GE diffusion gradient directions (CV11: custom tensor file, tensorXX.dat)

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Imagination at work.

Multi-shell DTI or DSI: How to prescribe?

With a Max b-value, multi-shell DTI (or any smaller b-values) can be specified using the entries (b-vector, mag<1) of custom tensor filename (CV11).

b-value$_{effective}$ = b-value$_{max}$ * (b-vecX^2 + b-vecY^2 + b-vecZ^2)

2000 s/mm^2

b-value$_{effective}$
= 2000 x 0.387298^2
= **300 s/mm^2**

b-value$_{effective}$
= **0 s/mm^2**

b-vecX	b-vecY	b-vecZ
107		
0.387298	0.000000	0.000000
0.000000	0.387298	0.000000
0.000000	0.000000	0.387298
−0.272813	−0.034121	−0.272813
0.272813	0.272813	0.034121
0.034121	0.272813	0.272813
0.000000	0.000000	0.000000
−0.632456	0.000000	0.000000
0.000000	0.632456	0.000000
0.000000	0.000000	0.632456
0.026816	−0.072479	−0.627712
−0.110616	−0.126807	−0.609687
−0.146919	−0.102837	−0.606525

/usr/g/bin/tensor**107**.dat

b-value definition
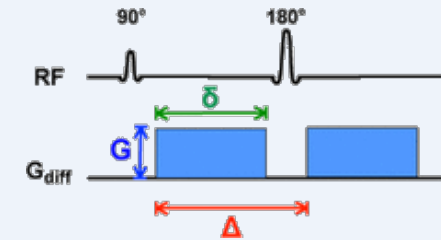
$b = \gamma^2 \, G^2 \, \delta^2 \, (\Delta - \delta/3)$

Details	Diffusion	Advanced

b-values: 1

#	b-value	NEX:
1	2000.0	1.0

NEX for T2: 1.0

Diffusion Direction: TENSOR

# of Diffusion Directions: 107

# of T2 Images: 1

Synthetic b-values: 0

Details	Diffusion	Advanced

User Control Variables

			Min	Max
CV5	Recon Type (0=Zero Filling, 1=Homodyne):	1.00	0.0	1.0
CV9	Shim Volume Mode (0=Default, 1=Breast):	0.00	0.0	2.0
CV11	Tensor filename = tensor[n].dat (research use >99):	107.00	0.0	65536.0

GE convention for diffusion gradient direction

- GE convention for diffusion gradient direction has <u>always</u> been in *"MR physics" logical coordinate*

    - X: Freq ⎤
    - Y: Phase ⎬ encoding direction
    - Z: Slice ⎦

- This is neither "with reference to the scanner bore" (like Siemens or Philips) nor "with reference to the imaging plane" (as expected by FSL tools)

tensor.dat

```
60
1.000000  0.000000  0.000000
0.361000  0.933000  0.000000
-0.255000  0.565000  0.785000
0.861000 -0.464000  0.210000
-0.307000 -0.766000  0.564000
-0.736000  0.013000  0.677000
0.532000  0.343000  0.774000
0.177000  0.965000  0.195000
0.771000  0.163000  0.615000
```

X: Freq **Y: Phase** **Z: Slice**
(0019,10bb) (0019,10bc) (0019,10bd)
DICOM private tags

dcm2niix

FSL bval/bvec format
(with reference to the imaging plane)

space-separated vs tab-separated values in tensorXX.dat

- Software version prior to **29.1**,

- PSD: played-out diffusion gradient is applied correctly regardless of "spaces" vs "tab" separator.

