Whole-Brain Functional and Diffusion Tensor MRI in Human Participants with Metallic Orthodontic Braces

Xinyuan Miao,[1,2] Yuankui Wu,[1,2,3] David Woods,[4] Moshe T. Stern,[5] Nicolas I.S. Blair,[6] Raag D. Airan,[7] Keri Rosch,[9,10] Jay J. Pillai,[3] James J. Pekar,[1,2] Peter C.M. van Zijl,[1,2] Jun Hua[1,2]

1 Neurosection, Division of MRI Research, Russell H. Morgan Department of Radiology and Radiological Science, Johns Hopkins University School of Medicine, Baltimore, Maryland, USA; 2 F.M. Kirby Research Center for Functional Brain Imaging, Kennedy Krieger Institute, Baltimore, Maryland, USA; 3 Department of Medical Imaging, Nanfang Hospital, Southern Medical University, Guangzhou, P.R. China; 4 Department of Orthodontics and Pediatric Dentistry, University of Maryland School of Dentistry, Baltimore, Maryland, USA; 5 Department of Orthodontics and Pediatric Dentistry, University of Maryland, Baltimore, Maryland, USA; 6 Department of Biomedical Engineering, Johns Hopkins University, Baltimore, Maryland, USA; 7 Division of Neuroradiology, Russell H. Morgan Department of Radiology and Radiological Science, Johns Hopkins University School of Medicine, Baltimore, Maryland, USA; 8 Department of Neurology, Johns Hopkins University School of Medicine, Baltimore, Maryland, USA; 9, Center for Neurodevelopmental and Imaging Research, Kennedy Krieger Institute, Baltimore, Maryland, USA 10, Department of Psychiatry and Behavioral Sciences, Johns Hopkins University School of Medicine, Baltimore, Maryland, USA

Introduction

MRI acquired using echo-planar-imaging (EPI) sequences are very sensitive to susceptibility artifacts in the presence of metallic objects, which presents a significant barrier for performing functional MRI (fMRI) and diffusion-tensor-imaging (DTI) in patients with metallic orthodontic material(1) and other head implants.

Purpose: To evaluate the ability to reduce susceptibility artifacts in healthy human subjects wearing metallic orthodontic braces for two alternative approaches: T2-prepared (T2prep) fMRI(2,3) and diffusion-prepared-DTI with 3D fast-gradient-echo readout (4).

