Application of independent component analysis (ICA) to identify and separate tumor arterial input function (AIF) in dynamic contrast enhanced-MRI

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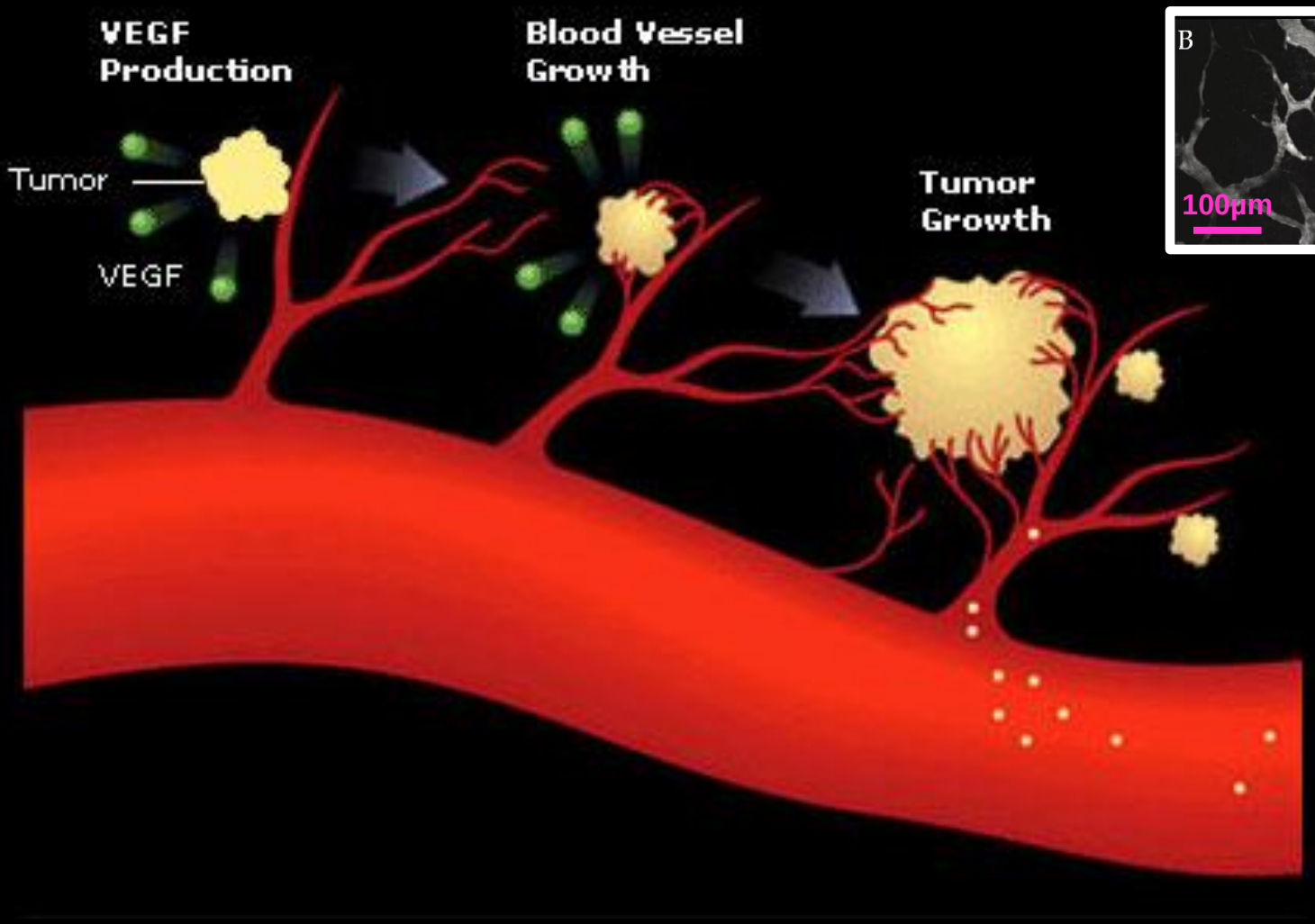
Field MITACS conference

June 20, 2011

Tumor Angiogenesis



Illustrations: courtesy of http://www.reishiscience.com/Benefits_2.html
In-vivo images: D. Fukumura et al., MICROVASCULAR RESEARCH, 2007.

