ORIGINAL PAPER

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Inter- and intraoperator reliability of brain tissue measures using magnetic resonance imaging

Received: 25 November 2002 / Accepted: 3 July 2003

Abstract Grey matter, white matter and cerebrospinal volume in the human brain were measured using magnetic resonance image analysis software BRAINS. Ten volunteers were scanned in the MR sequence (3D-SPGR; 1.5-mm slice thickness and T2 images; 3 mm slice thickness). Two operators obtained ten volume measures of grey matter, white matter and cerebrospinal fluid (CSF) in the intracranial box, frontal box, temporal box, parietal box and occipital box. The same data set of ten scans was segmented and the volumes measured on a second occasion by one operator using the same procedure. The interoperator and intraoperator reliabilities for measures of the three brain tissues were very good, with reliability coefficients (intraclass correlation coefficients) ranging between 0.971 and 0.999. The segmentation and measurement are useful for volumetric studies in the human brain using BRAINS.

Key words classification · magnetic resonance imaging · reliability · segmentation · Talairach boxes · intracranial volume

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Introduction

A previous study from our research collaborator reported excellent reliability and reproducibility of brain tissues measurements from segmented MR scans (Agartz et al. 2001). At the Department of Neuropsychiatry, Kansai Medical University, our research group is developing a database for brain morphology using MRI scans in order to clarify involvement of the pathophysiology in structural brain changes. In the present study, we examined the inter- and intraoperator reliability of measurements of segmented brain tissue volumes from MR scans. To segment brain tissues, we used the BRAINS software for MR image analysis (Andreasen et al. 1992, 1993). Harris et al. reported excellent reliability and validity using the BRAINS program (Harris et al. 1999). There is no evidence of the reliability for brain tissue measures in the left and right hemispheres separately from any other research groups except Agartz et al. (2001). We report left and right absolute volumes of grey matter, white matter and CSF in intracranial volume, frontal box, temporal box, parietal box and occipital box according to the Talairach atlas (Talairach and Tournoux 1988). The aim of this study was to test the inter- and intraoperator reliability of volume measurements from the segmentation of MRI scans using the BRAINS program.

Methods

The protocol was approved by the Institute Review Board at Kansai Medical University. All subjects gave written informed consent.

Subjects

All subjects were recruited at the Department of Neuropsychiatry, Kansai Medical University. Age range was 26–41 years. All subjects were Japanese. Eight subjects were healthy males and one subject was a healthy female. One subject was a male patient with schizophrenia. Inclusion criteria were informed consent. Exclusion criteria were

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metal devices in the body, pregnancy or current or past treatment for a psychiatric disorder according to DSM-IV criteria (American Psychiatric Association 2000) except for one schizophrenic patient. Alcohol or drug dependence (DSM-IV), a history of cancer, organic brain disease or brain trauma or any other significant somatic disease that may affect brain function were also exclusion criteria.

Magnetic resonance scans

The subjects were examined with a 1.5 Tesla GE Signa (Milwaukee, Wis. USA) system. Table 1 presents MRI protocol of T1-weighted images and T2-weighted images. From visual inspections, all scans were judged to be excellent without any obvious motion artifacts. All scans were found to lack gross clinical pathology as evaluated by a neuroradiologist. The scan data were stored on magnetic optical disk.

Automated segmentation

MR data analysis was performed using the BRAINS software (Andreasen et al. 1992, 1993, 1996). The standard workup of an MR scan was highly automated but manual interventions were preferred in order to optimize the classification of structures characterized by mixed tissue contents. Detailed information about the segmentation procedure and evaluation of validity were described previously (Harris et al. 1999; Agartz et al. 2001). The scan data were transferred from a magnetic optical disk for processing on Silicon Graphics O2 workstations. The T1 images were loaded and resampled so that the interhemispheric fissure was aligned vertically in the horizontal and coronal views, and the line between the anterior commissure (AC) and posterior commissure (PC). The alignment of the interhemispheric fissure defined the left and right hemisphere division. For adaptation of Talairach grip at each dataset, each brain was defined in the Talairach space. The T2 weighted images were resampled and coregistrated to the resampled T1 weighted images (Woods et al. 1998). After fitting T1 images and T2 images, the T1 and T2 data sets were spatially resliced with a voxel size of $1.0 \times 1.0 \times 1.0\ mm^3$.

