Improving the Accuracy of Diffusion MR Tractography Using RESTORE

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Abstract

Diffusion magnetic resonance (MR) imaging is an effective tool in the assessment of the central nervous system. Diffusion MR tractography, which uses diffusion tensor imaging (DTI) techniques, may be useful in exploring the connectivity between different regions of the brain and examining changes in brain mircostructure in several diseases, including cancer and multiple sclerosis. However, DTI with spin-echo echo-planar imaging suffers from various types of artifacts. Previous studies have shown both thermal noise and spatially and temporally varying artifacts can affect the estimated tensors. Here we show that these artifacts can cause significant error in diffusion tractography and that the error can be reduced by using a robust estimation of tensors by the outlier rejection method.

Keywords: Diffusion MR, tractography, robust tensor fitting, cardiac pulsation.

Introduction

Diffusion MR tractography using diffusion tensor imaging (DTI) is a relatively new technique which provides the opportunity to explore brain microstructure and study connectivity between different brain regions. It is by far the only approach available to study the white matter fiber tracking in human brain non-invasively. White matter fiber tractography is not only an important method for measuring brain connectivity, but also has great potential for studying both neurological and psychiatric disorders [1-3]. However, artifacts are common in clinical DTI datasets. Signal variability in diffusion weighted imaging (DWI) can be influenced by both thermal noise and spatially and temporally varying artifacts such as subject motion and cardiac pulsation. Previous studies [4-6] show those artifacts can affect the estimated tensor elements and their derived quantities such as Trace and Fractional Anisotropy (FA). Nevertheless, the effect of those artifacts on the result of diffusion tractography has not yet been studied.

The RESTORE method—a robust estimation of tensors by outlier rejection—which was previously proposed by our group [4] is an effective technique to identify the outliers in DWI, and then to improve the accuracy of tensor elements. Our purpose here was to examine how the spatially and temporally varying artifacts can affect diffusion tensor tractography, and to investigate if the RESTORE method can also improve the accuracy of diffusion tractography.

Materials and Method

Pulsations during the cardiac cycle can cause severe artifacts in diffusion weighted images acquired when cardiac gating is not used, and cardiac gating is not commonly used in clinical diffusion data acquisitions because of the long acquisition time. These artifacts affect both trace and anisotropy values and are most pronounced in data acquired at specific time points during systole. Previous studies have shown that data acquired at about 120 ms after the onset of the R wave are very prone to corruption by cardiac pulsation [7].

Data Acquisition

In order to assess the performance of the RESTORE method on white matter fiber tracking in human brain in the presence of cardiac pulsation artifacts, we acquired ECG-gated brain DT-MRI data sets from a healthy volunteer with five different trigger delays after the onset of the R wave. One dataset was acquired during the critical systolic period (120 ms delay) and four during the diastolic period when cardiac induced artifacts are less pronounced (320, 370, 420 and 520 ms delay). Images were acquired on a CNV LX 1.5 GE MRI System (General Electric, Milwaukee, WI) with a diffusion-weighted, spin-echo, single-shot, EPI sequence with $2 \times 2 \times 4$ mm^3 resolution and 42 slices to cover the whole

brain. Each dataset consisted of eight replicates of b=1100 s/mm^2 images acquired using the 6 direction gradient scheme [8] and 8 b=0 images for a total of 56 images. Prior to the diffusion tensor computation, all images were corrected for eddy current distortion and rigid-body brain motion using the approach of Rohde *et al.* [9]. The diffusion tensor was computed using the nonlinear least square [10] and the RESTORE [4] methods in 2 sets of pooled data: a "superset" consisting of the 4 diastolic acquisitions plus the systolic one, and a "diastolic set" containing only the 4 diastolic acquisitions. The fiber tracking result shown in the next section was produced using DTI- Studio [11] with 4 seed points selected in the region of the internal capsule, and with the stopping FA value set at 0.2 and the maximum turn angle set at 45 degrees.

Result

Figure 1 shows the fiber tracking results of the internal capsule. Fig. 1 (a) shows the 4 selected seed points, Fig. 1 (b) shows the tracking result using the nonlinear least squares fitting method with the diastolic data set, Fig. 1 (c) shows the tracking result also using the nonlinear fitting method but with the superset, and Fig. 1 (d) shows the tracking result using the RESTORE method with the superset. Clearly the computed tract of the internal capsule was miscalculated in Figure 1 (c) because the left and right parts are not connected anatomically. This error is mainly due to the cardiac pulsation artifact, i.e., by including the systolic time points in the nonlinear fitting procedure. Application of RESTORE to the superset (see Fig. 1 (d)) gave results most similar to those obtained with the diastolic set (see Fig. 1 (b)), thus improving the accuracy of tractography in the non cardiac gating DTI data. The tracks were superimposed with the FA map for display.

Discussion

As stated in [4], the potential weakness of the RESTORE method—and other robust estimation methods—is the reliance on data redundancy. Problems may arise if the dataset does not have enough good data points to correctly identify outliers. The percentage of artifactual data points that can be tolerated can depend on the degree of redundancy of the data set, or on the number of directions used in the gradient sampling scheme. Fortunately, the tendency is to use more gradient directions (> 24) when diffusion tensor imaging is used for tractography.

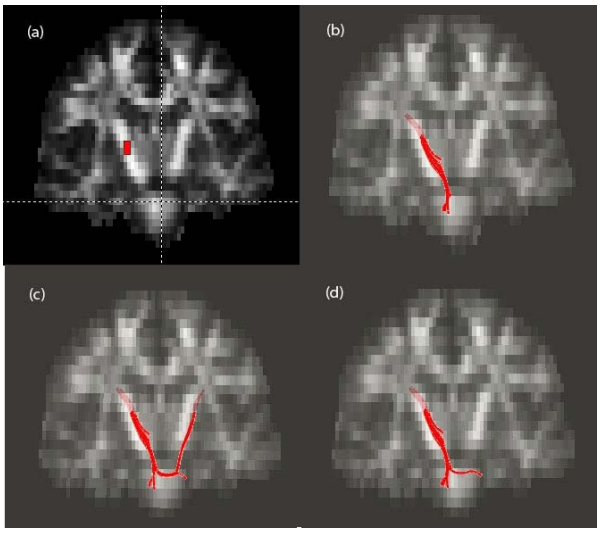

Fig. 1 (a) The FA map with four seed points in the internal capsule, and the results of diffusion tensor tractography using nonlinear fitting method with (b) diastolic set only, and (c) superset, and (d) using the RESTORE method with superset.

Conclusion

We show that white matter fiber tracking in human brain using clinical diffusion tensor data can be affected by cardiac pulsation artifacts. The error can be significant which may lead to a faulty diagnosis or inappropriate treatment. The RESTORE method is a feasible technique for identifying such outliers and effectively improving the white matter fiber tracking results. Use of robust tensor fitting in DTI tractography is suggested primarily for data acquired without cardiac gating.

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