Retrospective motion correction in diffusion-weighted imaging by using optimum order for measuring diffusion directions

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TARGET AUDIENCE Scientists and physicians who are interested in motion correction of diffusion-weighted (DW) imaging.

PURPOSE A number of methods, such as HARDI (high-angular-resolution diffusion imaging)[1], have been proposed to extract more information from a DW signal. Many of them involve measuring the DW signal by using a much-larger number of diffusion directions than required for DTI (diffusion tensor imaging). The measurement of a large number of diffusion directions often suffers from subject motion, causing errors in calculated diffusion parameters. A previous study addressed this problem by using an interleaved navigator for motion correction[2]. This approach, however, requires an increase in scan time in order to acquire navigator data. In this study, a method for retrospective motion correction of diffusion-weighted images by using the optimum order for measuring diffusion directions is proposed. The method requires no additional scanning because the navigator images used for motion correction are obtained from imaging data only.

METHODS As for the proposed method, motion is corrected retrospectively by using intermediate mean-diffusivity (MD) maps, which are generated from groups of six consecutive DW images. The key to efficiently correcting motion is the order of diffusion direction measurement. The order is determined by calculating the volume of a polyhedron composed of six consecutive diffusion directions in order to scatter directions. Therefore, the image contrast of MD maps is kept constant while DW image contrast changes depending on diffusion direction. The proposed correction process, summarized in Figure 1, is composed of the following steps. In step 1, MD_i maps are calculated from six DW images taken in the optimum measurement order. In step 2, the presence of subject motion is detected by calculating the difference between MD_i and MD_{i+1}. In step 3, if the motion is detected, a spatial transformation is performed only on DWI_{i+6}, which is the last of the six images used to calculate MD_{i+1} to be scanned. The spatial transformation is determined by minimizing the sum of the squares of the difference between MD_i and MD_{i+1}. Furthermore, the diffusion direction of DWI_{i+6} is also modified according to the spatial transformation, and MD_{i+1} is recalculated by using the modified DW image and diffusion direction.

In this study, we determined the optimum measurement order of 21 diffusion directions. The effects of motion correction by the proposed method were evaluated using a numerical-simulation model. Two-dimensional spin-echo DW echo planner imaging was performed, by using a 1.5-T MRI system (ECHELON Vega, Hitachi Medical Corporation, Japan), on the brain of a healthy volunteer to make a diffusion-tensor simulation model. The scan parameters used are listed as follows: TR/TE, 3300/120 ms; FOV, 240 mm; matrix, 128x128; 21 diffusion directions; b-value, 1000 s/mm^2. 100 datasets with different motion timing and spatial transformation were simulated from diffusion-tensor model and 21 predetermined diffusion directions. Random noise was added to the respective datasets. MD and FA (fractional anisotropy) maps were calculated either with or without motion correction. Systematic errors were evaluated by using the ratio of the difference between the model value and mean simulated value to the model value. Random errors were evaluated by using the ratio of the standard deviation of simulated values to the model value.

RESULTS Twenty-one predetermined diffusion directions used in the proposed method are shown in Figure 2. It shows that the 21 directions are uniformly distributed. Volumes of polyhedrons composed of six consecutive diffusion directions are plotted in Figure 3. Although the volume of an icosahedron composed of six typical diffusion directions is 0.56, the volumes of polyhedrons with the proposed six diffusion directions are 0.56 ± 0.012. The results show that the respective six diffusion directions are scattered. MD and FA maps calculated with or without the motion correction are shown in Figure 4. The proposed method can reduce artifacts at the edge of the frontal cortex (see red arrows) and the splenium of the corpus callosum (see green arrows). Calculation errors of FA and MD, with or without motion correction are listed in Table 1. The systematic and random errors of MD and FA calculated with proposed motion correction are significantly less than those calculated without motion correction.

CONCLUSION We demonstrated that the proposed retrospective motion-correction method can reduce calculation error caused by subject motion in diffusion MRI without the need for additional scan time.

REFERENCES

1 Bhat H, et al. ISMRM 2012;113. 2 Engström M, et al. ISMRM 2013;2579.

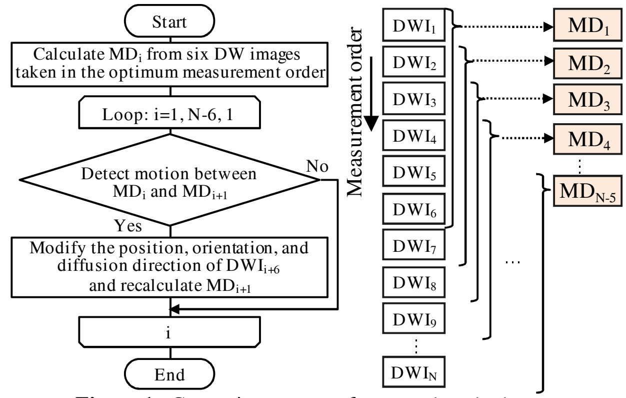

Figure 1. Correction process of proposed method

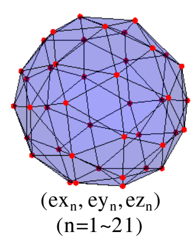

Figure 2. Twenty-one predetermined diffusion directions.

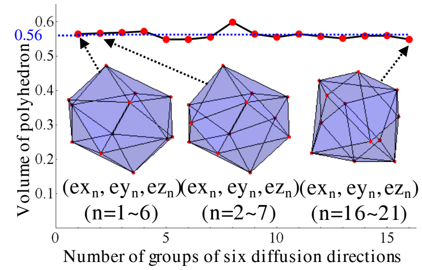

Figure 3. Volumes of polyhedron of six consecutive diffusion directions.

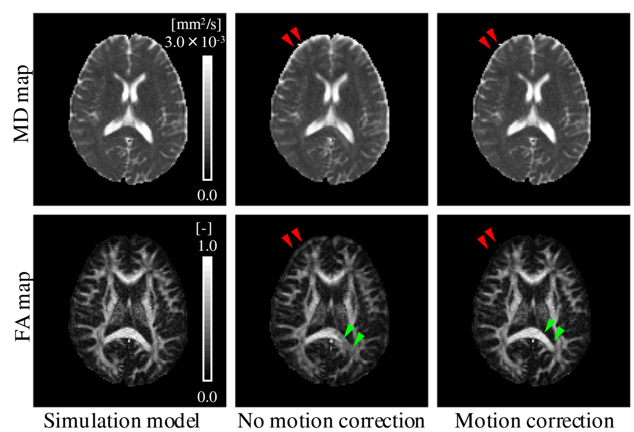

Figure 4. MD and FA maps with or without motion correction.

Table 1. Calculation error of MD and FA calculated with or without motion correction

		motion correction	
		Off	On
MD	Systematic error [%]	4.36 ± 7.00	1.16 ± 1.52**
	Random error [%]	7.77 ± 7.80	0.66 ± 0.71**
FA	Systematic error [%]	21.14 ± 33.13	6.90 ± 6.01**
	Random error [%]	33.39 ± 33.31	4.46 ± 3.65**

**P<0.01