- **However**, information in DICOM tags is lost (wrong) with "tab" separator. (X=Y=Z in DICOM)

- Version 29.1 or later, you can use "tab"

space-separated

```
102
0.000000 0.000000 0.000000
0.654875 0.355659 0.666817
0.271924 0.933965 0.231877
-0.781703 0.152743 -0.179657
-0.118810 0.110437 0.986756
-0.552748 0.108005 -0.127037
-0.326879 0.866547 0.377155
0.394817 0.108337 -0.912350
0.155639 0.477851 0.643508
-0.906253 0.349334 -0.238058
0.110053 0.337891 0.455029
-0.566330 0.470917 -0.676393
0.558540 -0.665203 -0.495518
0.002542 0.026310 -0.407392
-0.648904 -0.611989 -0.452098
0.265763 -0.689599 -0.347116
-0.435216 0.497941 0.750095
0.060085 -0.972644 -0.224396
-0.187923 0.487620 0.245448
```

tensor4321.dat

X: (0019,10BB): 0.654875
Y: (0019,10BC): 0.355659
Z: (0019,10BD): 0.666817

tab-separated

```
102
0.000000    0.000000    0.000000
0.654875    0.355659    0.666817
0.271924    0.933965    0.231877
-0.781703   0.152743    -0.179657
-0.118810   0.110437    0.986756
-0.552748   0.108005    -0.127037
-0.326879   0.866547    0.377155
0.394817    0.108337    -0.912350
0.155639    0.477851    0.643508
-0.906253   0.349334    -0.238058
0.110053    0.337891    0.455029
-0.566330   0.470917    -0.676393
0.558540    -0.665203   -0.495518
0.002542    0.026310    -0.407392
-0.648904   -0.611989   -0.452098
0.265763    -0.689599   -0.347116
-0.435216   0.497941    0.750095
0.060085    -0.972644   -0.224396
-0.187923   0.487620    0.245448
```

tensor4321.dat

X: (0019,10BB): 0.654875
Y: (0019,10BC): 0.654875
Z: (0019,10BD): 0.654875   Wrong

Information in DICOM & Software version

Diffusion b-value:

Public tag (0018, 9087), Private tag (0043, 1039)

Diffusion b-vector:

X: (0019, 10bb), Y: (0019, 10bc), Z: (0019, 10bd)

For software version 26 or older (ex. DV26),

- If you modify PSD to use a custom tensor file (for example, tensor1234.dat), PSD played-out diffusion gradient is correctly from tensor1234.dat.

- However, information in DICOM (0019, 10bb/c/d) is from tensor.dat, *not* from your custom tensor1234.dat specified in PSD

For software version 27 or later,

- Both PSD played-out diffusion gradient and information in DICOM is from the custom filename (CV11)
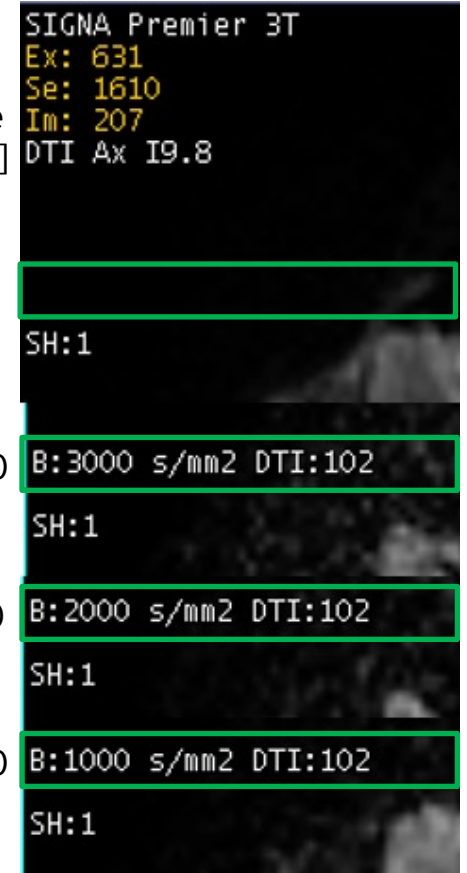
Multi-shell DTI in clinical mode (version 29.1)

- From software version **29.1**, custom tensor (CV11) in clinical mode

- Pre-load most widely used tensor files in product

  - ADNI, HCP, ABCD, UK biobank, ABCD

- Correct b-value in DICOM tags (0018, 9087) (0043, 1039)

  - Round to nearest multiple of 5 (ex. 1999.8 → 2000)

