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GE HealthCare

B0 Mapping Information for fMRI/DTI

Information for fMRI research users

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Rev 1.3

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Scope and Purpose

This document is intended to provide information about the 2D and 3D B0 Mapping PSD available on scanners built by GE Healthcare. All these information is expected to help research users to acquired B0 Maps and to facilitate users who wish to apply distortion corrections to EPI data (Echo planar Imaging – fMRI and DTI) using popular 3rd party research tools like SPM/FSL/AFNI. This information is only applicable to the pulse sequences 2D B0Map and 3D B0Map.

Intended Use Limitation

The instructions given in this document are intended to be used for research purposes only.

Introduction

This section is a simple reminder about B0 Mapping, for more details we refer the reader to Koch et al. (2009) and Jezzard et al (1995) given in the Reference section.

Usually, B0 Mapping is performed using a 2D or 3D two-echo Gradient-echo (GRE) or RF spoiled GRE (SPGR). It can also be performed with two separate single-echo acquisitions with varying TEs. B0 Mapping requires the complex data for each echo with appropriate coil element combination (e.g. using ASSET). The phase of these complex images evolves as a function of some unknown initial phase (ϕ_0), the ΔB_0 and the echo-time T_E. Let consider two complex images I_1 and I_2 acquired at T_{E_1} and T_{E_2}. These images can be written as

$$I_1 = \rho_0 e^{j\phi_1} \text{ and } I_2 = \rho_0 e^{j\phi_2}.$$

And the phases can be decomposed as

$$\phi_1 = \phi_0 + \gamma \Delta B_0 T_{E_1} \text{ and } \phi_2 = \phi_0 + \gamma \Delta B_0 T_{E_2}.$$

Then the phase difference gives

$$\Delta\phi = \phi_2 - \phi_1 = \gamma \Delta B_0 (T_{E_2} - T_{E_1}) = \gamma \Delta B_0 \Delta T_E.$$

The B0 Map can thus be extracted by

$$\Delta B_0 = \frac{\Delta\phi}{\gamma \Delta T_E},$$

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Which can be converted into Hertz

$$\Delta f_0 = \frac{\Delta\phi}{2\pi\Delta T_E}.$$

Very often, the $\Delta\phi$ is computed directly by taking the phase of the complex division of the complex images I_2 and I_1:

$$\Delta\phi = \phi_2 - \phi_1 = arg\left(\frac{I_2}{I_1}\right).$$

The two pulse sequences described in the next section "Pulse Sequences" output the magnitude of the first echo $|I_1|$ and the B0 Map itself in Hertz, Δf_0.

Sometimes, it might be useful to go back to the phase difference $\Delta\phi$ (in radians) from the B0 Map Δf_0 (Hz) to apply some phase unwrapping (such as FSL's PRELUDE, Jenkinson (2003)) which would require the phase difference in radians as input. This can be easily achieved by

$$\Delta\phi = 2\pi\Delta f_0\Delta T_E.$$

Also, in some cases, you might have to convert the B0 Map Δf_0 (Hz) in rad/s. This can be simply achieved by $\Delta\omega_0 = 2\pi\Delta f_0$.

The choice of T_{E_1} and T_{E_2} (hence ΔT_E) is important. For human scanning, the T_E is often set to a small multiple of the fat-water period (such as fat and water are in-phase), the ΔT_E is set to the fat-water period such that the chemical shift contribution has the same phase in each image as detailed in Jezzard et al (1995).

Pulse Sequences

In this section, we will describe the locations on the scanner of the B0 Mapping PSDs, how to set them up and how to use them. Note that the two pulse sequences (2D and 3D) output the magnitude of the first echo and the B0 Map itself in Hertz.

B0 Mapping PSDs Locations

On GE scanners, there are two different B0 Mapping PSDs:
- a 2D version (since the DV24 software release)
- and a 3D version (since the RX28 software release).

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These PSDs come in the form of a type-in PSDs which, in practice, is a simple soft link to specific PSD binary files. The table below summarizes the binary file locations and the links location for pre- and post-MR30.0 systems.

