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ORIGINAL ARTICLE

Surface-Based Morphometry of Human Brain: Intra-Individual Comparison Between 3T and 7T High Resolution Structural MR Imaging△

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Key words: MRI; ultra high field; morphometry; brain; cortex

Objective High resolution structural MR imaging can reveal structural characteristics of cerebral cortex and provide an insight into normal brain development and neuropsychological diseases. The aim of this study was to compare cortical structural characteristics of normal human brain between 3T and 7T MRI systems using surface-based morphometry based on high resolution structural MR imaging.

Methods Twelve healthy volunteers were scanned by both 3T with 3D T1-weighted fast spoiled gradient recalled echo (3D T1-FSPGR) sequence and 7T with 3D T1-weighted magnetization-prepared rapid gradient echo (3D T1-MPRAGE) sequence. MRI data were processed with FreeSurfer. The cortical thickness, white and gray matter surface area, convexity, and curvature from data of 3T and 7T were measured and compared by paired *t*-test.

Results Measurements of mean cortical thickness, total white matter surface area and gray matter surface area of 3T were larger than those of 7T (left hemisphere: P=0.000, 0.006, 0.020 respectively; right hemisphere: P=0.000, 0.000, 0.000 respectively). Surface-based morphometry over the whole brain demonstrated both reduced and increased measurements of cortical thickness, white and gray surface area, convexity, and curvature at 7T compared to 3T.

Conclusions Inconsistency of brain structural attribute between 3T and 7T was confirmed, and researchers should be cautious about data when using ultrahigh field MR system to investigate brain structural changes.

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MAGNETIC resonance imaging (MRI) can reveal the development of normal human brain and abnormal changes of brain with high resolution. The high resolution structural imaging can further evaluate brain structural changes (eg. brain volume, cortical thickness, sulcus convexity, etc.) *in vivo*.[1] Assessment of structural difference mainly includes visual observation, voxel-based cortical thickness analysis, and voxel-based morphometry, which could reflect macroscopical structural characteristics.[2,3] Fine structural imaging of brain could reveal the intrinsic changes in brain development and brain disorders, which warrants further evaluation.

Ultrahigh field (7T) MRI has been used to study multiple sclerosis in recent years. It was thought to be a more valuable tool in assessing cortical damage because it detected much more cortical lesions than other MRI systems.[4,5] Cortical lesions were evaluated by visual observation of T2* and T2 turbo spin-echo (TSE) images and white matter attenuation (WHAT) images. Combined with computational neuroimaging, clinical functional MRI (fMRI) demonstrated that ultrahigh field MR systems provided a clinically relevant increase in sensitivity, although 7T images inevitably suffer from significant increases in ghosting artifacts, and artifacts from head motion.[6] A recent study revealed that there was a small difference in the mean cortical thickness among five healthy volunteers between 3T and 7T MRI system.[7] However, the sensitivity of structural imaging on 7T MRI has not been fully investigated.

Methods using MRI to evaluate brain structural changes include voxel-based morphometry, cortical thickness mapping and region-of-interest-based volumetry.[1,8,9] These methods could be used to detect changes of brain structure in a variety of brain disorders. However，for detection of subtle changes in brain structure over the whole brain, these methods were relatively insufficient.

Surface-based morphometry (SBM) analysis represents a group of brain morphometry techniques, which was used to construct and analyze surface attribute for brain structure.[10,11] It had been widely used to evaluate brain structural changes in mild cognitive impairment, Alzheimer's disease, attention-deficit hyperactivity disorder, etc.[12,13] Theoretically, image resolution is closely associated with magnetic field strength, and high field strength could improve the spatial resolution and signal noise ratio (SNR). However, ultrahigh field strength could also be apt to produce ghosting, head motion artifacts and heterogeneous signal intensity,[6] which could affect the evaluation of subtle structures. There haven't been enough data on using 7T MRI for evaluation of structural imaging. Therefore, the aim of this study was to investigate the brain structural differences of 7T MRI compared with 3T MRI using surfaced-based morphometry technique.

MATERIALS AND METHODS

Subjects

This study was approved by the ethics committee of our institutional review board. Written informed consent was obtained from all participants. Twelve healthy Chinese volunteers were recruited in the study, including 11 females and 1 male, aged 18 to 46 (mean 32±7.5) years old. No subjects had any history of neurodegeneration, psychiatric disorder, cranium trauma, inflammatory disease of central nervous system, using psychoactive drugs or hormonotherapy.