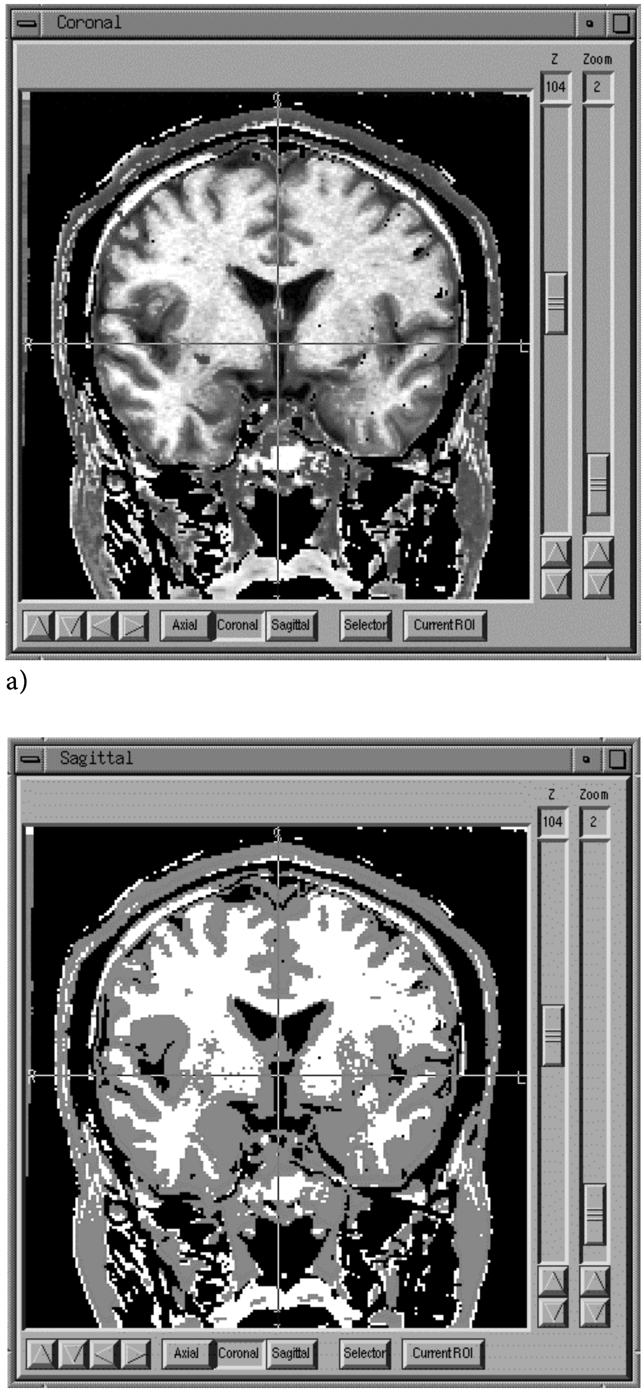
Operators were required to pick samples of venous blood from the sigmoidal sinus on ten coronal slices, samples of grey matter from the thalamus and samples of white matter in subcortical regions on twenty coronal slices. After picking tissue samples, the whole brain image was classified into grey matter, white matter and CSF (Cohen et al. 1992). The program provided a continuous classification and a discrete classification (Fig. 1) (Harris et al. 1999). An Artificial Neural Network in BRAINS automatically identified intracranial structures (Magnotta et al. 1999). Segmentation procedures were performed twice by one operator (GO) for the intraoperator reliability and by two operators (KT and GO) for the interoperator reliability.