MR29.1 and earlier		
	Binary files location	Links location
2D B0 Map	/usr/g/service/mclass/B0map /usr/g/service/mclass/B0map.psd.ice	/usr/g/bin/B0rf /usr/g/bin/B0rf.psd.ice
3D B0 Map	/usr/g/bin/efgre3d /usr/g/bin/efgre3d.psd.ice	/usr/g/bin/3db0map /usr/g/bin/3db0map.psd.ice
MR30.0 and later		
	Binary files location	Links location
2D B0 Map	/srv/nfs/psd/bin/service/B0map /srv/nfs/psd/bin/service/B0map.psd.ice	/srv/nfs/psd/service/B0rf /srv/nfs/psd/service/B0rf.psd.ice
3D B0 Map	/srv/nfs/psd/bin/efgre3d /srv/nfs/psd/bin/efgre3d.psd.ice	/srv/nfs/psd/psd/3db0map /srv/nfs/psd/psd/3db0map.psd.ice

Please note that, depending on your scanners software release and specific hardware, you might have different files and links extensions. Instead of the extension ".psd.ice" you might have ".psd.o" (e.g. on DV24 systems), and you might have an additional files with the extension ".psd.mgd" (e.g. on DV26 systems). However, you will find the files and links in the same directories.

To check if these links already exist on your specific system, simply open a terminal (a.k.a. command window or C-Shell) and type: `ls -l [link location]`
And replace [link location] by one of the links locations given in the table above (pay attention to the extension depending on hardware and software release).

For example, on a MR29.1 system you can perform the following command and you get the given results:

```
{sdc@MySystem}[75] ls –l /usr/g/bin/3db0map /usr/g/bin/3db0map.psd.ice
lrwxrwxrwx. 1 root root 7  Jan  1  2010 /usr/g/bin/3db0map -> efgre3d*
lrwxrwxrwx. 1 root root 15 Jan  1  2010 /usr/g/bin/3db0map.psd.ice -> efgre3d.psd.ice
```

By default, these links are already created on your system. In case these links do not exist, you will have to create them. This can be done, by using the command "ln -s". Please note that users are only allowed to create links in /usr/g/bin (on MR30+ system the /srv/nfs directory is protected and cannot be modified by users).

To create these links, use the appropriate command given below (use the extension applicable to your specific systems).

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For MR29.1 systems and earlier:

```
ln -s /usr/g/service/mclass/B0map /usr/g/bin/B0rf
ln -s /usr/g/service/mclass/B0map.psd.ice /usr/g/bin/B0rf.psd.ice
ln -s /usr/g/bin/efgre3d /usr/g/bin/3db0map
ln -s /usr/g/bin/efgre3d.psd.ice /usr/g/bin/3db0map.psd.ice
```

For MR30.0 systems and later:

```
ln -s /srv/nfs/psd/bin/service/B0map /usr/g/bin/B0rf
ln -s /srv/nfs/psd/bin/service/B0map.psd.ice /usr/g/bin/B0rf.psd.ice
ln -s /srv/nfs/psd/bin/efgre3d /usr/g/bin/3db0map
ln -s /srv/nfs/psd/bin/efgre3d.psd.ice /usr/g/bin/3db0map.psd.ice
```

2D B0 Mapping

To load 2D B0 Map PSD (“B0rf”), start by loading a basic “2D Fast GRE” from the GE templates. To do that, open the protocol library (add sequence) and select GE > Adult > Templates > 2D Gradient Echo > Fast GRE, push it to the multi-protocol basket and click “Accept”. See the illustration on Figure 1.

Then, edit this pulse sequence (select the pulse sequence and click “Setup”), select the coil and anatomical region (“Brain” or “Head”), then click on “imaging options” and “more”. You should now see the free field “PSD Name”; and in this field type B0rf and strike the return key. Then you can select the options “Extended Dynamic Range” and “Sequential”. Finally, you can click “accept”. These steps are illustrated on Figure 2.

