Diffusion Weighted Imaging using a Reduced-View Projection Reconstruction Imaging (RV-PRI)

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Introduction

Diffusion-weighted projection reconstruction imaging (DW-PRI) methods [1-2] provide images without significant artifacts such as geometric distortion, blurring and ghosting, which are the major problems of DW images acquired using echo-planar-imaging (EPI) methods. However, DW-PRI sequences are slower than EPI and DW projection data (PD) are sometimes degraded due to heart-beat motion. We propose a method to restore the degraded data and to reconstruct a DW image by acquiring PD with a reduced number of projection views, and consequently reducing the acquisition time.

Methods

Step 1. Restoration of Degraded Data: As is generally the case with diffusion tensor imaging (DTI), one conventional non-DW image and multi-directional DW images are acquired. If a required number of projection views for each DW image is *n* (increment of the view angle = α), MRI signals are acquired from *n* views for a non-DW image and *n/2* views (increment = 2α) for DW images. The acquired MRI signals are converted to PD using 1D fourier transform (FT), and the PD are converted to images (i.e. temporary images) using inverse radon transform (IRT) [3]. Due to the heart-beat motion, DW-PD include some degraded data, causing streak artifacts in a reconstructed DW image. In order to prevent the streak artifacts, the temporary DW image is converted back to the regenerated PD having *n/2* projection views by RT. Then, the restored PD are composed of non-degraded original PD and the regenerated PD in place of the initially degraded PD, with which an improved DW image can be reconstructed using IRT. **Step 2. Generation of PD at Missing Positions:** As stated previously, PD from only *n/2* projection views are acquired whereas the necessary number of projection views for the final DW image is *n*. Thus, the other half of the PD, which is not acquired using the imaging sequence (i.e. the PD at missing positions), should be generated by other means. In order to do so, the DW image from step 1 is converted to PD using RT, having *n* projection views. The DW-PD then consists of *n* PD, which are the restored *n/2* PD from step 1 at even positions and the calculated *n/2* PD in place of the missing views at odd positions. **Step 3. Interpolation of High Frequency Information:** From the regenerated *n* PD of step 2, *n/2* PD at even positions are kept untouched hereafter because they are the improved version of the directly acquired PD. The other *n/2* PD at odd positions are the estimated data, and thus lacking information needs to be supplemented. Since low frequency information determines the overall contrast of an image, it is nearly constant regardless of the number of projection views as long as the same diffusion gradients are applied. On the other hand, images with different diffusion gradients would have similar high frequency information as long as they are reconstructed using the same number of projection views because high frequency information is determined by the detailed edge components of an image. Based on the analysis provided in the discussion section, high frequency information of non-DW MRI signals using *n* projection views can be exploited for restoration of high frequency information in DW MRI signals. Thus, for the *n/2* PD at odd positions, low frequency information ($<\omega_{cutoff}$) from the regenerated n/2 PD is interpolated with high frequency information ($>\omega_{cutoff}$) from the non-DW-PD acquired using *n* projection views in the frequency domain. Using the regenerated PD, consisting of acquired and improved *n/2* PD at even positions and interpolated *n/2* PD at odd positions, a final DW image can be reconstructed.

Results

By applying a spin-echo (SE) DW-PRI sequence to a human brain, 6 DW images (b=1000s/mm^2, directions=(0,1,-1), (1,1,0), (0,1,1), (1,0,1), (1,-1,0), (-1,0,1)) were acquired with 90 projection views and a non-DW image was acquired with 180 views using 3.0 Tesla MRI scanner (ISOL Technology). The imaging parameters were as follows: 256 points/view, number of slices=20, slice thickness=2mm, FOV=240×240mm^2, and TE/TR=100/2000ms. The acquisition time was 3min. for each DW image and 6min. for a non-DW image. A reference dataset consisting of 6 DW and one non-DW images were acquired using 180 views. Images were reconstructed using the proposed method. Figure 1 shows one of 6 DW images reconstructed from PD having reduced views (90 views), interpolated views generated by the proposed method (180 views), and original views acquired as a reference (180 views). The images at middle row and bottom row of Fig.1 show directional anisotropy (DA) and fractional anisotropy (FA), respectively. As Fig. 1 demonstrates, the proposed method produces DW images similar to the reference DW image acquired using the full projection views. The proposed method was also confirmed by a simulation using the Shepp-Logan phantom image. DW-PD with 90 and 180 views and non-DW-PD both with 180 views were prepared from the Shepp-Logan phantom image with an arbitrary diffusion weighting. 180-view DW-PD was generated using the proposed method and reconstructed to an image. The image was compared with the image reconstructed from originally acquired 180-view DW-PD. As shown in Fig.2, the cutview data of the DW image generated by the proposed method is almost the same as that of the original DW image.