Interoperator reliability

MR scans from ten subjects with a mean age of 33.4 ± 6.2 years underwent segmentation procedures by two operators (KT and GO) to

Table 1 Magnetic Resonance Imaging Protocol

	T1 weighted images (3D SPGR)	T2 weighted images
Scan plane	Coronal	Coronal
Field of view	24.0 cm	24.0 cm
Slice thickness	1.5 mm	3.0 mm
Slice gap	0 mm	0 mm
Repetition time (TR)	24 ms	6000 ms
Echo time (TE)	6.0 ms	84 ms
Acquisition matrix	256x192	256x192
NEX	1	1



b)

Fig. 1 **a** A continuous classification of coronal section. **b** A discrete classification of the same section as continuous image

check interoperator reliability. The operators were blind to subject identity and diagnosis. Left and right volumes of grey matter, white matter and CSF in intracranial volume, frontal box, temporal box, parietal box and occipital box were calculated using the continuous and the discrete methods for classification. The interoperator reliability was assessed by calculating the intraclass correlation coefficient (ICC) for both continuous and discrete measurements of each tissue (Shrout et al. 1979).

Intraoperator reliability

The same set of MR scans was performed twice by one operator (GO) for intraoperator reliability. The time interval between the first and second segmentation by the same operator were in the range of 20–137 days (mean number of days ± SD was 47 ± 38). ICCs were calculated for both the continuous and the discrete measures for assessment of the intraoperator reliability.

Results

Interoperator reliability

Table 2a presents the mean volumes of the intracranial tissue in the left and right sides, with continuous and discrete classification for the first and second operator. Table 2b presents the intraclass correlation coefficients for the grey matter, white matter and CSF, in the left and right sides. The range of ICC was 0.983–0.997.

Table 3a presents the mean volumes of frontal box, temporal box, parietal box and occipital box in the left and right side, with continuous and discrete classification by two operators. Table 3b presents the interoperator reliability with the ICC range of 0.971–0.997.

Table 2a Intracranial class volumes (ml) of grey matter, white matter and CSF, on the left and right sides, with continuous and discrete classification by two operators

	Continuous		Discrete	
	Operator 1	Operator 2	Operator 1	Operator 2
Grey matter				
Left	412.4±32.7	414.8±33.3	437.3±35.9	440.9±38.4
Right	408.9±31.0	410.3±30.3	440.4±33.9	443.2±33.8
White matter				
Left	225.0±18.1	224.8±17.8	251.7±21.7	251.1±20.4
Right	233.0±22.7	232.4±22.7	256.4±25.1	255.6±24.1
CSF				
Left	124.9±30.3	123.1±29.0	73.3±36.3	71.7±34.6
Right	123.9±26.7	122.2±27.2	68.9±32.2	68.2±32.5

Values are means ± SD

Table 2b Intraclass correlation coefficients (ICCs) for intracranial tissue class volumes on the left and right sides, with continuous and discrete classification by two operators

	Continuous ICCs	Discrete ICCs
Grey matter		
Left	0.996	0.988
Right	0.989	0.983
White matter		
Left	0.994	0.986
Right	0.988	0.994
CSF		
Left	0.992	0.994
Right	0.985	0.997

Table 3a Volumes (ml) of grey matter, white matter and CSF, in frontal box, temporal box, parietal box and occipital box, on the left and right sides, with continuous and discrete classification for the first and second operator (values are means ± SD)

