Magnetic Resonance Histology

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Goals

Defn  Magnetic Resonance Histology
Technical Infrastructure
Application
Dissemination
Spatial Resolution: Man vs Mouse

1 mm$^3 = 1 \mu l$

.021 mm$^3 \sim 1 \times 10^{-5}$ $\mu l$

100,000 X
<table>
<thead>
<tr>
<th>Clinical MRI</th>
<th>Pre Clinical MRI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resolution</td>
<td>1 mm³ (1 ul)</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>1</td>
</tr>
<tr>
<td>Magnetic Field</td>
<td>1.5-3.0T</td>
</tr>
<tr>
<td>Bore Diameter</td>
<td>1 m</td>
</tr>
<tr>
<td>Gradients</td>
<td>50 mT/m</td>
</tr>
<tr>
<td>Imaging Time</td>
<td>&lt; 1 hr</td>
</tr>
</tbody>
</table>

1 Million X 1 Million X 3-5 X 0.1 X 60 X 240 X
Magnetic Resonance Histology

Structure of tissue as seen via MR microscopy
Nondestructive
3 (and more) dimensional
“Proton Stains”
Inherently Digital
Proton Stains ??
A New *in vivo* Method for Quantitative Analysis of Stroke Lesions Using Diffusion-Weighted Magnetic Resonance Microscopy

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\[ S_{\text{diff}} = Se^{-b\cdot D} \]
Mechanism of Detection of Acute Cerebral Ischemia in Rats by Diffusion-Weighted Magnetic Resonance Microscopy

Helene Benveniste, MD, PhD; Laurence W. Hedlund, PhD; and G. Allan Johnson, PhD
“Proton Stains”

properties of water

Spin Lattice Relaxation  T1
Spin Spin Relaxation  T2
Diffusion
  Axial Diffusivity
  Radial Diffusivity
  Mean Diffusivity
  Fractional Anisotropy
  Clr FA
Paxinos, G, Franklin, K.B.J
A quantitative magnetic resonance histology atlas of postnatal rat brain development with regional estimates of growth and variability
Evan Calabrese a,b, Alexandra Badea a, Charles Watson c,d, G. Allan Johnson a,b,*

Diffusion tensor magnetic resonance histology reveals microstructural changes in the developing rat brain
Evan Calabrese, G. Allan Johnson *
E Calabrese and GA Johnson, Diffusion tensor histology in the developing rat brain, Neuroimage 79:329-339, 2013
Postnatal Diffusion Tensor Changes

Postnatal Changes in White Matter
Quantitative mapping of trimethyltin injury in the rat brain using magnetic resonance histology

G. Allan Johnson a,b,*, Evan Calabrese a,b, Peter B. Little c, Laurence Hedlund a, Yi Qi a, Alexandra Badea a
Study Design

Trimethyl Tin
  Control (saline) n=8
  Lo Dose @ 8 mg/kg n=8
  Hi Dose @ 12 mg/kg n=8

High Field MRI @ 7T
  GRE @ 39 um isotropic resolution
  DTI @ 78 um isotropic resolution

Conventional Histology (H&E)
  Blinded X 2 readers
  4 specimens
Diffeomorphic Mapping

Source

Target-Atlas
Image Registration and Statistics

Automated Image Registration

Pixel-wise Statistical Comparisons

Sham Group

Treated Group
Automated Registration/Segmentation

Diffusion-Weighted MRI

\[ \phi_1 = \gamma \delta G x_1 \]
\[ \phi_2 = -\gamma \delta G x_2 \]
\[ \Delta \phi = \gamma \delta G (x_1 - x_2) \]
Diffusion Tensor Imaging

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

eigenvalues: \( D_1, D_2, D_3 \)

eigenvectors: \( V_1, V_2, V_3 \)
Diffusion Tractography

A Diffusion MRI Tractography Connectome of the Mouse Brain and Comparison with Neuronal Tracer Data

Evan Calabrese, Alexandra Badea, Gary Cofer, Yi Qi, and G. Allan Johnson
Quantitative Connectivity Matrix
Postmortem Diffusion MRI of the Human Brainstem and Thalamus for Deep Brain Stimulator Electrode Localization

Evan Calabrese, Patrick Hickey, Christine Hulette, Jingxian Zhang, Beth Parente, Shivanand P. Lad, and G. Allan Johnson
An Atlas of the Human Brainstem
Bottleneck: Data to Understanding
Image Library

Hi Performance Cloud Computer

Many (remote) users

Cloud Gateway

Interactive Protocols
LIBRARIES
Browsing available libraries here and preview upcoming libraries with limited time trial access.

Each library is a collection of images with an image explorer optimized for the collection. All the libraries are large (10-50GB) multidimensional image arrays, 3, 4 or 5 dimensions providing unique insight into complex biology and medicine. Libraries of the mouse, rat, and monkey brain have been assembled from magnetic resonance microscopy data with spatial resolution more than 100,000 X that of clinical MRI. The library of the human brain stem provides diffusion tractography at 6000 X the resolution of a clinical scan. The Visible Mouse allows one to electronically "dissect" the live animal. Clinical examples of CT and MRI assemble in a single place. Thematic collections of anonymized studies with annotation by some of the world's leading radiologists and clinicians providing case studies for teaching and understanding human disease. Optical microscopy libraries provide data from existing new technologies of optical coherence tomography and light sheet microscopy with seamless navigation through data sets as large as a terabyte. Exploration software in each library saves views, supports annotation, and allows uploads of reference or other images for comparison.
A lot of help from my friends!

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Yi Qi, MD