MRI acquisition

Images were acquired by a GE 3T MR system (SIGNA EXCITE, GE Healthcare) and a SIEMENS 7T MR system (SIEMENS MAGNETOM Investigational Device 7T syngo MR B15). For 3T MR system, we used a conventional eight channel quadrature head coil and a high resolution 3D T1-weighted fast spoiled gradient recalled echo (3D T1-FSPGR) sequence [repetition time (TR)=6.3 ms, echo time (TE)=2.8 ms, Flip angle=15°, field of view(FOV) = 24cm×24cm, Matrix=256×256, number of acquisition (NEX)=1]. For 7T MR system, we used a 24 channel quadrature head coil, and 3D T1-weighted magnetization-prepared rapid gradient echo (3D T1-MPRAGE) sequence [TR=2.2 ms, TE=3.2 ms, Flip angle=7°, FOV=22cm×32cm, Matrix =320×320, NEX=1]. The scan protocol was identical for all subjects.

MR image data processing

All MR structural image data were processed using FreeSurfer (V5.3.0, http://surfer.nmr.mgh.harvard.edu). The cortical surface was automatically segmented from high resolution structural images; gyral anatomy was aligned to the standard spherical template using surface convexity and curvature measures; the cortical thickness, white matter surface area, gray matter surface area, convexity, and curvature were estimated.[10,14,15]

In this study, we used different Gaussian smoothing kernel to evaluate the effect of full width at half maximum (FWHM) on statistics. Because the significant clusters became more concentrated with the increase of FWHM size (Fig. 1), and FWHM 5 mm made the significant clusters look like normal distribution, FWHM 5mm was selected and

applied to statistical surface mapping.

Statistical analysis

The mean cortical thickness, white matter surface area, gray matter surface area, convexity, and curvature on structural images were compared between 3T and 7T by paired t-test using SPSS (version 19.0) software. The structural differences between 3T and 7T were analyzed by paired t-test with false discovery rate (FDR) corrected using FreeSurfer (Version 6.0, http://www. freesurfer. net). $P<0.05$ was considered statistically significant.

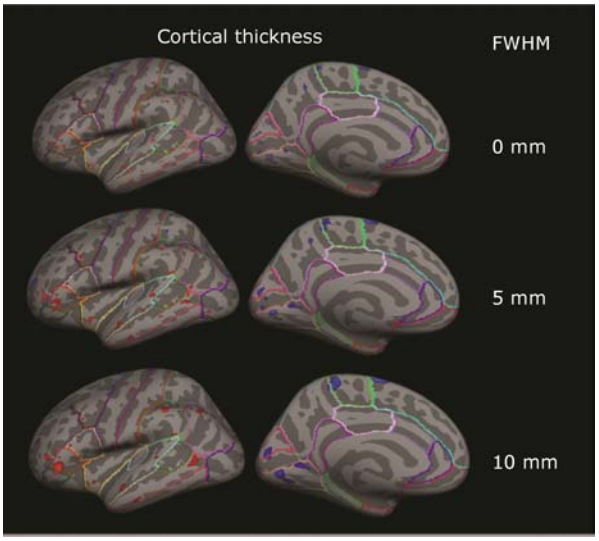

Figure 1. Changes of mean cortical thickness at 7T compared to 3T using 0 mm, 5 mm, and 10 mm FWHM width. The distribution of clusters of FHWM 0 mm was evidently more disperse than that of FHWM 5mm (4 clusters) and that of FWHM 10 mm (1 cluster) in the left inferior parietal lobe.

RESULTS

Comparison of mean structural variables between 3T and 7T

Table 1 demonstrated that the measurements of mean cortical thickness, total white matter surface area and total gray matter surface area of each hemisphere of 3T were significantly larger than those of 7T (left: $P=0.000$, 0.006, 0.02 respectively; right: $P=0.000$, 0.000, 0.000 respectively). The mean cortical thickness of 7T was reduced by 12.44% in the left hemisphere and 14.04% in the right hemisphere compared with that of 3T. Total white and gray matter surface area of 7T were reduce by 15.00% and 11.46% respectively in the left hemisphere, and 24.05% and 21.88% respectively in the right hemisphere, as compared with those of 3T.

In the left hemisphere, measurements of mean convexity and mean curvature showed no significant difference between 3T and 7T ($P=0.461$, 0.134 respectively). In the right hemisphere, the mean convexity (0.48±0.01 mm^{-1}) at 3T was larger than that at 7T (0.47±0.02 mm^{-1}, $P=0.04$); the mean curvature (0.15±0.00 mm^{-1}) at 3T was smaller than that at 7T (0.15±0.00 mm^{-1}, $P= 0.00$).

Surface-based morphometry over the whole brain of 3T and 7T

Cortical thickness analysis over the whole brain demonstrated that the regions with reduced cortical thickness at 7T compared with 3T were mainly located in bilateral frontal and temporal lobes, and the regions with increased cortical thickness mainly in the medial cortex of left hemisphere and right precentral gyrus. The right medial cortex had no increase in cortical thickness (Fig. 2).

