DTI TOPUP Distortion Correction at the CFMRI

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Introduction

Standard DTI images acquired with echo-planar readout are known to have susceptibility-induced geometric distortions. The conventional method for correcting the geometric distortions uses dual echo-time field mapping approaches. In 2003, Anderson et al [1] proposed an alternative method in which DTI images acquired in opposing phase encoding directions are used to estimate the field and to correct for distortions. Compared to the conventional method, this alternative method provides more robust and effective performances in correcting distortions. An implementation of this method has recently been made available by FSL via a tool called TOPUP. To take advantage of this tool, we have created three DTI protocols on the GE MR750 3T scanners. These three protocols provide different acquisition setups to support a range of research needs, and all three protocols acquire images in two opposite phase encoding directions.

Table 1 summarizes the three protocols and their recommended use. More detailed information on each protocol is provided below the table.

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[1] *J.L.R. Andersson, S. Skare, J. Ashburner How to correct susceptibility distortions in spin-echo echo-planar images: application to diffusion tensor imaging. NeuroImage, 20(2):870-888, 2003.*

Table 1

	Protocol 1	Protocol 2	Protocol 3
Number of scans	One DTI scan	Two DTI scans	Two calibration scans + One DTI scan
Typical Scan time (depends on # diffusion directions)	3 - 10mins	6 - 20mins	3 - 10mins
Resolution	2x2x2 mm^3	2x2x2 mm^3	2x2x2 mm^3
Pros	There is only one scan. No additional scans are needed.	Most effective in correcting distortions. Works with ASSET.	Most Flexible; user could keep existing DTI protocols and just add the calibration scans. Works with ASSET.
Cons	It does not work with ASSET, which leads to reduced slice coverage per unit time.	Scan time is doubled due to the requirement for two separate scans.	Need to pay attention to shim settings between scans.
Recommendation to use	Use for easy protocol setup and scanning	Best for use when scan time is not a limiting factor and the best correction results are desired.	Use when adopting or upgrading an existing DTI protocol without the need for changing DTI parameters (* see Note).
* Note	# of DTI slices must be even for all three protocols		

Protocol 1

Description
Protocol 1 consists of one scan:

- DTI-TOPUP

By default Protocol 1 acquires two T2 (or b=0) images at the beginning of the scan. The first T2 image uses reversed phase encoding direction, whereas the second T2 image and the subsequent diffusion weighted images use forward phase encoding direction. Due to the requirement of opposite phase encoding directions, the number of T2 images must be 2 or greater.

Location on the scanner
Adult -> Head -> DTI_TOPUP
The protocol is available on both 3T West and 3T East scanners.

Parameters
User should adjust b value and number of directions to fit study needs. Other parameters to customize include: FOV, slice thickness, number of slices (must be even), TR, and matrix size.

Advanced option

The following CVs are set under the advanced tab and can be customized as needed:

CV1: pepolar = 2 or 3 (do not set to 0 or 1). The pepolar parameter controls the phase encoding direction, i.e. pepolar = 2 corresponds to forward phase encoding, whereas pepolar = 3 corresponds to reverse phase encoding. In a typically MRI setup, forward phase encoding causes compression of the frontal lobe and stretching of the occipital lobe; whereas reverse phase encoding causes stretching of the frontal lobe and compression of the occipital lobe. Since stretching is easier to correct than compression, one could choose this parameter accordingly for the specific areas of brain being studied.

CV2: rhmethod = 1 (prevent interpolation to 256 in the reconstructed images)

Cv4: ssgr fat suppression = 1 (reverses spin echo refusing gradient polarity to better suppress fat signal)

Shim settings and scan instructions
Shim is set to Auto. After saving Rx, press Scan to start.

Protocol 2

Description
Protocol 2 consists of two DTI scans:

- DTI-fwd
- DTI-rvs

The DTI-fwd scan acquires data in forward phase encoding direction, whereas the DTI-rvs scan acquires data with reversed phase encoding direction. All parameters must match between the two scans except the phase encoding direction. This protocol is also available with ASSET option ON.

Location on the scanner
Adult -> Head -> DTI_TOPUP
The protocol is available on both 3T West and 3T East scanners.

Parameters
User should set the number of T2 images, the number of diffusion directions and b value as desired. The same parameters must be applied to both scans.

Other parameters to customize include: FOV, slice thickness, number of slices (must be even), TR, and matrix size. Again, the same parameters must be applied to both scans.

Advanced option
The following CVs are set under the advanced tab and can be customized as needed:

CV2: rhmethod = 1 (to prevent interpolation to 256 in the reconstructed images)

CV4: ssgr fat suppression = 1 (reverses spin echo refusing gradient polarity to reduce remaining fat signal)

Shim settings and scan instructions

The order of the two scans can be swapped. However, the first scan can have shim set to Auto and the second scan must have the shim set to OFF. For each scan, save Rx and press Scan.