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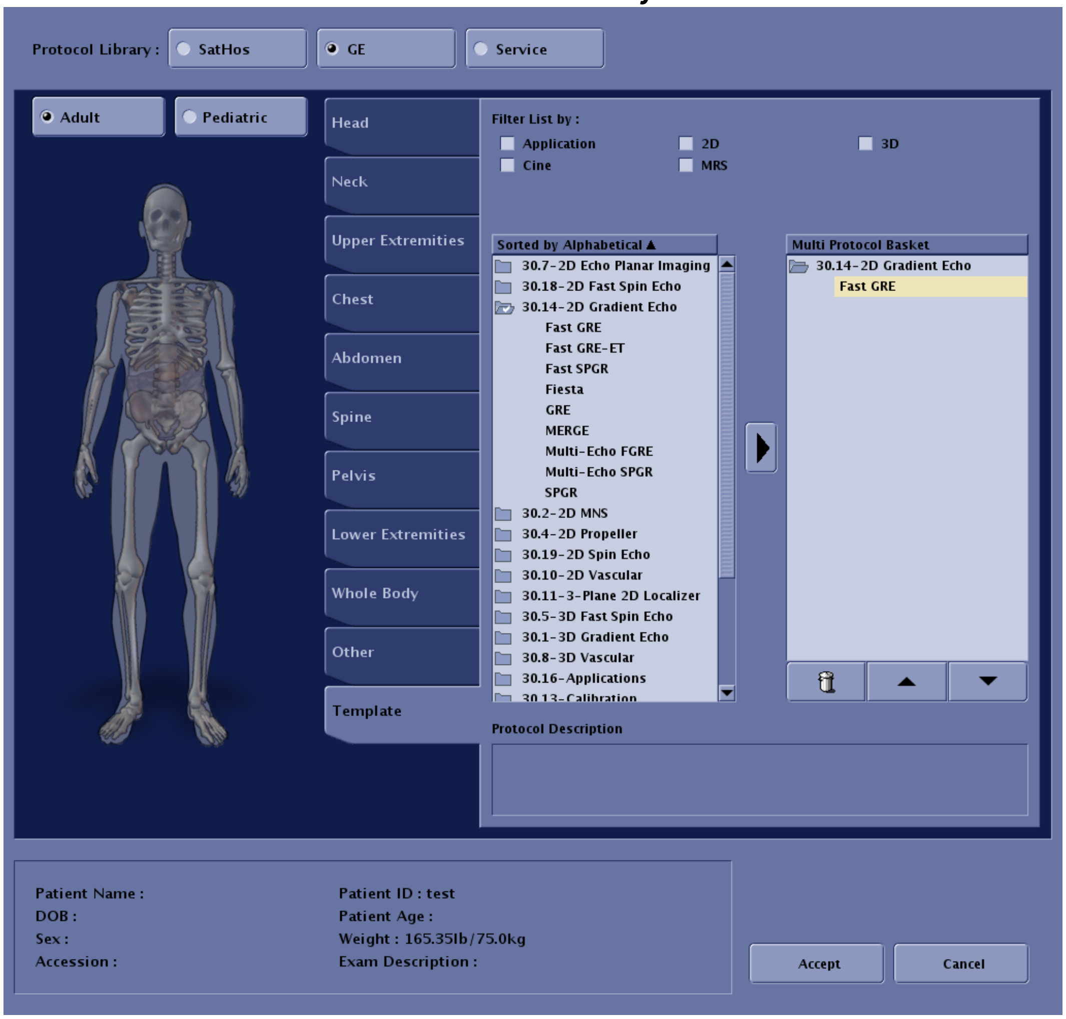

Figure 1: Basic 2D Fast GRE to use to setup the 2D B0 Map PSD (type-in B0rf). For this PSD, it is recommended to start with a basic 2D Fast GRE PSD before loading the B0rf type-in.