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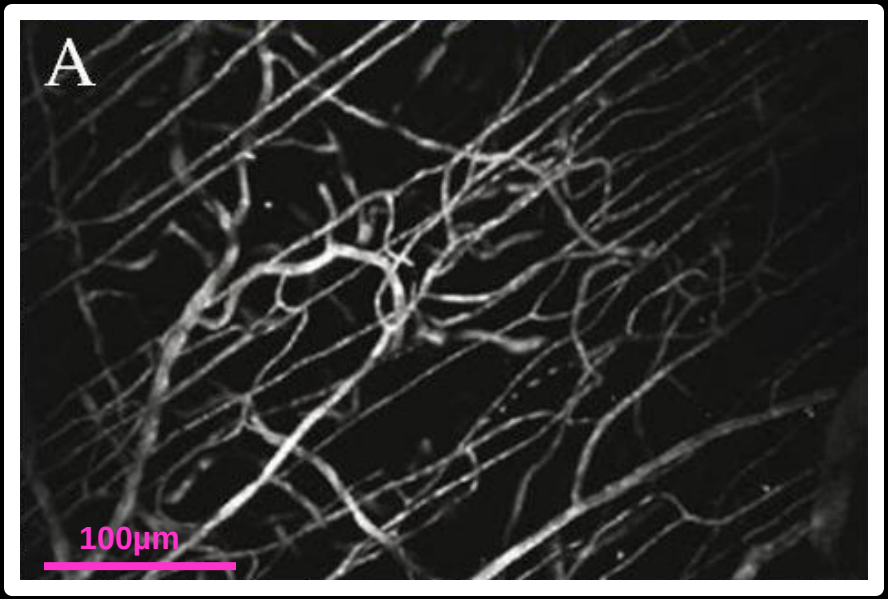
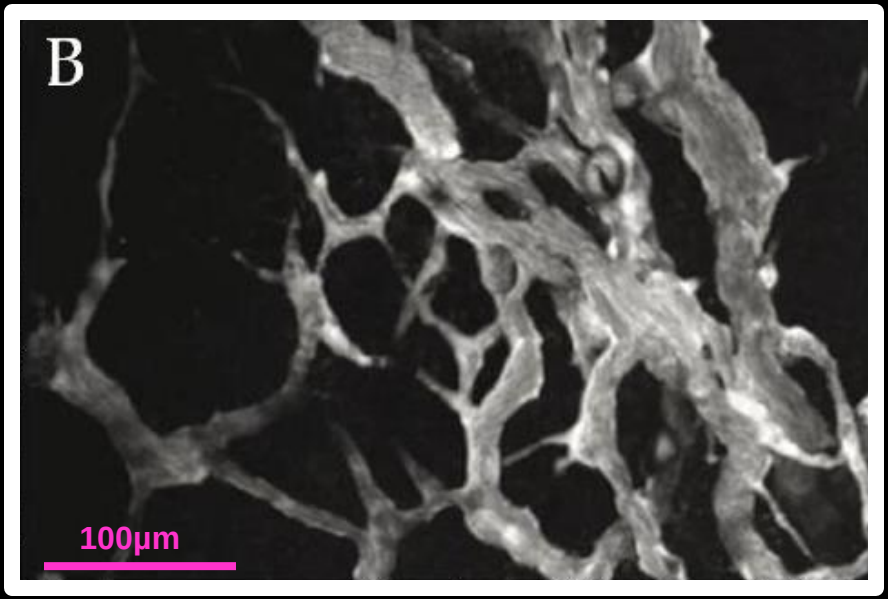
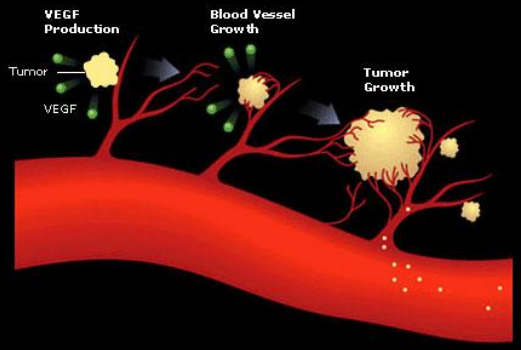
Tumor Vasculature