Table 1. Comparison of the mean cortical thickness, total gray/white surface area, mean convexity and mean curvature between 3T and 7T ($n=12$)§

	Mean cortical thickness (mm)	Total white surface area (mm^2)	Total gray surface area (mm^2)	Mean convexity (mm^{-1})	Mean curvature (mm^{-1})
Left hemisphere					
3T	2.468±0.088	0.080±0.008	0.096±0.010	0.481±0.012	0.147±0.002
7T	2.161±0.090	0.068±0.010	0.085±0.010	0.485±0.014	0.148±0.004
t	8.452	2.641	2.722	0.817	1.310
P value	0.000	0.006	0.020	0.461	0.134
Right hemisphere					
3T	2.478±0.094	0.079±0.008	0.096±0.010	0.482±0.011	0.147±0.003
7T	2.130±0.084	0.060±0.007	0.075±0.008	0.469±0.021	0.154±0.005
t	9.570	4.462	5.715	1.836	4.350
P value	0.000	0.000	0.000	0.040	0.000

§:Plus-minus values are means±standard deviation.

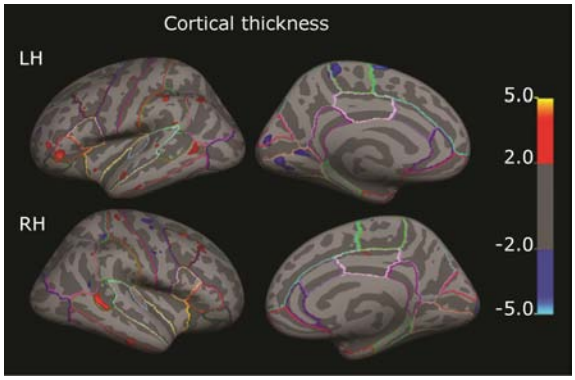

Figure 2. The increased (blue clusters) and decreased (red clusters) mean cortical thickness of bilateral cerebral cortex at 7T compared with 3T. LH, left hemisphere; RH, right hemisphere.

Compared with 3T, the regions with reduced white surface area at 7T were demonstrated in left parietal and occipital lobes, right perisylvian region, cuneus, and precuneus. Two clusters with increased cortical thickness were detected in the precentral and middle temporal gyri (Fig. 3A). The distribution of reduced gray surface area mainly involved bilateral frontal, parietal and occipital region, especially the parietal lobe (Fig. 3B). The reduced convexity distributed widely in bilateral cerebrum (Fig. 4A), and only several clusters showed increase convexity at 7T compared with 3T. The whole brain analysis also demonstrated that the curvature decreased in some regions and increased in other regions (Fig. 4B).

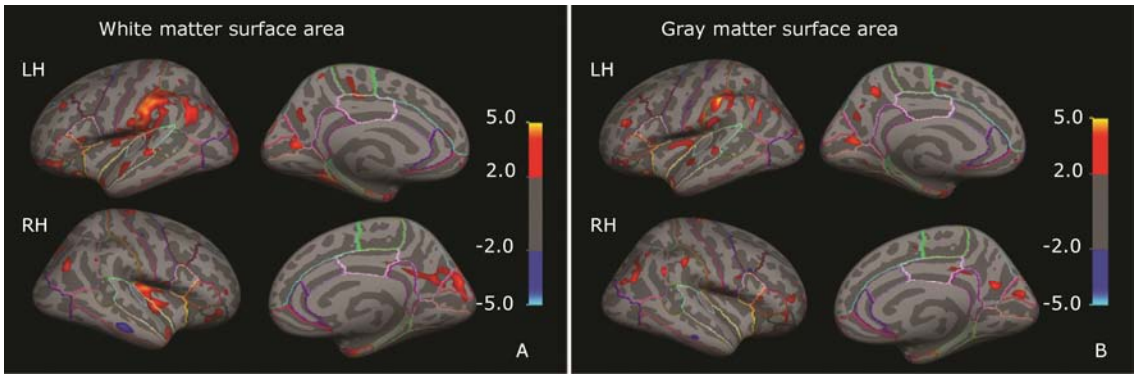

Figure 3. The increased (blue clusters) and decreased (red clusters) surface area of white matter (A) and gray matter (B) of bilateral cerebrum at 7T compared with 3T.