	Continuous		Discrete	
	Operator 1	Operator 2	Operator 1	Operator 2
Frontal box Grey matter				
Left	133.7±9.3	133.7±9.6	137.6±10.5	137.8±10.1
Right	135.5±6.0	135.6±6.4	141.9±9.0	142.3±8.5
Frontal box White matter				
Left	79.0±7.9	79.6±7.8	91.1±10.1	91.7±10.2
Right	86.9±9.9	87.9±9.7	97.6±11.5	98.5±11.3
Frontal box CSF				
Left	49.1±17.0	49.6±17.8	33.0±21.3	33.6±22.1
Right	51.6±16.4	52.2±16.9	33.6±21.3	33.9±21.3
Temporal box Grey matter				
Left	80.1±8.7	81.1±9.6	86.7±10.5	88.0±1.3
Right	75.3±5.9	75.9±6.7	84.1±9.2	84.5±9.5
Temporal box White matter				
Left	34.7±4.4	35.0±4.6	38.1±5.4	38.0±5.8
Right	38.9±4.7	38.6±4.7	41.3±4.9	40.9±4.8
Temporal box CSF				
Left	18.1±4.0	18.4±4.3	8.2±6.1	8.2±5.9
Right	17.2±2.8	17.4±2.8	5.9±2.7	5.8±2.6
Parietal box Grey matter				
Left	72.1±6.3	73.3±5.6	74.3±7.0	75.1±6.8
Right	73.4±6.7	73.6±6.6	75.9±6.7	76.3±6.9
Parietal box White matter				
Left	46.8±4.7	47.0±4.4	53.8±5.9	53.9±5.6
Right	48.3±7.0	48.9±7.2	54.7±7.4	55.1±8.0
Parietal box CSF				
Left	24.1±6.9	23.9±6.3	14.7±8.6	14.4±8.1
Right	22.2±6.1	22.0±5.6	11.7±7.4	11.5±6.6
Occipital box Grey matter				
Left	40.1±5.8	40.5±5.5	42.7±5.9	43.6±5.5
Right	37.4±6.8	37.6±6.5	39.4±6.2	40.2±6.6
Occipital box White matter				
Left	21.7±3.7	21.9±3.9	24.4±4.5	24.5±4.8
Right	18.3±4.5	18.0±4.5	20.4±5.1	20.1±5.2
Occipital box CSF				
Left	7.3±2.2	7.4±2.0	2.0±1.7	1.9±1.6
Right	6.1±2.4	6.0±1.9	1.5±1.7	1.4±1.4

Intraoperator reliability

Table 4a presents the mean volumes of intracranial tissue in the left and right sides, with continuous and discrete classification by one operator on two occasions. The intraoperator reliability for measures was excellent with the ICC range of 0.985–0.999 (Table 4b).

Table 3b Intraclass correlation coefficients (ICCs) for tissue class volumes in Talairach boxes, on the left and right sides, with continuous and discrete classification for two operators

	Continuous ICCs	Discrete ICCs
Frontal grey matter		
Left	0.983	0.980
Right	0.975	0.982
Frontal white matter		
Left	0.981	0.983
Right	0.983	0.981
Frontal CSF		
Left	0.993	0.997
Right	0.992	0.997
Temporal grey matter		
Left	0.987	0.987
Right	0.982	0.985
Temporal white matter		
Left	0.979	0.978
Right	0.981	0.988
Temporal CSF		
Left	0.990	0.997
Right	0.989	0.990
Parietal grey matter		
Left	0.971	0.976
Right	0.989	0.981
Parietal white matter		
Left	0.989	0.991
Right	0.989	0.985
Parietal CSF		
Left	0.992	0.987
Right	0.990	0.993
Occipital grey matter		
Left	0.981	0.973
Right	0.981	0.987
Occipital white matter		
Left	0.972	0.987
Right	0.976	0.976
Occipital CSF		
Left	0.973	0.975
Right	0.968	0.981

Table 4a Intracranial volumes (ml) of grey matter, white matter and CSF, on the left and right sides, with continuous and discrete classification for one operator on two occasions