Protocol 3

Description

Protocol 3 consists of three scans:

- DTI_cal_fwd (24sec)
- DTI_cal_rev (24sec)
- DTI

The first two scans of this protocol are calibration scans with forward and reversed phase encoding directions respectively. They are used to estimate the field map, which is then applied to the DTI scan to correct distortions. The subsequent DTI can be any DTI scan (i.e, either GE standard DTI or the DTI supplied with this protocol). The only requirement is that the Rx info must match among all three scans, e.g.   FOV, slice thickness, number of slices and matrix size. This protocol is also available with ASSET option ON.

Location on the scanner

Adult -> Head -> DTI_TOPUP
The protocol is available on both 3T West and 3T East scanners.

Parameters

For the two calibration scans, user may customize TR, FOV, slice thickness, number of slices (must be even), and matrix size. Please keep in mind that Rx information must match the DTI scan.

For the DTI, user should set the number of T2 images, the number of diffusion directions and the b value. Other parameters to customize include: FOV, slice thickness, number of slices (must be an even number), TR, and matrix size. Remember that the Rx info of the DTI scan must match the Rx info of the calibration scans.

Advanced option

User should not change any advanced options in the calibrations scans.

For the DTI scan, if you are using the GE standard DTI, no change should be made in the advanced tab. If you are using the DTI supplied with this protocol, the following CVs under the advanced tab can be customized as needed:

CV1: pepolar = 0 or 1 (do not set to 2 or 3). The pepolar parameter controls the phase encoding direction, i.e. pepolar = 0 corresponds to forward phase encoding, whereas pepolar = 1 corresponds to reverse phase encoding. In a typically MRI setup, forward phase encoding causes compression of the frontal lobe and stretching of the occipital lobe; whereas reverse phase encoding causes stretching of

the frontal lobe and compression of the occipital lobe. Since stretching is easier to correct than compression, one could choose this parameter accordingly for the specific areas of brain being studied.

CV2: rhmethod = 1 (to prevent interpolation in the reconstructed images)

CV4: ssgr fat suppression = 1 (reverse spin echo refusing gradient polarity to reduce remaining fat signal)

Shim settings and scan instructions

The two calibration scans can be either before or after the DTI scan. Regardless the order, the first scan of the set can have shim set to Auto, the following two scans in the set must have the shim set to OFF. For each scan, save Rx and press Scan.

TOPUP Distortion Correction

We provide a C-Shell script "processtopup" for processing the data acquired with the above protocols. Processtopup first prepares the GE dicom data and converts it into NIFTI format and then calls the TOPUP tool from FSL to unwarp the distortion. More information on the FSL TOPUP tool is available at the FSLwiki website (http://fsl.fmrib.ox.ac.uk/fsl/fslwiki/topup).

Required software

1. Processtopup (http://fmri.ucsd.edu/download/processtopup)

2. AFNI (http://afni.nimh.nih.gov/afni/)

3. FSL version 5.0 or above (http://fsl.fmrib.ox.ac.uk/fsl/fslwiki/)
   (The Environment Variable FSLOUTPUTTYPE must be set to NIFTI_GZ.)
   (The Environment Variable FSLDIR must be set and point to the FSL installation folder.)

   Note: The acquired DTI data must have an even number of slices (requirement of the FSL TOPUP tool). If the number of slices is odd, processtopup will remove the last slice from the data.

Usage
processtopup -dsnum <num of DTI dir> -d1 <data dir> [-d2 <data dir> -d3 <data dir> <options>] -o <outstem>"

Required Inputs
  -dsnum <number of DTI data directories, 1, 2 or 3>
  if -dsnum 1
     -d1 <DTI data dir>
  if -dsnum 2"

-d1 <DTI_fwd data dir>
   -d2 <DTI_rvs data dir>
 if -dsum 3
   -d1 <Cal1_dir>
   -d2 <Cal2_dir>"
   -d3 <DTI data dir>
   Note: The -d1 and -d3 inputs must have the same phase encoding direction;
 -o <unwarpped filename stem>"

Optional Inputs
  -tmpdir   : specify tmp dir name
  -nocleanup   : disables removal of temporary files

Output
  <outstem> - unwarpped volume filename stem

Examples

  Protocol 1:
      >>processtopup -dsnum 1 -d1 dti_dir -o myoutput

  Protocol 2:
      >> processtopup -dsnum 2 -d1 dti_fwd -d2 dti_rvs -o myoutput

  Protocol 3:
      >> processtopup -dsnum 3 -d1 cal_fwd -d2 cal_rvs -d3 dti_fwd -o myoutput

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