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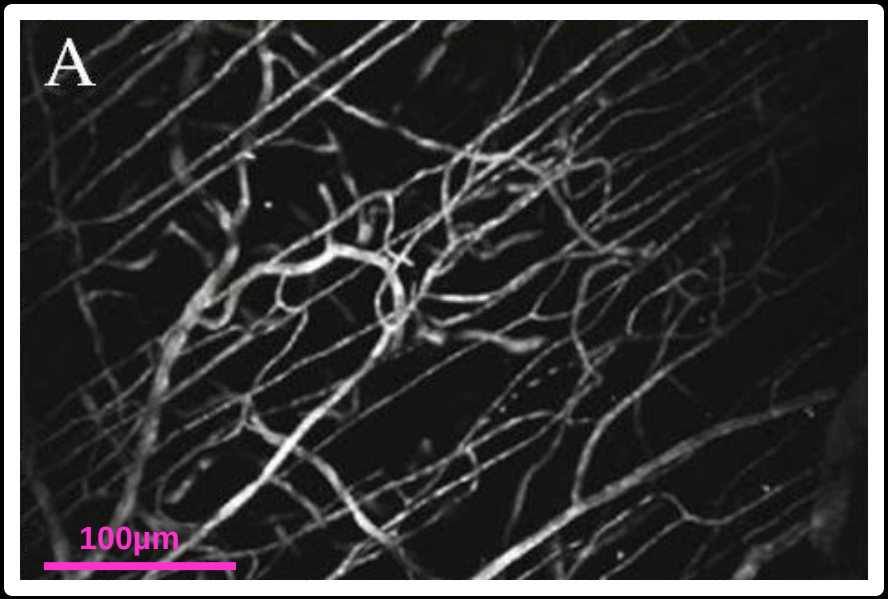

