1}{\sqrt{2\pi\sigma_n^2(h_n)}}\, e^{\frac{-(I_n-\mu_n(h_n))^2}{2\sigma_n^2(h_n)}}$$

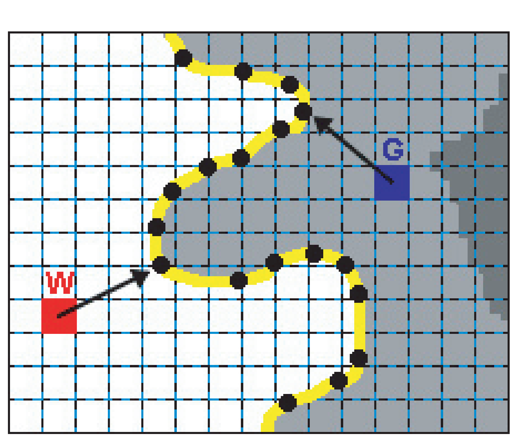
Segmentation recalibration into CSF, GM and WM is performed via Neyman-Pearson Likelihood Ratio Test [1]:

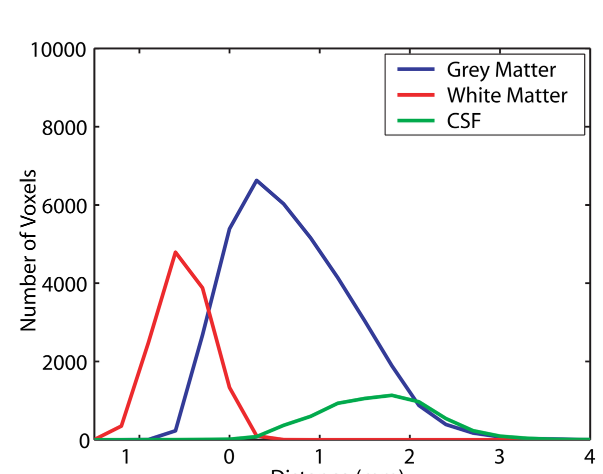
$$\frac{p(I_n \mid h_n = G)}{p(I_n \mid h_n = CSF)} \underset{C}{\overset{G}{\gtrless}} \theta_{C/G},\quad \frac{p(I_n \mid h_n = W)}{p(I_n \mid h_n = G)} \underset{G}{\overset{W}{\gtrless}} \theta_{G/W}$$

The MRI subvolume is binarized according to the threshold $\theta_{G/W.}$ A topology correction method is applied to the binarized volume to remove handles. The original intensity of the modified voxels is then adjusted. This ensures that the binarization of the edited image is the same as the topologically correct binary image. A connectivity-consistent isosurface algorithm is used to extract the isosurface of the edited image [2,3]. Dynamic programming is used to define a closed-path boundary of the subsurface [4].

Labeled Cortical Distance Maps (LCDM)

Following Miller et al. [5], we generated LCDMs which are histograms of labeled tissue compartments of GM, WM and CSF computed as a function of distance from the GM/WM isosurface as illustrated below. Normalizing the histograms by the corresponding total volume yielded Cortical Mantle Distance (CMD) profiles of GM distribution as a function of distance independant of total GM volume.





References:

[1] Ratnanather, JT, Wang, L, et al, 2004 *Psychiatry Research: Neuroimaging* 132: p. 53-68.
[2] Han, X, et al, 2002 *IEEE Trans. Med. Imag.*, 21: p. 109-121.
[3] Han, X, et al, 2001 *CVPR'2001, vol. 2. IEEE*, Kauai, HI. p. 765-770.
[4] Khaneja, N, et al, 1998 *IEEE Trans. Pattern Anal. Mach. Intell.*, 20: p.1260-1265.
[5] Miller, M. I. et al. 2003 *Proc. Nat'l Acad. Sci* 100: 15172-15177.