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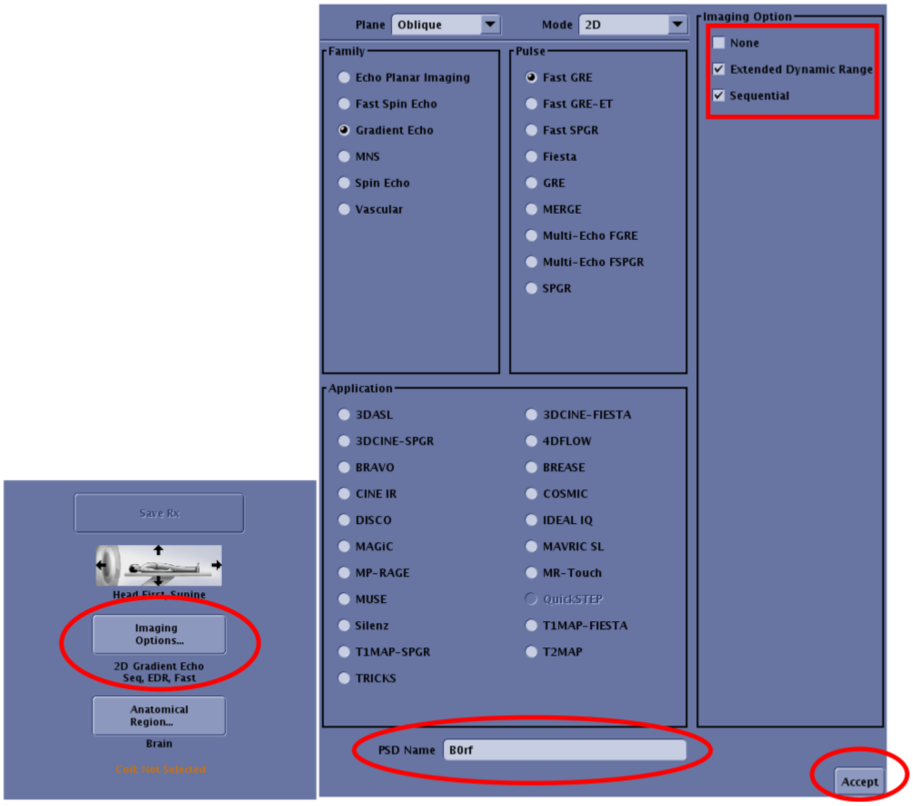

Figure 2: Loading the B0rf type-in PSD (2D B0 Map) with the available imaging options. After entering B0rf in "PSD Name", don't forget to hit the return key, then the imaging options of the 2D B0 Map will become visible.

At this stage, you should be able to enter the acquisition parameters of the 2D B0 Map. A screenshot of the 2D B0 Map UI is given on Figure 3 below. In the advanced tab, the CV2 gives control to access two different "Scan Modes".

If "Scan Mode" is set to 0 (service mode), the T_E is set by the user via the standard TE UI input and the ΔT_E via the "B0 Field Mapping Range in Hz" (CV4) using

$$\Delta TE = \frac{1}{2 \times CV4}.$$

Put another way, if "B0 Field Mapping Range in Hz" (CV4) is set to 150 Hz the ΔTE is calculated to cover a frequency range going from -150 Hz to +150 Hz.

If "Scan Mode" is set to 1 (patient mode), the T_E is fixed to the smallest multiple of the fat-water period (depends on the B0 field strength), the ΔT_E is set to the fat-water period and the "B0 Field Mapping Range in Hz" (CV4) is then ignored.

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Note that, if the matrix size is a power of 2 (i.e., 32x32, 64x64, 128x128 and 256x256), the reconstructed images will be at the same size without interpolation (zero filling). However, if the matrix size is larger than 256x256, the images will be reconstructed at 512x512, and if the matrix size is larger than 512x512, the images will be reconstructed at 1024x1024. In case you select a non-power of 2 matrix size between 32x32 and 256x256 (e.g., 90x90), the images will be reconstructed by default at 256x256. If you want to remove the default interpolation (i.e., images acquired at 90x90 to be reconstructed at 90x90) you will have to adjust manually the CVs rhrcxres, rhrcyres and rhimsize to the acquisition matrix size. In practice, changing rhrcxres should be enough as its value will be recopied to rhrcyres and rhimsize (but better to double check in case this behavior is different for a particular software release).

Figure 3: GUI of the 2D B0 Map. Most of the parameters are common to all pulse sequences. The parameters specific to the B0 Map are in the Advanced tab.

Once the basic 2D B0 Map PSD is setup, we recommend saving it in a protocol for easier and faster inclusion in other protocols and modification.

