Diffusion Tensor Imaging Analysis

Sonia Pujol, Ph.D.
Instructor of Radiology
Surgical Planning Laboratory
Harvard Medical School
http://www.spl.harvard.edu/
Diffusion Weighted Imaging

- Non-invasive *in vivo* information on the structure of organized tissues:
  - Brain white matter fiber bundles
  - Myocardium fiber
- Clinical applications
  - Brain ischemia
  - Schizophrenia
  - Multiple Sclerosis
Diffusion Tensor Imaging Analysis

- DWI Acquisition
- Tensor Calculation
- Scalar Maps
- 3D Visualization
The Life Cycle of Imaging Data

- Acquisition
- Storage
- Visualization
- Analysis
Diffusion Tensor Imaging Analysis

- DWI Acquisition
- Tensor Calculation
- Scalar Maps
- 3D Visualization

Diffusion Tensor Imaging Analysis. Sonia Pujol, Ph.D. Massachusetts Institute of Technology - HST.583
Diffusion Weighted Imaging (DWI)

Single-shot Diffusion Weighted Echo-Planar Imaging (EPI)

- Fast and robust to motion artifacts

Line Scan Diffusion Imaging (LSDI)

- Robust to magnetic-susceptibility artifacts and geometric distortion
DWI Acquisition: Example

Parameters
• FOV 220 mm x 165 mm
• Slice thickness 4 mm
• Slice spacing 1 mm

Acquisition Time
• EPI: 6 minutes
• LSDI: 35 minutes
DWI Acquisition

The result of a DWI acquisition is a series of 3D Volumes of data related to the patient, after application of Diffusion Sensitizing Gradients.

Example: 2 Baselines and 12 Gradients.
Diffusion Weighted Imaging

The signal is dimmer when the direction of the applied gradient is parallel to the principal direction of diffusion.
Diffusion Weighted Imaging

Example: Correlation between the orientation of the 11th gradient and the signal intensity in the Splenium of the Corpus Callosum
Acquisition Parameters (1)

DWI Volume characteristics

- Image Dimensions
- Slice Spacing
- Slice Thickness
- Pixel size
- Image Origin
- Image Orientation
- Endianess
- Datatype

The Life Cycle of Imaging Data. SPujol (HST.583)
Loading the DWI Volume

Click on **Add Volume** to load the DWI dataset.
Loading the DWI Volume

The **Props Panel** of the module Volumes appears.

Select **Nrrd Reader** in the **Properties** field.
Loading the DWI Volume

Browse to load the file **dwi.nhdr**

Check that the path to the file **dwi.nhdr** is correct. If needed, manually enter it.

Enter the name **dwi** and click on **Apply**.
Loading the DWI Volume

The DWI images appear in the viewer.

Adjust the Window and Level of the images, and left-click on **Or** to change the orientation to **Slices**

Diffusion Tensor Imaging Analysis. Sonia Pujol, Ph.D.
Massachusetts Institute of Technology - HST.583
Loading the DWI Volume

Change the **Field Of View (FOV)** to 2000
Loading the DWI Volume

The sagittal and coronal viewers display the 14 DWI volumes: 2 baselines and 12 gradients.
Display the axial and sagittal slices inside the viewer.

Use the axial slider to observe the baselines and gradient volumes.
Diffusion Weighted Imaging
Diffusion Tensor Imaging Analysis

DWI  DTI  FA  Glyphs & Tracts
Diffusion Weighted Imaging

\[ S_i = S_0 e^{-b \hat{g}_i^T D \hat{g}_i} \]

(Stejskal and Tanner 1965, Basser 1994)

\{S_i\} represent the signal intensities in presence of the diffusion sensitizing gradients \( \hat{g}_i \).
Diffusion Weighted Imaging

$S_i = S_0 e^{-b\hat{g}_i^T \hat{D} \hat{g}_i}$

(Stejskal and Tanner 1965, Basser 1994)

$S_0$ is the signal intensity with no gradient.
Diffusion Weighted Imaging

\[ S_i = S_0 e^{-b \hat{g}_i^T D \hat{g}_i} \]

\( \hat{g}_i \) represents the direction of the Diffusion Sensitizing Magnetic Field Gradient.
Diffusion Weighted Imaging

\[ S_i = S_0 e^{-b\hat{g}_i^T \hat{D}\hat{g}_i} \]

\( b \) is the LeBihan’s factor describing the pulse sequence, gradient strength and physical constants.
Diffusion Weighted Imaging

\[ S_i = S_0 e^{-b\hat{g}_i^T D \hat{g}_i} \]

\( D \) is the Diffusion Tensor

\[ D = \begin{bmatrix}
  D_{xx} & D_{xy} & D_{xz} \\
  D_{yx} & D_{yy} & D_{yz} \\
  D_{zx} & D_{zy} & D_{zz}
\end{bmatrix} \]

3x3 symmetric matrix
Acquisition Parameters (2)

DWI Volume characteristics

Diffusion Sensitizing Gradients Orientation

(Xg,Yg,Zg)
Tensor Calculation

Step 1: Estimate the **Diffusion Tensor terms** \( D_{ij} \) from the DWI images in each voxel

\[
\mathbf{D} = \begin{bmatrix}
D_{xx} & D_{xy} & D_{xz} \\
D_{yx} & D_{yy} & D_{yz} \\
D_{zx} & D_{zy} & D_{zz}
\end{bmatrix}
\]
Tensor Calculation