Discussion

As a justification for the interpolation in step 3, frequency characteristics of non-DW and DW images were analyzed as follows: Two axial brain images of 256×256 matrix sizes were reconstructed from (a) DW-PD acquired with 90 views and (b) non-DW-PD acquired with 180 views. By 2D FT, these images were converted to frequency-domain data (FDD). Using various cutoff frequencies (ω_{cutoff}) ranging from 0 to π, sets of interpolated FDD were generated so that values at 0~ω_{cutoff} were taken from FDD of (a) and data at ω_{cutoff}~π from FDD of (b). The interpolated FDD was converted back to an image, and then root-mean-squared-error (RMSE) between the interpolated image and a corresponding DW image acquired with 180 views was calculated. The calculated RMSE from 8 axial slice images of three different human brains was plotted as shown in Fig. 3. It can be deduced that low-frequency information ($<0.4\pi$) of DW images from 180-view and 90-view DW-PD is similar, whereas high-frequency information ($>0.4\pi$) of DW image from 180-view and non-DW image from 180-view is similar. Thus, high-frequency information of non-DW image can be used to compensate for the loss in high-frequency information of a DW image. This can be an effective compensation method because a non-DW image is usually acquired along with DW images to analyze the diffusion characteristics of an object.

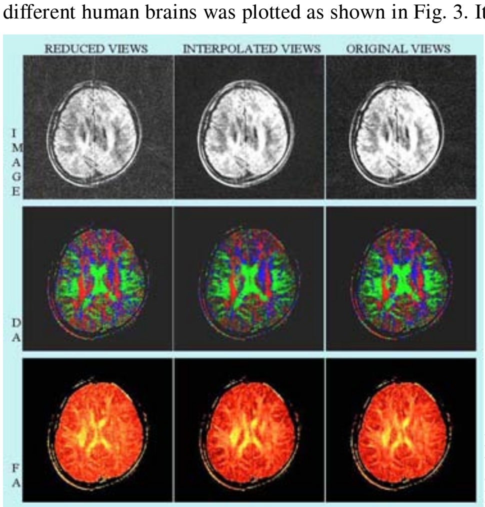

Fig 1. Top row: Images reconstructed using PD with reduced (90), interpolated (180 by proposed method), and original (180) views, Middle row: directional anisotropy, Bottom row: fractional anisotropy

Conclusions

Based on the assumption that most of DW information is represented by the low-frequency terms, we proposed a method to generate high resolution DW images from a PD acquired with reduced number of projection views. When the proposed method is used, full projection views is required only for the non-DW image and DW images can be reconstructed from PD with reduced number of projection views using high-frequency information of the non-DW image. As a result, the acquisition time can be reduced to 4/7 of the conventional acquisition time in case of (6+1)-direction DW imaging. The proposed method has shown a possibility of reducing the imaging time while keeping the image quality.

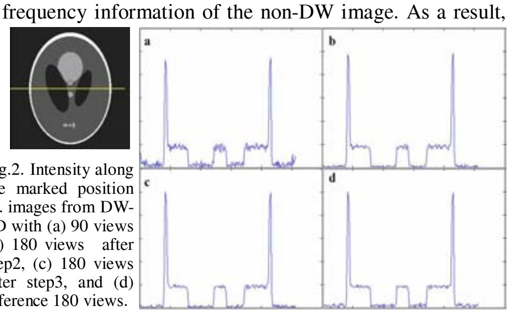

Fig.2. Intensity along the marked position of. images from DW-PD with (a) 90 views (b) 180 views after step2, (c) 180 views after step3, and (d) reference 180 views.

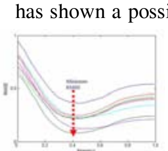

Fig.3 RMSE of interpolated and acquired 180-view DW images.

References [1] Jung KJ et al. MRM 19:239 (1991); [2] Gmitro AF et al. MRM 29:835 (1993); [3] Cho ZH et al. Foundations of Medical Imaging 80, 269-285 (1993)