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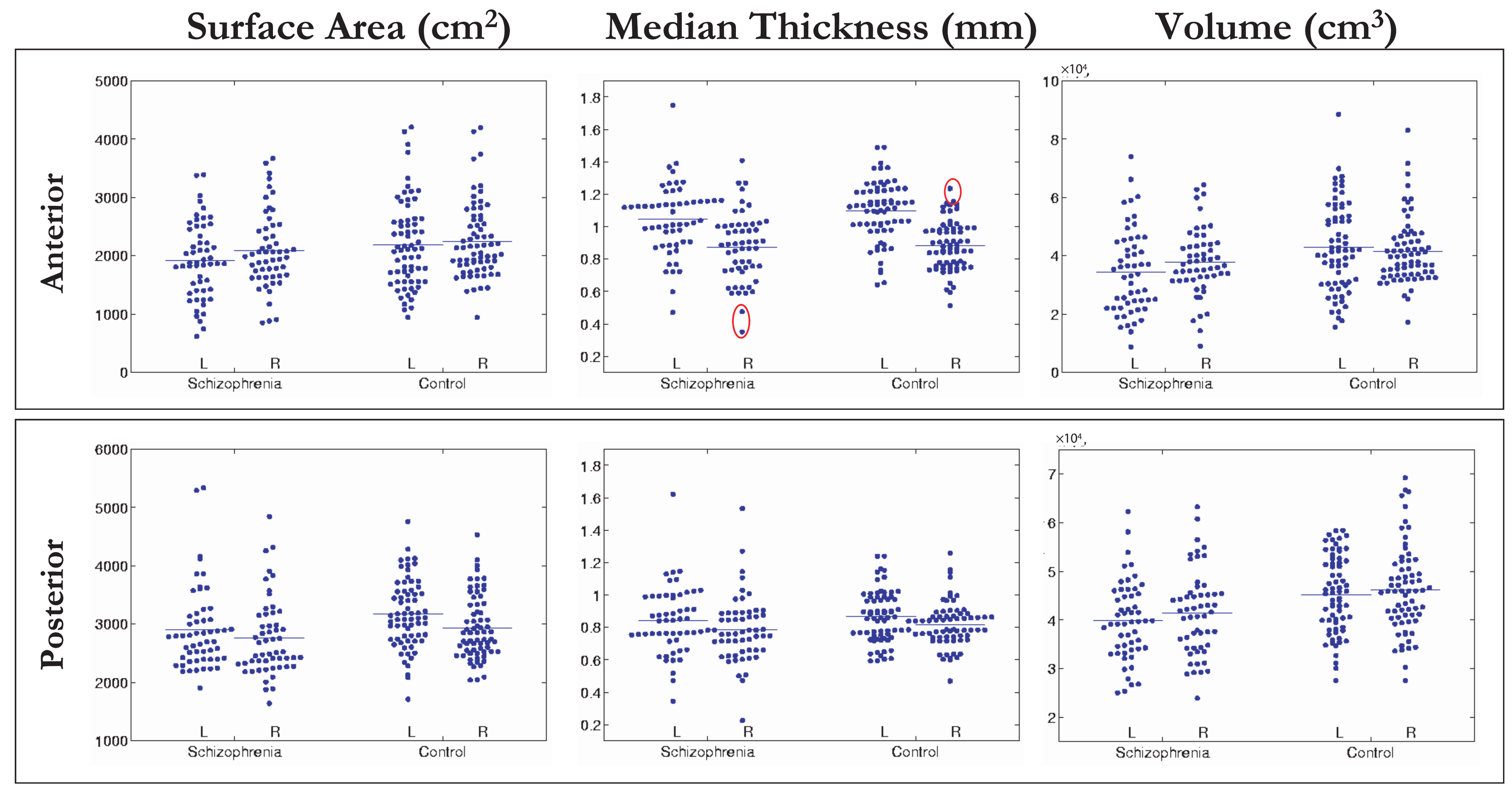
Results

Surface Area (cm²) | **Median Thickness (mm)** | **Volume (cm³)**



Cortical thickness metrics projections onto 3-D surface for 2 outlier subjects/group (circled in red above)