  - **dcm2niix** (v1.0.20201102 or later) reports bval/bvec correctly and consistently for both new/existing datasets

Correct b-value annotation (ABCD)

SIGNA Premier 3T
Ex: 631
Se: 1610
Im: 207
DTI Ax I9.8

b-value [s/mm²]

b=0

SH:1

b=3000   B:3000 s/mm2 DTI:102

SH:1

b=2000   B:2000 s/mm2 DTI:102

SH:1

b=1000   B:1000 s/mm2 DTI:102

SH:1

		Min	Max
	User Control Variables		
CV5	Recon Type (0=Zero Filling, 1=Homodyne):	1.00	0.0	1.0
CV9	Shim Volume Mode (0=Default, 1=Breast):	0.00	0.0	2.0
CV11	Tensor filename = tensor[n].dat:	90.00	0.0	65536.0

Details   Diffusion   Advanced

ADNI
ALZHEIMER'S DISEASE
NEUROIMAGING INITIATIVE

Human Connectome Project

biobank uk
Improving the health of future generations

Adolescent Brain Cognitive Development®
Teen Brains. Today's Science. Brighter Future.

Appendix:
Pre-loaded multi-shell tensor files

Imagination at work.

tensor8313: HCP (Human Connectome Project)

tensor8313.dat

- Three-shells DTI
- # of directions = 270, Max b-value = 3000
  - 1000 x 90
  - 2000 x 90
  - 3000 x 90
- # of directions = 296, Max b-value = 3000
- WITH interleaved b0 values
  - 0 x 26
  - 1000 x 90
  - 2000 x 90
  - 3000 x 90

https://humanconnectome.org/storage/app/media/documentation/s1200/HCP_S1200_Release_Appendix_I.pdf

```
# Multi-shell tensor8313.dat file
#
# Date generated: 2018-02-07 14:33:01
#
# Please use the following configuration on the MR Operator Console:
#  - Advanced tab: CV11 - tensor file name: n=8313
#  - Diffusion tab: b-value: 3000
#
#  - WITH interleaved b0 values (270 directions + 26 b0 volumes):
#     - Diffusion tab: number of directions (TENSOR): 296
#
#  - WITHOUT interleaved b0 values:
#     - Diffusion tab: number of directions (TENSOR): 270
#
#
# This file should be placed in /usr/g/bin
#
# Multi-shell details:
#  - DTI shell 1: b value = 1000; directions = 90
#  - DTI shell 2: b value = 2000; directions = 90
#  - DTI shell 3: b value = 3000; directions = 90
#
# Interleaved b0 details:
#  - The 296 directions comprise 270 tensor directions and 26 b0 volumes, each one interleaved every 10 directions.
#
# Identical directions are unique.
```

tensor4321: ABCD (Adolescent Brain Cognitive Development)

tensor4321.dat

- Four-shells DTI
- # of directions = 96, Max b-value = 3000
  - 500 x 6
  - 1000 x 15
  - 2000 x 15
  - 3000 x 60
- # of directions = 102, Max b-value = 3000

– WITH interleaved b0 values

  - 0 x 6
  - 500 x 6
  - 1000 x 15
  - 2000 x 15
  - 3000 x 60

The ABCD Study (https://abcdstudy.org/)

```
# Multi-shell tensor4321.dat file for ABCD (Adolescent Brain Cognitive Development) study
# Diffusion gradient vectors for GE scanners
#
# Please use the following configuration on the MR Operator Console:
#  - Advanced tab: CV11 - tensor file name: n=4321
#  - Diffusion tab: b-value: 3000
#  - Diffusion tab: number of T2 : 1 (with 102, 6 x intreleaved b0 included in diffusion) or 7 (with 96)
#  - Diffusion tab: number of directions (TENSOR): 96 or 102
#
# This file should be placed in /usr/g/bin
#
# Multi-shell details:
# Diffusion 102 (WITH Interleaved b0 values)
#  - Interleaved b0: b value = 0 s/mm2; directions = 6
#  - Shell 1: b value =  500 s/mm2; directions = 6
#  - Shell 2: b value = 1000 s/mm2; directions = 15
#  - Shell 3: b value = 2000 s/mm2; directions = 15
#  - DTI shell 4: b value = 3000 s/mm2; directions = 60
# Diffusion 96
#  - Shell 1: b value =  500 s/mm2; directions = 6
#  - Shell 2: b value = 1000 s/mm2; directions = 15
#  - Shell 3: b value = 2000 s/mm2; directions = 15
#  - Shell 4: b value = 3000 s/mm2; directions = 60
#
# [Reference]
# ABCD Summary of Neuroimaging Parameters
# https://abcdstudy.org/images/Protocol_Imaging_Sequences.pdf
```