	Continuous		Discrete	
	Occasion 1	Occasion 2	Occasion 1	Occasion 2
Grey matter				
Left	412.4±32.7	416.9±29.7	437.3±35.9	442.5±32.7
Right	408.9±31.0	412.2±30.2	440.4±33.9	445.2±32.2
White matter				
Left	225.0±18.1	226.2±18.1	251.7±21.7	252.7±22.2
Right	233.0±22.7	233.6±23.1	256.4±25.1	256.8±26.2
CSF				
Left	124.9±30.3	126.4±30.4	73.3±36.3	73.7±36.0
Right	123.9±26.7	125.6±26.9	68.9±32.2	69.3±31.8

Values are means ± SD

Table 4b Intraclass correlation coefficients (ICCs) for intracranial tissue class volumes of the left and right sides, with continuous and discrete classification for one operator on two occasions

	Continuous ICCs	Discrete ICCs
Grey matter		
Left	0.988	0.985
Right	0.985	0.992
White matter		
Left	0.995	0.994
Right	0.999	0.996
CSF		
Left	0.998	0.999
Right	0.996	0.999

Table 5a presents the mean volumes of frontal box, temporal box, parietal box and occipital box in the left and right side, with continuous and discrete classification by one operator on two occasions. The range of ICC for intraoperator reliability was 0.974–0.999 (Table 5b).

Proportion of tissue class volumes

The proportion of tissue class volumes in the intracranial volume was 53.7 % grey matter, 30 % white matter and 16.3 % CSF in the continuous classification, and 57.4 % grey matter, 33.3 % white matter and 9.3 % CSF in the discrete classification.

Discussion

The inter- and intraoperator reliability to measure volumes of intracranial volume, frontal box, temporal box, parietal box and occipital box was excellent for both continuous and discrete segmentation. This study was the first report of inter- and intraoperator reliability to measure volumes of Talairach boxes.

Regarding the proportion of relative tissue volumes, our results were similar to the results from the study of Agartz et al. (2001). In the present study, both the ventricular and surface CSF were measured as the CSF volume. The cerebellum, which is characterized by very thin folia, may demonstrate a lower validity for grey/white segmentation. However, inter- and intraoperator reliability for volume measurements of grey and white matter added together in cerebellar regions by manual tracing was excellent with a range of 0.95–0.99 (Okugawa et al. 2002a).

Neuroimaging studies suggested that structural brain changes were involved in the pathophysiology of psychiatric disorders (e. g., Boccardi et al. 2002; Okugawa et al. 2002b; Takahashi et al. 2002). One advantage of this program was its utility in the collection of large amounts of MR data because it was a highly automated procedure.

In conclusion, the inter- and intraoperator reliability

Table 5a Volumes (ml) of grey matter, white matter and CSF, in frontal box, temporal box, parietal box and occipital box, on the left and right sides, with continuous and discrete classification for one operator on two occasions (values are means ± SD)