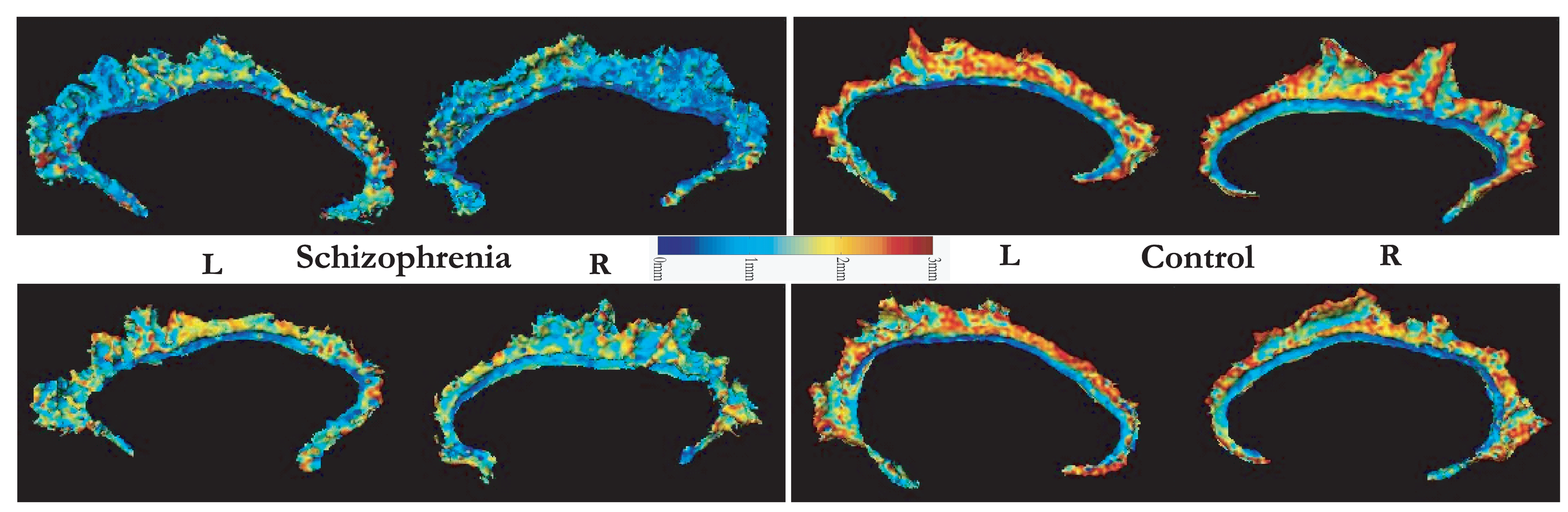


Table 1: group comparisons of schizophrenia vs control

	Schizophrenia				Control			
	Left		Right		Left		Right	
	Anterior	Posterior	Anterior	Posterior	Anterior	Posterior	Anterior	Posterior
Surface Area (mm^2)	*19.2	*29.0	20.9	*27.6	21.9	31.7	22.5	29.3
Median Thickness (mm)	*1.05	*0.84	*0.87	0.79	1.10	0.87	0.88	0.82
Volume (mm^3)	**34.4	**39.8	37.8	**41.4	42.8	45.2	41.4	46.2

* $p < 0.05$ Schizophrenia < Control, ** $p < 0.01$ Schizophrenia < Control

Table 2: p-values for asymmetry

	Left-Right Asymmetry				Anterior-Posterior Asymmetry			
	Schizophrenia		Control		Schizophrenia		Control	
	Anterior	Posterior	Anterior	Posterior	Left	Right	Left	Right
Surface Area (mm^2)	.0868(ℓ)	.0072*(g)	.1757(ℓ)	.0001*(g)	<.0001*(ℓ)	<.0001*(ℓ)	<.0001*(ℓ)	<.0001*(ℓ)
Median Thickness (mm)	<.0001*(g)	<.0001*(g)	<.0001*(g)	<.0001*(g)	<.0001*(g)	<.0001*(g)	<.0001*(g)	<.0001*(g)
Volume (mm^3)	.0638(ℓ)	.0596(ℓ)	.2537(g)	.1149(ℓ)	.0092*(ℓ)	.0248*(ℓ)	.0822(ℓ)	.0003*(ℓ)

* $p < 0.05$
ℓ = less than, g = greater than

- Surface areas of left anterior CG in schizophrenia subjects is less than those of control subjects. Likewise for median thickness and volume comparisons (Table 1).

- The surface areas of both Left and Right Posterior CG schizophrenia subjects is less than those of Control subjects. Likewise for volume comparisons (Table 1).

- The surface area of Left Posterior CG and median thickness of both Left Anterior and Posterior CG is significantly larger than those of Right for schizophrenia subjects. Likewise for control subjects (Table 2).

- The surface area of both Left and Right Anterior CG is significantly less than those of Posterior CG for schizophrenia subjects. Likewise for control subjects. The median thickness of both Left and Right Anterior CG is significantly larger than those of Posterior CG for schizophrenia subjects. Likewise for control subjects. The volume of both Left and Right Anterior CG is significantly less than those of Posterior CG for schizophrenia subjects; however the volume of only Right Anterior CG is significantly less than those of Posterior CG for control subjects (Table 2).

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