tensor1127: ADNI-3 Advanced

ADNI (Alzheimer's Disease Neuroimaging Initiative)

tensor1127.dat

- Three-shells DTI
- To match ADNI, use 1 b=0 volume
- # of directions = 126, Max b-value = 2000
- The "classic" ADNI-3 Advanced
  - 0 x 12
  - 500 x 6
  - 1000 x 48
  - 2000 x 60
- # of directions = 100, Max b-value = 2000
- The mayo-modified version of ADNI-3 Advanced for wide bore systems
  - 0 x 9
  - 500 x 6
  - 1000 x 38
  - 2000 x 47

```
# Multi-shell tensor1127.dat file for ADNI-3 Advanced Protocols (Alzheimer's Disease Neuroimaging Initiative)
# Diffusion gradient vectors for GE scanners
#
# Creator: Jaemin Shin Rob Reid, reid.robert@mayo.edu, 2020-04-09
#
# Please use the following configuration on the MR Operator Console:
#  - Advanced tab: CV11 - tensor file name: n=1127
#  - Diffusion tab: b-value: 2000
#  - Diffusion tab: number of T2 : 1
#  - Diffusion tab: number of directions (TENSOR): 126 or 100
#
# This file should be placed in /usr/g/bin
#
# Multi-shell details:
# Diffusion 126
#  The 126 vector version is the "classic" ADNI3 Advanced 3 shell set.
#  It is nominally intended for scanners capable of gradient amplitudes > 70 mT/m.
#  - Interleaved b0: b value = 0 s/mm2; directions = 12
#  - Shell 1: b value =  500 s/mm2; directions = 6
#  - Shell 2: b value = 1000 s/mm2; directions = 48
#  - Shell 3: b value = 2000 s/mm2; directions = 60
# Diffusion 100
#  The 100 vector version is intended to support multishell scanning in a reasonable time
#  on scanners with gradient coils with lower maximum strength.
#  - Interleaved b0: b value = 0 s/mm2; directions = 9
#  - Shell 1: b value =  500 s/mm2; directions = 6
#  - Shell 2: b value = 1000 s/mm2; directions = 38
#  - Shell 3: b value = 2000 s/mm2; directions = 47
#
# Both versions have their b values interspersed through the whole scan
# to minimize gradient heating, and the directions are spread over
# entire spheres to aid eddy current correction.
#
# The directions were optimized using an electrostatic repulsion scheme:
# Caruyer, Emmanuel, Christophe Lenglet, Guillermo Sapiro, and Rachid Deriche.
# "Design of multishell sampling schemes with uniform coverage in diffusion MRI."
# Magnetic Resonance in Medicine 69, no. 6 (2013): 1534-1540.
#
# http://adni.loni.usc.edu/adni-3/
#
```