Method

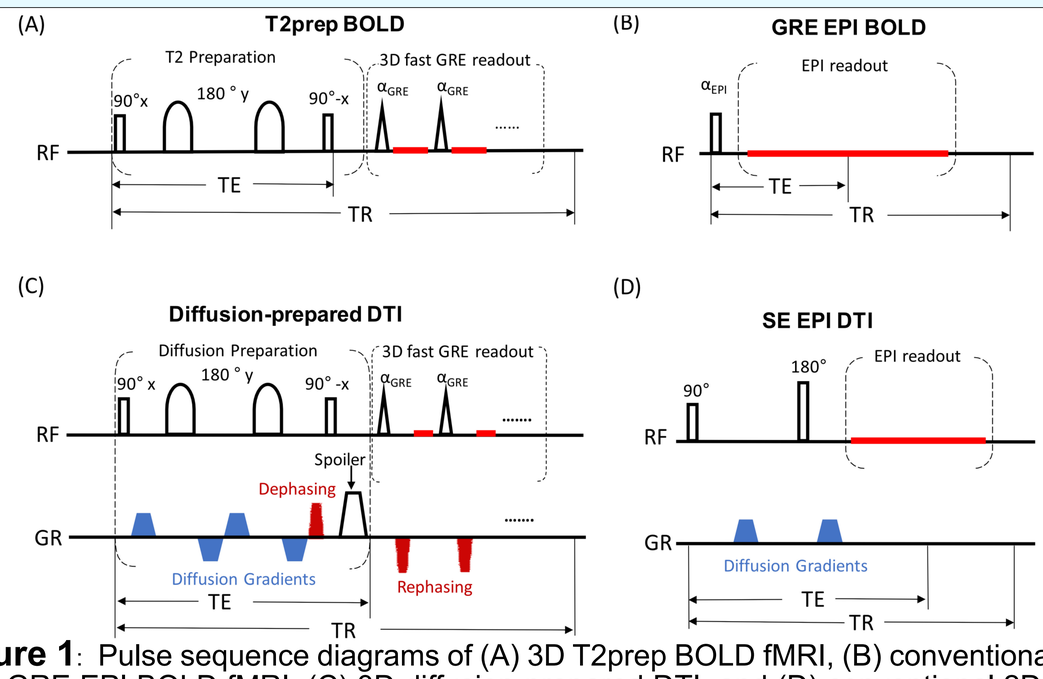

Figure 1: Pulse sequence diagrams of (A) 3D T2prep BOLD fMRI, (B) conventional 2D multi-slice GRE EPI BOLD fMRI, (C) 3D diffusion-prepared DTI, and (D) conventional 2D multi-slice SE EPI DTI. One entire image volume was acquired in a single repetition time (TR) period in all sequences to avoid the well-known phase errors in multi-shot approaches.

Six healthy participants (40±6yo, 3 females) were scanned at a 3T MRI scanner. Removable dental braces with bonding trays were used so that MRI images can be acquired with and without braces in the same participants. T2prep-fMRI and diffusion-prepared-DTI (**Figure 1**) were performed in healthy human subjects. Results were evaluated in regions with strong (EPI dropout regions for fMRI, and the inferior fronto-occipital fasciculus (IFOF) for DTI), and minimal (motor cortex for fMRI, and the posterior limb of internal capsule (PLIC) for DTI) susceptibility artifacts. Signal-to-noise ratios (SNR), contrast-to-noise-ratio (CNR) for fMRI, apparent-diffusion-coefficient (ADC) and fractional-anisotropy (FA) for DTI, and degree of distortion (quantified with the Jaccard-index (JI) that measures the similarity of geometric shapes) were compared in regions with strong or minimal susceptibility effects between the current standard EPI sequences and the proposed alternatives using paired t-test.

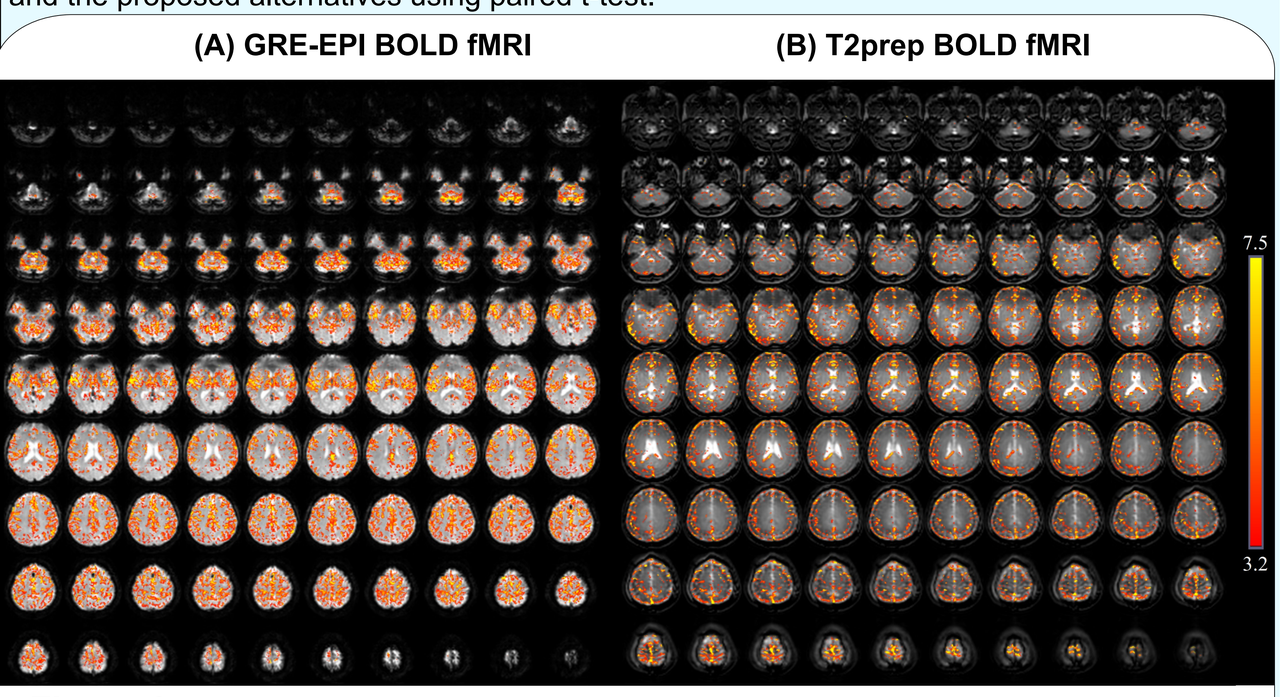

Figure 2: Activation maps overlaid on original fMRI images from the GRE EPI (A) and T2prep (B) BOLD fMRI approaches, respectively, in an axial imaging plane from a healthy participant wearing a titanium dental brace during a breath-hold task. The activated voxels are highlighted with their corresponding t-scores from the GLM analysis with identical statistical threshold. The range of the t-scores is indicated by the scale bar.