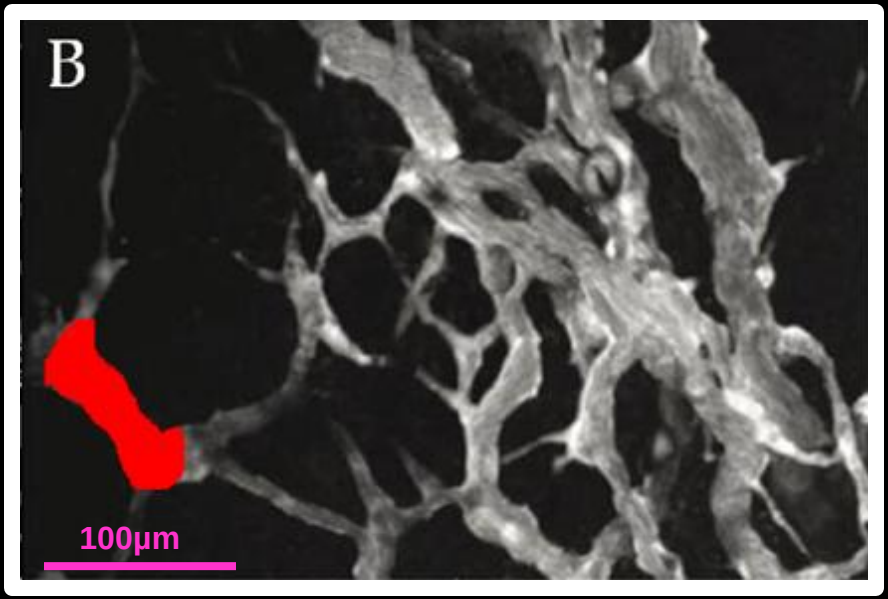

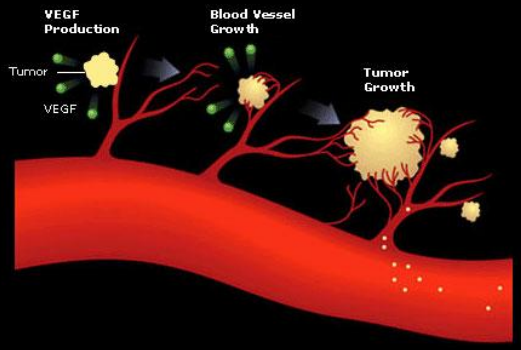

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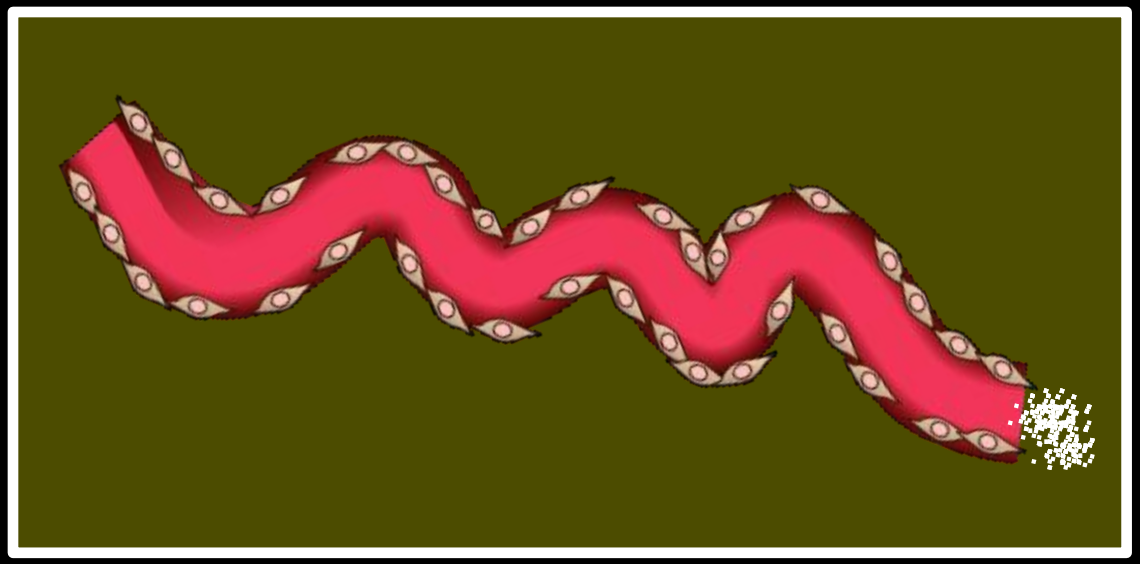
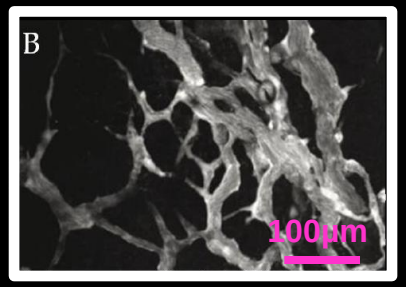
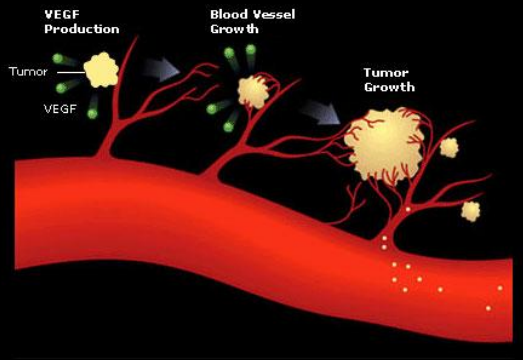
Pharmacokinetic Modeling