3D B0 Mapping

The procedure to load the 3D B0 Map PSD is very similar to the 2D version. To load the 3D B0 Map PSD (“3db0map”), start by loading a basic “3D Fast SPGR” from the GE templates. To do that,

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open the protocol library (add sequence) and select GE > Adult > Templates > 3D Gradient Echo > Fast SPGR, push it to the multi-protocol basket and click "Accept". See the illustration on Figure 4.

Figure 4: Basic 3D Fast SPGR to use to setup the 3D B0 Map PSD (type-in 3db0map). For this PSD, it is recommended to start with a basic 3D Fast SPGR PSD before loading the 3db0map type-in PSD.

Just like the 2D case, edit this pulse sequence (select the pulse sequence and click "Setup"), select the coil and anatomical region ("Brain" or "Head"), then click on "imaging options" and "more". You should now see the free field "PSD Name"; and in this field type 3db0map and strike the return key. Then you can select the options "Extended Dynamic Range" and "ARC". Finally, you can click "accept". These steps are illustration on Figure 5.

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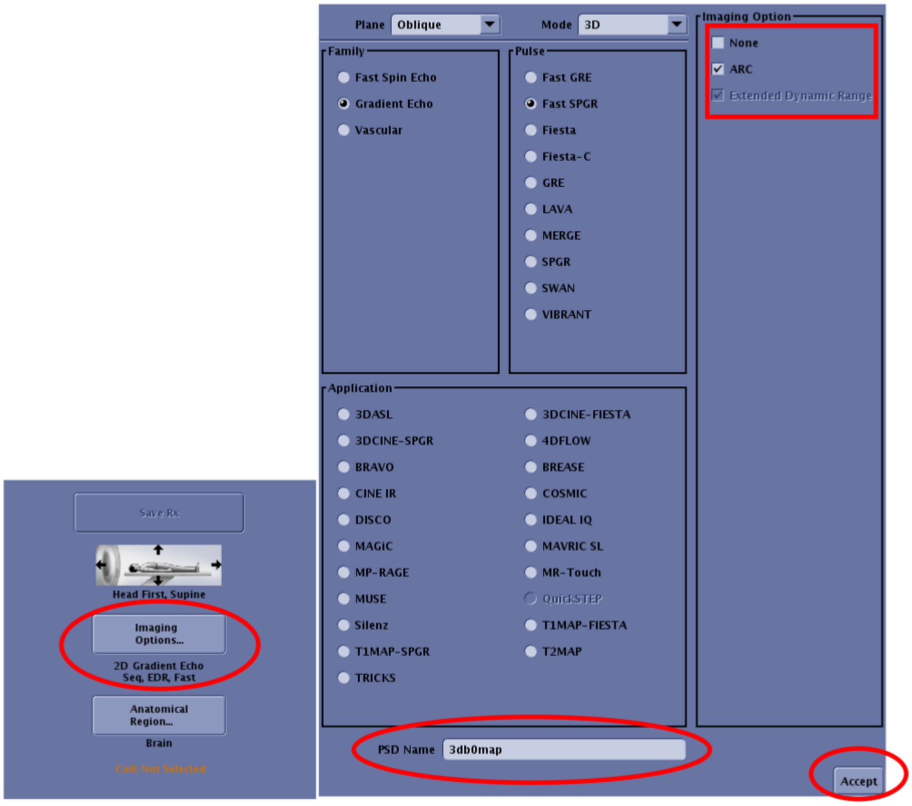

Figure 5: Loading the 3db0map type-in PSD (3D B0 Map) with the available imaging options. After entering 3db0map in "PSD Name", don't forget to hit the return key, then the imaging options of the 3D B0 Map PSD will become visible.

At this stage, you should be able to enter the acquisition parameters of the 3D B0 Map. A screenshot of the 3D B0 Map UI is given on Figure 6 below. The 3D B0 Map is very similar to the 2D B0 Map. In the advanced tab, the CV31 gives control to access two different "Scan Modes".

If "Scan Mode" is set to 0 (service mode), the T_E is set by the user via the standard TE UI input and the ΔT_E via the "B0 Field Mapping Range in Hz" (CV33) using

$$\Delta TE = \frac{1}{2 \times CV33}.$$

Put another way, if the "B0 Field Mapping Range in Hz" (CV33) is set to 150 Hz the ΔTE is calculated to cover a frequency range going from -150 Hz to +150 Hz.