	Continuous		Discrete	
	Occasion 1	Occasion 2	Occasion 1	Occasion 2
Frontal box				
Grey matter				
Left	133.7 ± 9.3	133.6 ± 9.5	137.6 ± 10.5	137.6 ± 11.4
Right	135.5 ± 6.0	135.2 ± 6.7	141.9 ± 9.0	141.6 ± 9.0
Frontal box				
White matter				
Left	79.0 ± 7.9	79.1 ± 7.3	91.1 ± 10.1	91.4 ± 9.4
Right	86.9 ± 9.9	86.4 ± 10.1	97.6 ± 11.5	96.2 ± 11.3
Frontal box				
CSF				
Left	49.1 ± 17.0	48.2 ± 16.4	33.0 ± 21.3	32.9 ± 21.6
Right	51.6 ± 16.4	50.6 ± 16.2	33.6 ± 21.3	33.5 ± 23.1
Temporal box				
Grey matter				
Left	80.1 ± 8.7	80.5 ± 8.9	86.7 ± 10.5	86.5 ± 10.7
Right	75.3 ± 5.9	75.4 ± 6.1	84.1 ± 9.2	84.9 ± 9.5
Temporal box				
White matter				
Left	34.7 ± 4.4	34.8 ± 4.6	38.1 ± 5.4	38.2 ± 5.1
Right	38.9 ± 4.7	38.8 ± 4.9	41.3 ± 4.9	41.0 ± 4.6
Temporal box				
CSF				
Left	18.1 ± 4.0	18.1 ± 4.1	8.2 ± 6.1	8.2 ± 5.9
Right	17.2 ± 2.8	17.2 ± 2.4	5.9 ± 2.7	5.8 ± 2.7
Parietal box				
Grey matter				
Left	72.1 ± 6.3	72.2 ± 6.6	74.3 ± 7.0	74.1 ± 7.7
Right	73.4 ± 6.7	73.3 ± 7.5	75.9 ± 6.7	75.3 ± 7.3
Parietal box				
White matter				
Left	46.8 ± 4.7	46.5 ± 5.0	53.8 ± 5.9	53.3 ± 6.3
Right	48.3 ± 7.0	48.7 ± 7.0	54.7 ± 7.4	55.6 ± 7.9
Parietal box				
CSF				
Left	24.1 ± 6.9	24.7 ± 6.6	14.7 ± 8.6	15.2 ± 9.0
Right	22.2 ± 6.1	22.8 ± 6.2	11.7 ± 7.4	12.8 ± 8.1
Occipital box				
Grey matter				
Left	40.1 ± 5.8	40.7 ± 6.0	42.7 ± 5.9	42.9 ± 6.3
Right	37.4 ± 6.8	37.6 ± 6.5	39.4 ± 6.2	39.1 ± 6.6
Occipital box				
White matter				
Left	21.7 ± 3.7	21.6 ± 4.0	24.4 ± 4.5	23.8 ± 4.6
Right	18.3 ± 4.5	18.8 ± 4.6	20.4 ± 5.1	20.7 ± 4.9
Occipital box				
CSF				
Left	7.3 ± 2.2	7.4 ± 2.0	2.0 ± 1.7	2.1 ± 1.7
Right	6.1 ± 2.4	6.4 ± 2.6	1.5 ± 1.7	1.4 ± 1.7

of tissue volumes intracranial volume, frontal box, temporal box, parietal box and occipital box were excellent. We were able to accumulate data for brain volumes for our database and to combine results from other groups using the BRAINS software.

Table 5b Intraclass correlation coefficients (ICCs) for tissue class volumes of Talairach boxes, on the left and right sides, with continuous and discrete classification for one operator on two occasions

	Continuous ICCs	Discrete ICCs
Frontal grey matter		
Left	0.989	0.982
Right	0.985	0.985
Frontal white matter		
Left	0.983	0.986
Right	0.994	0.985
Frontal CSF		
Left	0.994	0.991
Right	0.986	0.987
Temporal grey matter		
Left	0.990	0.976
Right	0.991	0.988
Temporal white matter		
Left	0.990	0.978
Right	0.984	0.979
Temporal CSF		
Left	0.988	0.997
Right	0.974	0.999
Parietal grey matter		
Left	0.984	0.984
Right	0.977	0.978
Parietal white matter		
Left	0.992	0.979
Right	0.993	0.974
Parietal CSF		
Left	0.991	0.987
Right	0.990	0.988
Occipital grey matter		
Left	0.982	0.985
Right	0.977	0.981
Occipital white matter		
Left	0.975	0.977
Right	0.987	0.975
Occipital CSF		
Left	0.982	0.994
Right	0.980	0.994

Acknowledgments Dr. Nancy C. Andreasen and her research group are acknowledged for excellent support of the implementation of the BRAINS program. We thank Dr. Yoshihisa Kibune for valuable statistical advice and the staff of the Departments of Neuropsychiatry and Radiology at Kansai Medical University.

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