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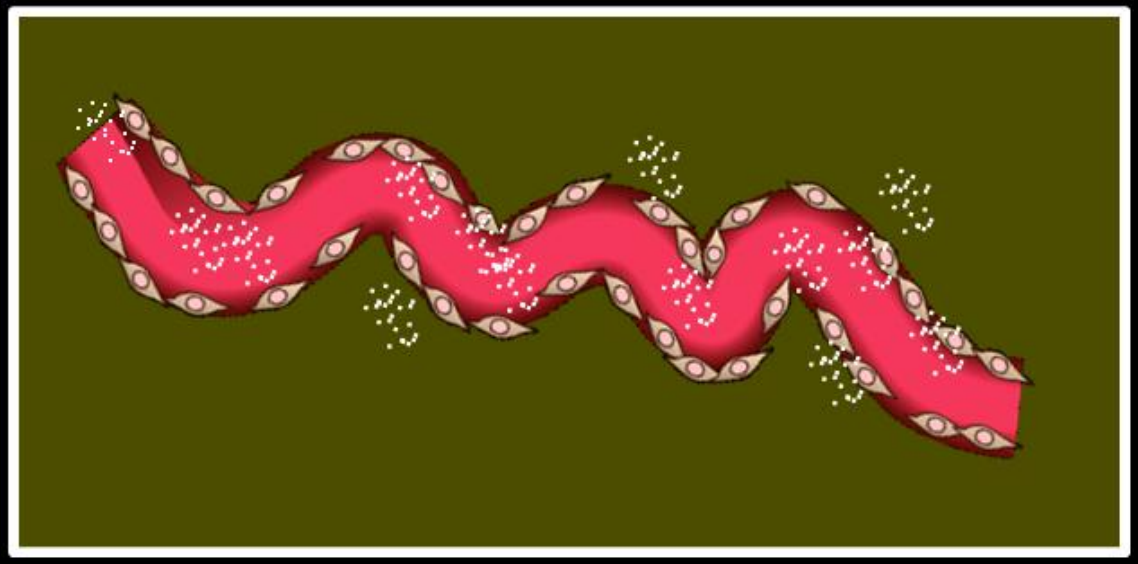