If "Scan Mode" is set to 1 (patient mode), the T_E is fixed to the smallest multiple of the fat-water period (depends on the B0 field strength), the ΔT_E is set to the fat-water period and the "B0 Field Mapping Range in Hz" (CV33) is then ignored and hidden.

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Note that, if the matrix size is a power of 2 (i.e., 32x32, 64x64, 128x128 and 256x256), the reconstructed images will be at the same size without interpolation (zero filling). However, if the matrix size is larger than 256x256, the images will be reconstructed at 512x512, and if the matrix size is larger than 512x512, the images will be reconstructed at 1024x1024. In case you select a non-power of 2 matrix size between 32x32 and 256x256 (e.g., 90x90), the images will be reconstructed by default at 256x256. If you want to remove the default interpolation (i.e., images acquired at 90x90 to be reconstructed at 90x90) you will have to adjust manually the CVs rhrcxres, rhrcyres and rhimsize to the acquisition matrix size. In practice, changing rhrcxres should be enough as its value will be recopied to rhrcyres and rhimsize (but better to double check at least once in case this behavior is different for a particular software release).

The 3D B0 map allows to use an in-plane acceleration of 2. As usual, this parameter is in the "Acceleration" tab. Of course, this can be set to an acceleration factor of 1, if you don't want any acceleration.

One of the limitations of the 3D B0 Map PSD is that it allows only an even number of slices per slab.