tensor521: UK Biobank

UK Biobank Brain Imaging

tensor521.dat

• Two-shells DTI

• To match UK Biobank, use 1 b=0 volume

• # of directions = 104, Max b-value = 2000

– Primary directions

- 0 x 4

- 1000 x 50

- 2000 x 50

• # of directions = 6, Max b-value = 2000

– Secondary directions to get blip-reversed b=0 scans for distortion correction

- 0 x 3

- 2000 x 3

```
# Multi-shell tensor521.dat file for UK Biobank Brain Imaging
# Diffusion gradient vectors for GE scanners
#
# Creator: Jaemin Shin (Jaemin.Shin@ge.com), 2020-05-04
#
# Please use the following configuration on the MR Operator Console:
#  - Advanced tab: CV11 - tensor file name: n=521
#  - Diffusion tab: b-value: 2000
#  - Diffusion tab: number of T2 : 1 (4 x intreleaved b0 included in diffusion)
#  - Diffusion tab: number of directions (TENSOR): 104
#
# This file should be placed in /usr/g/bin
#
# Multi-shell details:
# Diffusion 104
#  - Interleaved b0: b value = 0 s/mm2; directions = 4
#  - Shell 1: b value = 1000 s/mm2; directions = 50
#  - Shell 2: b value = 2000 s/mm2; directions = 50
# Diffusion 6 (optional)
# Short acquisition to get blip-reversed b=0 scans for distortion correction.
#  - Interleaved b0: b value = 0 s/mm2; directions = 1
#  - Shell 1: b value = 2000 s/mm2; directions = 3
#
# [Reference]
# UK Biobank Brain Imaging - Online Resources
# https://www.fmrib.ox.ac.uk/ukbiobank/protocol/
#
# Diffusion gradient vectors from Siemens DiffusionVectors:
# Primary directions 104 directions
# https://www.fmrib.ox.ac.uk/ukbiobank/protocol/NewDiffusionVectors230914.txt
# Secondary directions 6 directions
# https://www.fmrib.ox.ac.uk/ukbiobank/protocol/DiffusionVectors3b0.txt
#
```

Multi-shell tensor1225.dat file for **HCP Lifespan**
Diffusion gradient vectors for GE scanners
from Lifespan HCP-Development and HCP-Aging protocol package
(Version 2019.01.14)
#
01/25/2022
Creator: Jaemin Shin(Jaemin.Shin@ge.com), Baolian Yang(Baolian.Yang@ge.com)
#
Please use the following configuration on the MR Operator Console:
- Advanced tab: CV11 - tensor file name: n=1225
- Diffusion tab: b-value: 3000
- Diffusion tab: number of directions (TENSOR): 198
#
Multi-shell details:
Diffusion 198 = Diffusion 98 + 1 x b0 + Diffusion 99
- Interspersed b0: b value = 0 s/mm2; directions = 13
- Shell 1: b value = 1500 s/mm2; directions = 92
- Shell 2: b value = 3000 s/mm2; directions = 93
Diffusion 98
- Interspersed b0: b value = 0 s/mm2; directions = 6
- Shell 1: b value = 1500 s/mm2; directions = 46
- Shell 2: b value = 3000 s/mm2; directions = 46
Diffusion 99
- Interspersed b0: b value = 0 s/mm2; directions = 6
- Shell 1: b value = 1500 s/mm2; directions = 47
- Shell 2: b value = 3000 s/mm2; directions = 46
#

[Reference]
Harms MP, Somerville LH, Ances BM, Andersson J, Barch DM, Bastiani M,
Bookheimer SY, Brown TB, Buckner RL, Burgess GC, Coalson TS.
Extending the Human Connectome Project across ages: Imaging protocols
for the Lifespan Development and Aging projects.
Neuroimage. 2018 Dec 1;183:972-84.
https://doi.org/10.1016/j.neuroimage.2018.09.060
#
Emmanuel Caruyer, Christophe Lenglet, Guillermo Sapiro, Rachid Deriche.
Design of multishell sampling schemes with uniform coverage in diffusion MRI.
Magnetic Resonance in Medicine, 2013, 69:1534-1540.
http://dx.doi.org/10.1002/mrm.24736
#
Tool available at:
http://www.emmanuelcaruyer.com/q-space-sampling.php
#
Lifespan HCP-Development and HCP-Aging protocol package at:
https://www.humanconnectome.org/study/hcp-lifespan-development/project-protocol/imaging-protocols-hcp-development
#
https://www.humanconnectome.org/storage/app/media/protocols/HCP_VE11C_Prisma_201
01.14.zip