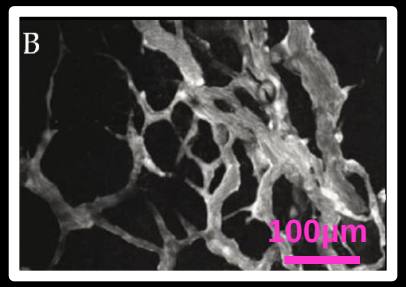

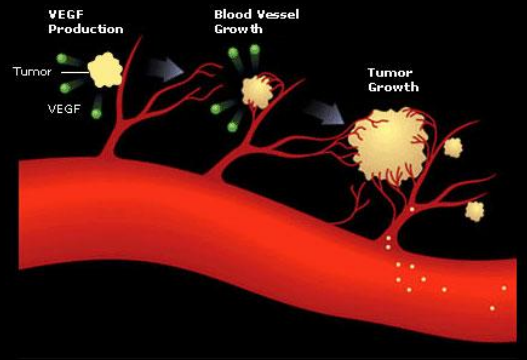

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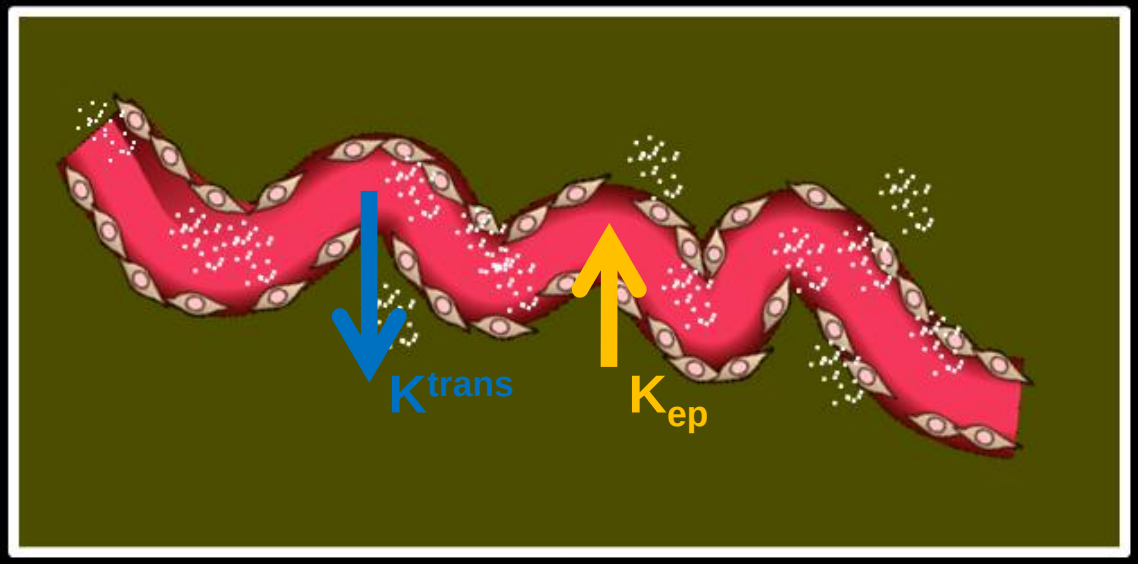