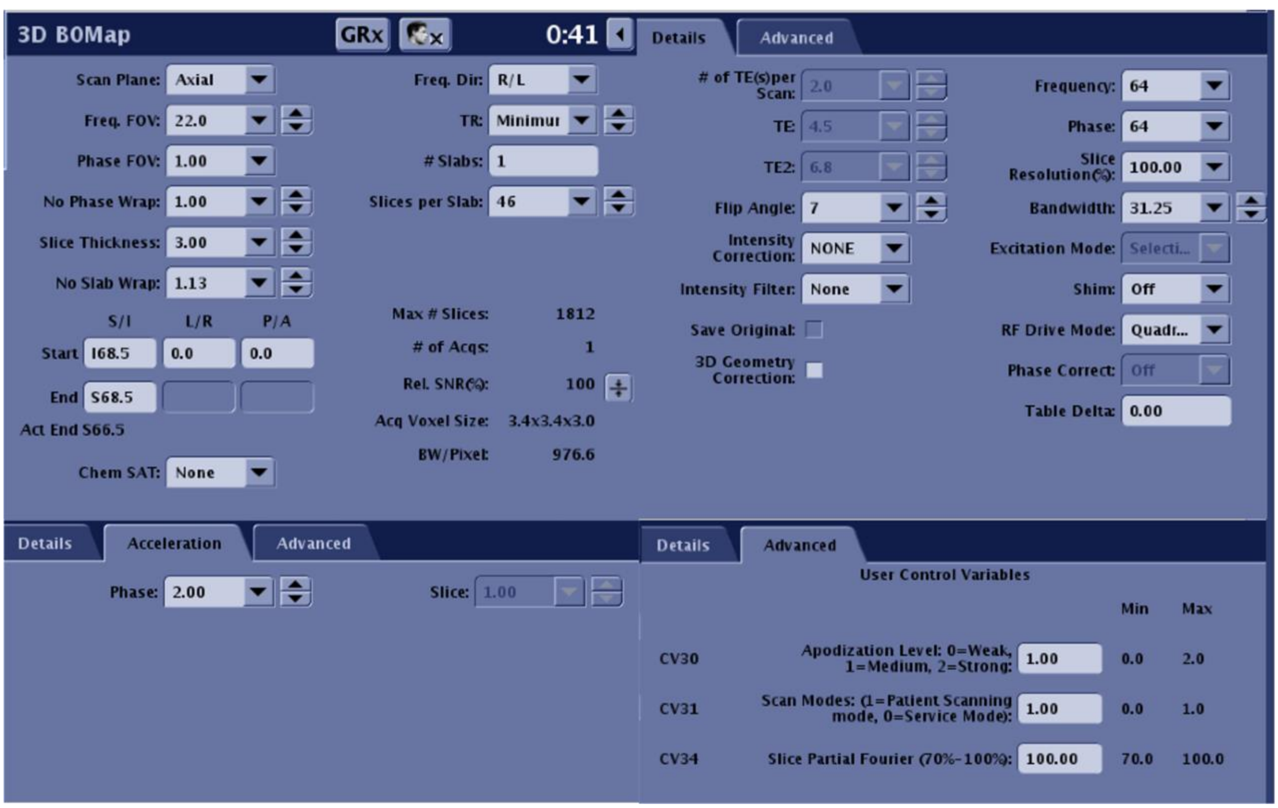

Figure 6: GUI of the 3D B0 Map PSD. Most of the parameters are common to all pulse sequences. The parameters specific to the B0 Map are in the Advanced tab.

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Installing the default B0 Mapping Protocols

To setup the 2D and 3D B0 Mapping PSD in an easy way, we provide a default protocol that needs to be installed on your scanner. This protocol is compatible with MR29.1 and later software release.

The protocol is in `B0_Mapping_PSDs_MR29.1_Protocol_vX.Y.tar.gz`. To install the protocol, please follow these instructions. If you need help you can ask your local research support representatives or your local FE.

First, place the file `B0_Mapping_PSDs_MR29.1_Protocol_vX.Y.tar.gz` on your scanner, let say in the research user directory which is `/usr/g/research`.

Then move the file into the local site protocol directory.

```
mv /usr/g/research/B0_Mapping_PSDs_MR29.1_Protocol.tar.gz /usr/g/wfprotocols/site/
```

untar the archive file using

```
cd /usr/g/wfprotocols/site/
tar xvzf /usr/g/research/B0_Mapping_PSDs_Protocol_vX.Y.tar.gz
```

then update the protocol database with

```
setupProtocols
```

finally delete the protocol archive

```
rm -f B0_Mapping_PSDs_MR29.1_Protocol_vX.Y.tar.gz
```

The protocol will then be available in the Protocol Library > Site > Adult > Templates > B0 Mappings PSDs.

Protocol Recommendations

The provided protocols might not exactly fit the specific purpose you might be interested in, and some protocol adaptations may be necessary.

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If you are scanning in "Patient scanning mode" (see advanced tab for both PSD) the TEs (hence ΔT_E) will be set automatically based on the fat-water period and will be suitable for typical B0 mapping acquisition on humans.

To set the T_R on the 2D B0Map, increase it until you have "# of acqs" is equal to 1 after setting the desired number of slices, it usually gives faster acquisitions. For 3D B0Map, the T_R can be safely set to "Minimum".

With the 3D B0Map, you have the option to use ARC to accelerate the acquisition if needed. If your acquisition is fast enough set the acceleration to 1, if not set it to 2.

For the flip angle, it is safe to use something around the Ernst angle (in degrees) usually computed as

$$\alpha_{Ernst} = \frac{180}{\pi}\cos^{-1}\left(-\frac{T_R}{T_1}\right)$$

where T_1 denote the average brain T_1 of ~850 ms at 3T.

If you acquired a B0 Map for making EPI distortion correction, you would probably want to set acquisition parameters to match the resolution of the EPI acquisition. Please note, that B0 fieldmap is a very smooth function that does not vary much with resolution and the presence of interpolation. Consequently, the B0 Map does not necessarily have to exactly match the EPI resolution. However, it should not be too different either. For example, if you EPI acquisition matrix size is 80x80 with 2.7mm slice thickness and 54 slices, a 3D B0Map at 128x128 with 2.7mm thickness and 54 slices or a 3D B0map with a matrix of 80x80 interpolated at 256x256 (same thickness), both will be perfectly usable for distortion correction. Depending on the tool you use, a resampling of the B0 fieldmap data in the EPI data space might be required.

Even though the interpolation is not problematic, it is probably simpler for most users to acquire their B0 Maps with an acquisition matrix which is already a power of 2 to avoid interpolation or to simply remove it manually for non-power of 2 acquisition matrix.