Results: fMRI

Figure 2: In participants wearing braces, activation was detected in most regions with minimal susceptibility artifacts using both methods, less activations were detected in the dropout region with GRE EPI BOLD than with T2prep BOLD.

Table 1: tSNR, ΔS/S, and CNR in the dropout region were all significantly higher in T2prep BOLD than in EPI images.

In the same subjects when not wearing braces, tSNR, ΔS/S and CNR in the dropout region were comparable (P>0.1) in T2prep scans, but were significantly improved (P<0.001) in EPI scans compared to corresponding results with braces. The results in the motor cortex were comparable (P>0.1) with and without braces.

Table 1. Group-averaged quantitative results from all subjects for the comparison of GRE EPI and T2prep BOLD fMRI.

	SNR	ΔS/S (%)	CNR
With braces			
Dropout region			
T2prep	37.8 ± 2.38	2.30 ± 0.66	0.83 ± 0.16
EPI	15.5 ± 5.29	1.81 ± 0.23	0.29 ± 0.10
P value	<0.001*	<0.001*	<0.001*
Motor cortex			
T2prep	41.6 ± 5.92	2.36 ± 0.73	1.08 ± 0.52
EPI	48.9 ± 7.61	2.58 ± 0.44	1.38 ± 0.40
P value	0.05	0.56	0.21
Without braces			
Dropout region			
T2prep	37.0 ± 2.45	2.93 ± 0.54	1.14 ± 0.12
EPI	45.3 ± 6.31	2.83 ± 0.43	1.29 ± 0.16
P value	0.06	0.33	0.06
Motor cortex			
T2prep	44.4 ± 2.23	2.81 ± 0.59	1.27 ± 0.58
EPI	52.8 ± 5.77	2.84 ± 0.42	1.48 ± 0.10
P value	0.10	0.91	0.18

Results: DTI

Figure 3 shows typical raw diffusion-weighted images, ADC, and color-coded FA maps from one subject wearing braces. While SE-EPI shows signal loss in many brain regions (e.g. the frontal lobe in the slice shown), no obvious artifacts were visible in the diffusion-prepared EPI in the entire brain. Color coded FA maps obtained from SE-EPI DTI showed spurious results in the inferior frontal lobe near the brace (red arrow in **Figure 3**), affecting visualization of the IFOF, as compared to diffusion-prepared color FA maps in the same subject. Geometric distortion (**Figure 4**) was minimal in diffusion-prepared DTI, but was substantial in SE-EPI DTI (significantly lower Jaccard index (JI) in each slice, P < .001), and the degree of distortion varied with the location of the slice.

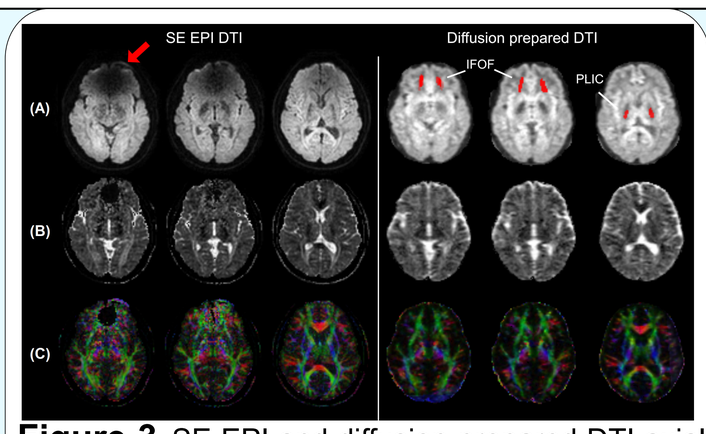

Figure 3. SE EPI and diffusion-prepared DTI axial images acquired at 3T on a participant wearing a metallic dental brace: (A) raw diffusion weighted images, (B) calculated ADC maps, and (C) FA map color coded by v1 orientation (standard RGB convention). Susceptibility artifacts were observed on the SE EPI image in regions close to the brace (red arrow). No obvious artifacts were seen on the diffusion-prepared DTI image. The ROIs of the IFOF and PLIC used in subsequent quantitative analysis are highlighted on the diffusion-prepared DTI images with red.

