Anisotropic Diffusivity Measured with Fluorescence Recovery after Photobleaching (FRAP)

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Bioengineering Building

Drug Discovery Building

James E. Clyburn Research Center

BioE Labs

BioE Classrooms
Diffusion in Biological Systems

Cell (1)
- Control
- Treatment

Cartilaginous Tissue (3)

MR-Based Diffusion Techniques (2)

Cell death caused by injection of autologous cells due to limited nutrient supplies

(Wu and Yao, 2013)
FRAP in 2D by Confocal Microscopy

(Lippincott-Schwartz et al., 2003)
Isotropic vs. Anisotropic Diffusion

A. Most FRAP studies assume diffusion is isotropic

B. The solute diffusion could be anisotropic in many biological systems

Diffusion Coefficient: $D$

Diffusion Tensor: $\begin{bmatrix}
D_{xx} & D_{xy} & D_{xz} \\
D_{xy} & D_{yy} & D_{yz} \\
D_{xz} & D_{yz} & D_{zz}
\end{bmatrix}$

(Shi & Yao 2010)
Anisotropic and Inhomogeneous Diffusion in TMJ Disc (2D FRAP)

(Shi & Yao, 2013)
3D Diffusion Measurements in ECMs (3D FRAP)

Results of 3D diffusion tensors of FITC-Dextran (70KDa and 150KDa) in the porcine ligament tissues

(Shi & Yao, 2014)
Anisotropic Diffusion in Electrospun Gelatin Scaffolds

Solute: 10K FD, 20K FD (fluorescein dextran)
Diffusion Measurements: Diffusion Cell Method

Diffusivities of glucose and lactate in cartilage endplate of spine disc. (Wu & Yao, 2016)

<table>
<thead>
<tr>
<th>Strengths</th>
<th>Limitations</th>
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<tr>
<td>• Classic diffusion experiment</td>
<td>• 1D measurement</td>
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<td>• Apply mechanical strain</td>
<td>• Time-consuming</td>
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<td>• Effective diffusivity at tissue level</td>
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Electrical Conductivity Method: Ion Diffusion

Ion (Na+, Cl-) diffusivities in human temporomandibular joint disc (male vs. female). *(Wright and Yao, 2013)*

**Strengths**
- Simple and fast measurement
- Repeatable measurement
- Apply mechanical strain
- Measure ECM fixed charge density

**Limitations**
- 1D measurement
- Tissue level
- Small ions
Inhomogeneous and Anisotropic Conductivity

(Jackson, Yao, & Gu, 2006)
Fixed Charge Density in Human TMJ Disc

(Coombs & Yao, 2017)
Permeability vs. Porosity in Hydrogel and Cartilage

Variation of Darcy permeability ($K$) with water volume fraction ($\phi^w$)

$$K = a \left( \frac{\phi^w}{\phi^s} \right)^n$$

$\alpha = 0.00339 \text{ nm}^2$

$n = 3.236$

$R^2 = 0.9995$

(Yao & Gu, 2003)
Permeability vs. Porosity in AF with Trypsin Treatment

Open-circuit permeability of porcine annulus fibrosus (AF)

- Control (n=16)
- Trypsin treated (n=8)

Curve-fitting (95% confidence level)

\[ K = a \left( \frac{\phi_w}{\phi_s} \right)^n \]

- \( a = 0.00044 \pm 0.00047 \)
- \( n = 7.193 \pm 0.732 \)
- \( R^2 = 0.92 \)

(Gu & Yao, 2003)
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