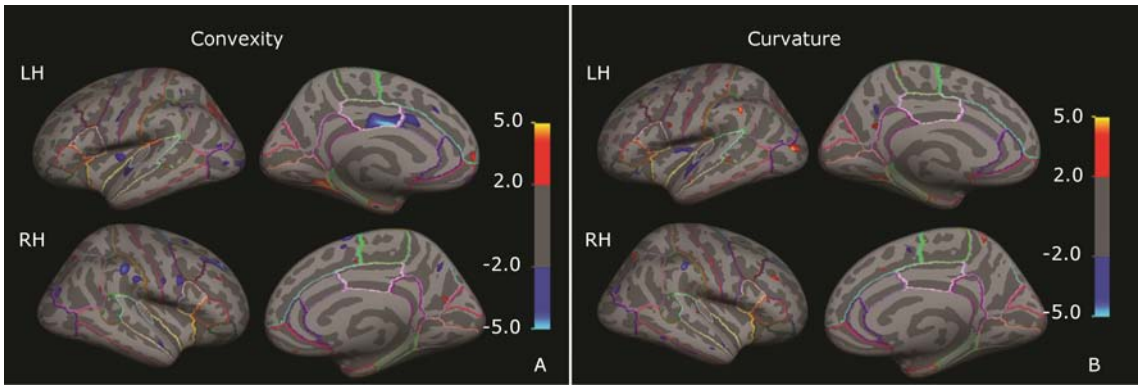

Figure 4. The increased (blue clusters) and decreased (red clusters) convexity (A) and curvature (B) of bilateral cerebrum at 7T compared with 3T.

DISCUSSION

This study provided the insight into the effects of magnetic field strength on measurements of brain structures. A study demonstrated that cortical thickness in 7T images reduced by approximately one sixth to one third compared with that in 3T images, which suggested that the true cortical thickness may be overestimated by most current MR studies.[7] In this study, the reduction of mean cortical thickness was detected at 7T, and surface-based morphometry over the whole brain analysis demonstrated the reduction of cortical thickness in some specific brain regions compared with 3T, which was partially consistent with the previous study.[7] However, some brain regions in medial cortex of left hemisphere and right precentral gyrus

presented increased cortical thickness at 7T compared with 3T. Therefore, the effect of ultrahigh magnetic field strength of MRI on brain structural characteristics was heterogeneous.

Other structural attributes (including white surface area, gray surface area, convexity and curvature) presented subtle differences in 7T MRI compared with 3T MRI. With different magnetic field strength, the observed structural differences may be related to the difference of signal intensity distribution. In ultrahigh field MR system, it is easier to distinguish gray/white matter and CSF/gray matter to achieve a fine segment, from which the generated gray/white matter interface is different from that of 3T, and consequently induces the different cortical attributes. Therefore, special caution is needed when interpreting imaging findings generated from MRI modalities with different magnetic field strength, especially with ultrahigh magnetic field.

The results of mean structural attribute analysis in current study showed that underestimation of cortical thickness may exist at 7T compared to 3T. However, some studies reported that the cortical thickness could be overestimated at 3T compared with 1.5T.[16,17] The main reason for this discrepancy may be associated with signal intensity of images. Data of 1.5T and of 3T were similar in homogeneity of intensity; data of 3T had a relatively higher gray/white contrast in clinical observation; data of 7T had a heterogeneous intensity compared with 3T, and had a higher gray/white contrast than that of 3T. The other reason that influence the evaluation of cortical thickness was imaging sequence. The MRRAGE sequence presented a different contrast of gray/white matter compared with FSPGR sequence, which may constitute to the difference in measurements of cortical thickness between 3T and 7T MRI system.

For the imaging processing, we used the same workstation (operating system) and software in order to avoid the influence of the methodology.[18] Additionally, in this study, multiple Gaussian smoothing kernels were applied to investigate the effect of smoothing on the cortical thickness. The results suggested that with the increase of Gaussian smoothing kernel, the amount of clusters decreased, and the size of clusters increased (Fig. 1). Therefore, the same Gaussian smoothing kernel (5 mm) was used to reduce noise in the cortical thickness measurements.

This study confirmed that, compared with other brain structural attributes, surface areas of the white matter and gray matter of 7T were liable to be different from those of 3T (Fig.3-4). Therefore, it should be cautious when evaluating the surface area of brain structural changes with ultra high field MRI.

There were limitations in this study. Firstly, as an *in vivo* study, we did not perform pathological correlation. Secondly, the sample of 12 subjects was relatively small. Lastly, different manufacturers of the MR scanner and imaging sequences we used may affect image quality and brain structural measurements.

In conclusion, the inconsistency between 3T and 7T MR system in evaluating brain structural attribute was confirmed in this study. Researchers should be cautious in interpreting data when using ultrahigh field MRI system to investigate brain structural changes.

Conflict of interest statement

All authors have no conflict of interest to disclose.

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