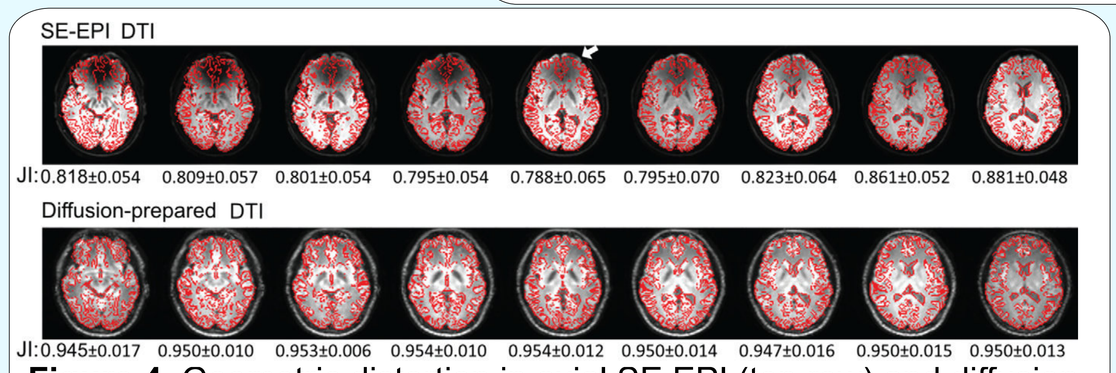

Figure 4. Geometric distortion in axial SE EPI (top row) and diffusion-prepared (bottom row) DTI images when compared to anatomical MPRAGE images in the same subject wearing metallic dental braces.

Table 2. Group-averaged quantitative results from all subjects (n=6) for the comparison of the SE-EPI and diffusion-prepared DTI approaches. In the IFOF close to the braces, SNR was significantly diminished in SE-EPI-DTI, whereas diffusion-prepared-DTI showed greater SNR, ADC and FA.

	SNR	ADC ($10^{-3}mm^2/s$)	FA
With braces			
Inferior fronto-occipital fasciculus (IFOF)			
diffusion-prepared	5.83 ± 1.47	0.75 ± 0.08	0.45 ± 0.07
SE-EPI	3.77 ± 0.70	0.16 ± 0.16	0.10 ± 0.12
P value	0.03*	<0.001*	<0.001*
Posterior limb of the internal capsule (PLIC)			
diffusion-prepared	5.73 ± 1.09	0.73 ± 0.04	0.61 ± 0.03
SE-EPI	6.97 ± 1.29	0.72 ± 0.03	0.59 ± 0.05
P value	0.05	0.88	0.33
Without braces			
Inferior fronto-occipital fasciculus (IFOF)			
diffusion-prepared	5.78 ± 1.11	0.79 ± 0.23	0.49 ± 0.02
SE-EPI	6.18 ± 0.48	0.80 ± 0.18	0.45 ± 0.01
P value	0.27	0.77	0.19
Posterior limb of the internal capsule (PLIC)			
diffusion-prepared	6.18 ± 1.64	0.68 ± 0.27	0.60 ± 0.01
SE-EPI	7.03 ± 1.48	0.69 ± 0.20	0.58 ± 0.01
P value	0.45	0.52	0.11

Table 2 summarizes the group-averaged quantitative results from all subjects from the ROI analysis (ROIs delineated in **Figure 3**). ADC, FA and SNR values were all comparable between diffusion-prepared and SE-EPI in the PLIC, a structure minimally affected by the susceptibility artifacts. In the IFOF, which is close to the dental braces, SNR was significantly diminished in SE-EPI, leading to erroneous ADC and FA values, whereas diffusion-prepared DTI showed greater SNR and reasonable ADC and FA values consistent with the literature (5). When the same scans were repeated in the same subjects without wearing the metallic dental braces, ADC, FA and SNR in both the PLIC and the IFOF became comparable between SE-EPI and diffusion-prepared DTI scans, all of which are within the typical range reported in the literature.

Conclusion

T2prep-fMRI and diffusion-prepared-DTI can acquire functional and diffusion MRI, respectively, in healthy human subjects wearing metallic dental braces with less susceptibility artifacts and geometric distortion than conventional EPI images. These two sequences are expected to provide an alternative approach in studies suffering from large susceptibility artifacts, for instance in the presence of metallic implants in the brain, or for adolescents wearing braces.

References

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