Step 2: Calculate the **main directions of diffusivity** and corresponding **diffusion values** in each voxel

\[
D = \begin{bmatrix}
D_{xx} & D_{xy} & D_{xz} \\
D_{yx} & D_{yy} & D_{yz} \\
D_{zx} & D_{zy} & D_{zz}
\end{bmatrix}
\]

Eigenvectors v1, v2, v3

Eigenvalues λ1, λ2, λ3
Physical Interpretation

The diffusion tensor $\mathbf{D}$ in the voxel $(I,J,K)$ can be visualized as an ellipsoidal isoprobability surface in which the principal axes correspond to the eigenvectors.
Tensor Calculation

Click on **Modules** in the Main Menu, and select **Visualisation → DTMRI**
Tensor Calculation

The panel **Input** of the DTMRI module appears

Click on the tab **Conv**
Tensor Calculation

Select the Input volume **dwi** and click on **ConvertVolume**
At the end of the calculation, Slicer displays the average of all diffusion weighted images `dwi_AvGradient` and the baseline volume `dwi_Baseline`.
Tensor Calculation

Adjust the Window and Level of the images

Left-click on Bg and select the volume dwi_Baseline
Tensor Calculation

Browse the baseline images (T2) to check if the anatomy is correct.
Diffusion Weighted Imaging
Diffusion Tensor Imaging Analysis

DWI

DTI

FA

Glyphs & Tracts
DWI Data Analysis

The tensors data contain information on tissue architecture and microstructure

- Overall displacement of molecules
- Variations of molecular displacements
- Orientation in space of tissues
Mean Diffusivity

- Characterizes the overall mean-squared displacement of molecules

\[ \text{Mean Diffusivity} = \frac{1}{3} \text{Trace}(\mathbf{D}) \]
Fractional Anisotropy

• Measure of the diffusion anisotropy

\[ FA = \frac{\sqrt{3}}{\sqrt{2}} \left| \frac{D - \frac{1}{3} \text{trace}(D)I}{|D|} \right| \]
Computing Fractional Anisotropy

In the DT-MRI module, click on **More** to navigate in the different panels.
Computing Fractional Anisotropy

Select the panel **Scalars**

Browse the menu **Create Volume** to see the list of calculations that Slicer can perform on the **dwi_Tensor** dataset.

Select **Fractional Anisotropy**

Click on **Apply**
Computing Fractional Anisotropy

The Viewer displays the FA volume.

Move the mouse in the slices to see FA values for each voxel.
Which image is correct?
Diffusion Tensor Imaging Analysis

DWI  DTI  FA  Glyphs & Tracts
3D Visualization

- Hypothesis: the direction of the fibers is collinear with the direction of the eigen-vector associated with the largest eigenvalue.
Glyphs

- Glyphs represent the major eigenvector field within a given slice.
Glyphs

Select the panel **Glyphs** in the DTMRI module

Select the Active DTMRI volume **dwi_Tensor**

Select **Glyphs on Slice** for the axial (red) view

Set **Display Glyphs On**
Glyphs

Color code
Blue is Superior-Inferior
Red is Left-Right
Green is Anterior-Posterior
Data Fusion

Superimpose the glyphs on the Fractional Anisotropy Map
Which image is correct?
Which image is correct?
The left one is correct
Streamline tractography

- Hypothesis: the direction of the fibers is collinear with the direction of the eigen-vector associated with the largest eigenvalue.
Tractography Panel

Click on Display Glyphs Off

Click on More and select the Panel **Tract** in the DTMRI module.
Tractography Panel

Select the Tab Settings

Left-click on Color
Tractography Panel

A Color selection panel appears

Select a new color for the tracts

Diffusion Tensor Imaging Analysis. Sonia Pujol, Ph.D.
Massachusetts Institute of Technology - HST.583
Create a single tract

Position the mouse on a point inside the Corpus Callosum, and hit the s key.
Create a single tract

A tract appears in the 3D Viewer.

Drag right mouse button down in the 3D Viewer to zoom in.
ROI Drawing

Select the **Editor** module in the main Menu.

Select the **Volumes** panel and click **Setup**

Select the Original Grayscale **FractionalAnisotropy_dwi_Tensor**

Select the Labelmap **Working**.

Click on **Start Editing**
ROI Drawing

Select the **Effects** panel

Left click on **Draw** in the Effects Menu
ROI Drawing

Select the Output Color #4
ROI Drawing

Select View→1x512 SAG in the Main Menu.

Draw a region of interest in the Splenium of the Corpus Callosum

Click on Apply in the module Editor.
ROI Seeding

Come back to the DTMRI module and select the panel **Tracts**.

Click on the tab **Seed** and select the SeedROI **Working**.

Select the **color label #4** corresponding to the ROI.
ROI Seeding

Click on **Seed Tracts**

A warning message appears, Click **Yes** if you are ready to process the data.
ROI Seeding

The tracts from the Splenium of the Corpus Callosum appear in the viewer.
3D Visualization of tissue orientation

Diffusion Tensor Imaging Data contain information on the three dimensional orientation of the tissues in the brain.
Conclusion

- Non-invasive in-vivo exploration of brain microstructures
- Analysis requires a rigorous knowledge of acquisition parameters
- 3D visualization of fiber pathways
Real Clinical Situation

• …is not straightforward
• DTI describes a Gaussian model of Diffusion
• Uncertainty induced by artifacts
• Fiber crossing remains a challenge
Diffusion Tensor Imaging Analysis

DWI Acquisition  
Tensor Calculation  
FA  
Glyphs & Tracts