In every case, please make sure the dropdown menus "Shim", "Intensity Correction" and "Intensity Filter" are set to "None" or "Off". In case, you are acquiring a B0 Map for EPI distortion correction you would not want the B0 Map to be acquired with shim settings that differs from the EPI acquisition, and you would not want the intensity to be modified by some filters.

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Information in the DICOM header

The information that you might need in the DICOMs is the T_{E_1}, Δ_{T_E} and T_{E_2}. The T_{E_1} can be found in the standard "Echo Time" field. The Δ_{T_E} can be extracted from (0019,10E2) providing some basic manipulation as detailed in "Appendix 1: DICOM Fields". Finally, the T_{E_2} can be computed by $T_{E_2} = T_{E_1} + \Delta T_E$.

DICOM To NIFTI Converter

There are many DICOM to NIfTI converters available. We recommend using the latest release of "dcm2niix" from Chris Rorden (https://github.com/rordenlab/dcm2niix) as it extracts the TE1 and TE2 of the B0 Map (and much other information) accurately for a wide range of our MR software releases.

When converting the B0 maps (2D or 3D), dcm2niix outputs two NIfTI files together with two JSON files (the BIDS sidecar). The first one is the magnitude images of the shortest echo, the second one is the B0 Map itself in Hertz. To easily identify each file, the B0 Map in Hertz has a name that ends with "_fieldmaphz.nii[.gz]" .

For example:

- 3D_B0Map_fieldmaphz.json
- 3D_B0Map_fieldmaphz.nii
- 3D_B0Map.json
- 3D_B0Map.nii

In the "_fieldmaphz.json" file, the fields "EchoTime1" and "EchoTime2" can be used to determine the ΔT_E if needed.

There is also a MATLAB alternative by Xiangrui Li (https://github.com/xiangruili/dicm2nii).

Contact

Please contact Brice Fernandez if you have questions regarding this document or post directly in the MR Collaboration Community Forum or GE Connectome Forum (www.gecares.com). Feedback and comments are welcome.

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Reference

1. Koch, K. M., Rothman, D. L., & de Graaf, R. A. (2009). Optimization of static magnetic field homogeneity in the human and animal brain in vivo. *Progress in nuclear magnetic resonance spectroscopy*, *54*(2), 69–96. https://doi.org/10.1016/j.pnmrs.2008.04.001
2. Jezzard, P., & Balaban, R. S. (1995). Correction for geometric distortion in echo planar images from B0 field variations. *Magnetic resonance in medicine*, *34*(1), 65–73. https://doi.org/10.1002/mrm.1910340111
3. Jenkinson M. (2003). Fast, automated, N-dimensional phase-unwrapping algorithm. *Magnetic resonance in medicine*, *49*(1), 193–197. https://doi.org/10.1002/mrm.10354

Revision history

Revision	Date	Document Author	Reason for change
1.0	20SEPT2022	Brice Fernandez	Initial version + Correction by a native English speaker (Gavin Houston)
1.1	25MAY2023	Brice Fernandez	Various corrections and rebranding
1.2	01JUL2023	Brice Fernandez	Updating some figure and added recommendations
1.3	05OCT2023	Brice Fernandez	Minor edits

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Appendix 1: DICOM Fields

The DICOM conformance statements can be found here:

- https://www.gehealthcare.com/products/interoperability/dicom.

Attribute	Tag	Comments
Instance Number	(0020,0013)	A running number that identifies a given image.
Echo Number	(0018,0086)	The echo number for a given image.
Repetition Time	(0018,0080)	Repetition Time (TR)
Echo Time	(0018,0081)	Echo Time (TE). This is TE1 for B0 Maps.
Delta TE	(0019,10E2)	Warning: This is not directly the value of Delta TE. Let consider X the value in (0019,10E2) then ΔT_E in microsecond can be computed as $$\Delta T_E = round\left(\left\|\frac{10^6}{2\pi X}\right\|\right)$$ In Matlab Notation: DeltaTE = round(abs(1e6/(2*pi*X)))
Software Versions	(0018,1020)	Software version of the equipment.
Slice Location	(0020,1041)	Relative position of the image plane in mm.
Protocol Data Block (compressed)	(0025,101B)	Protocol Data Block (compressed) corresponding to inputs in the UI.