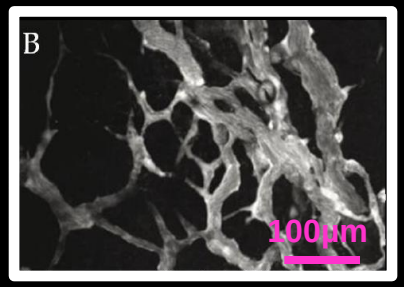

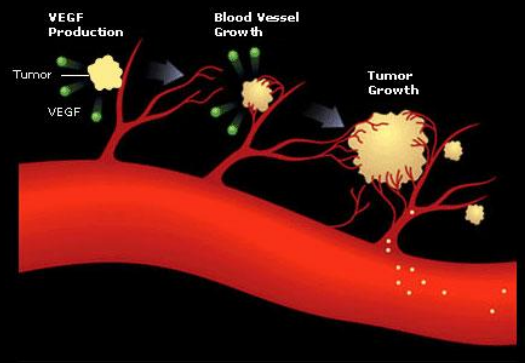

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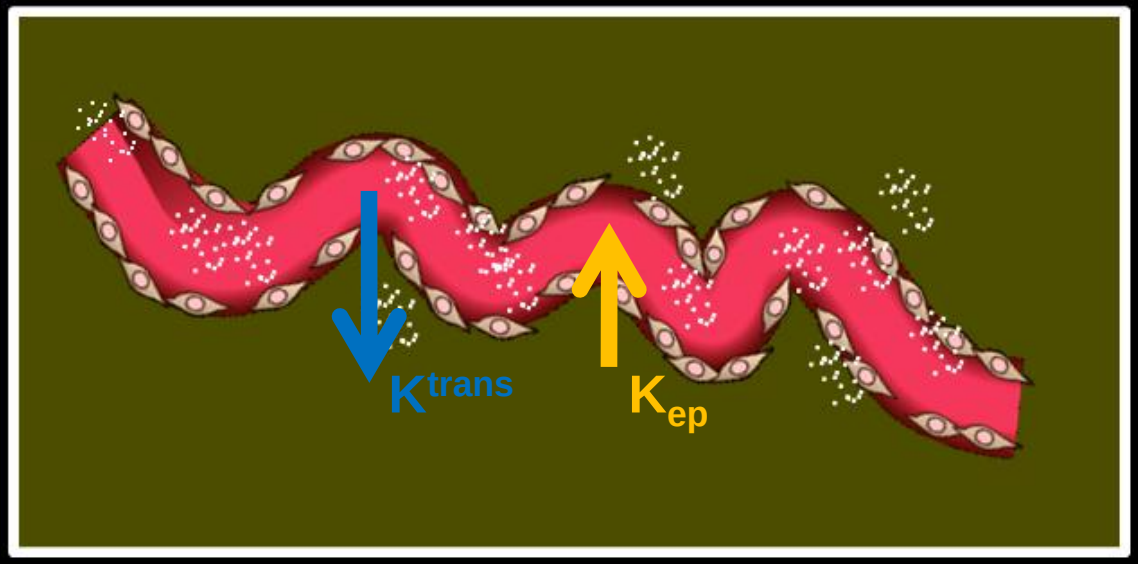
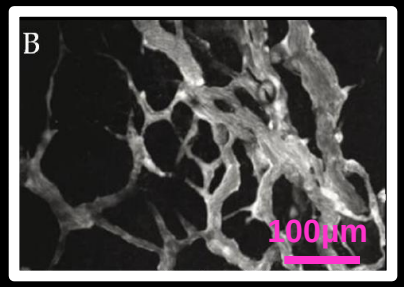
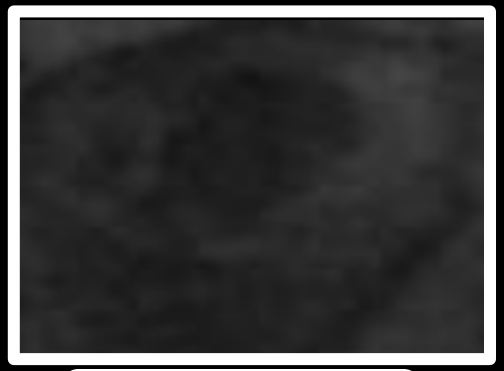
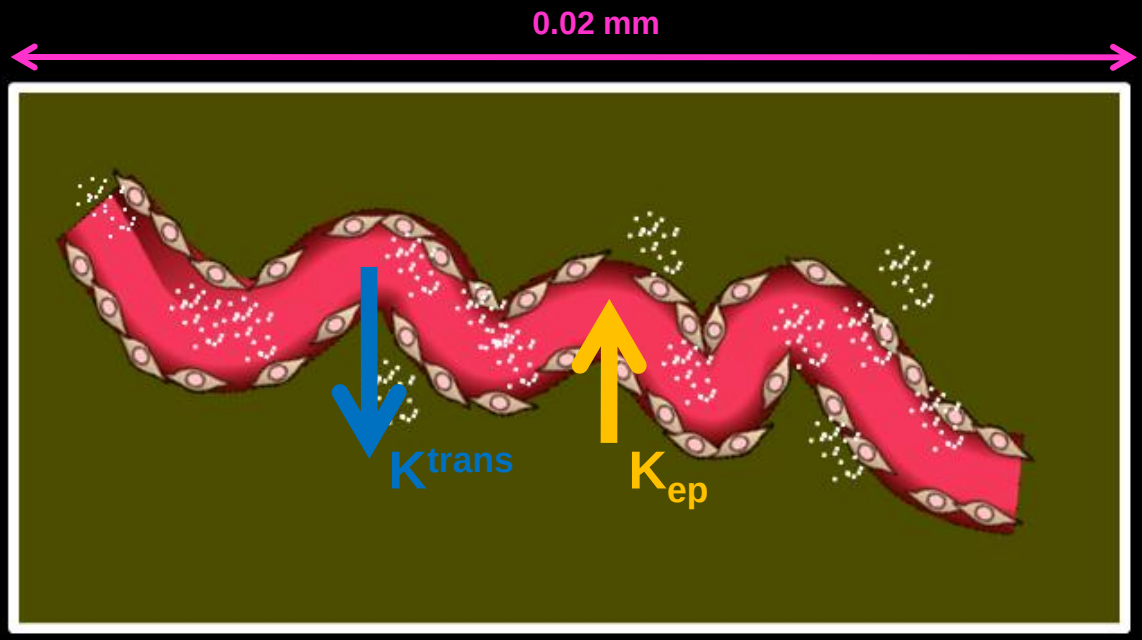


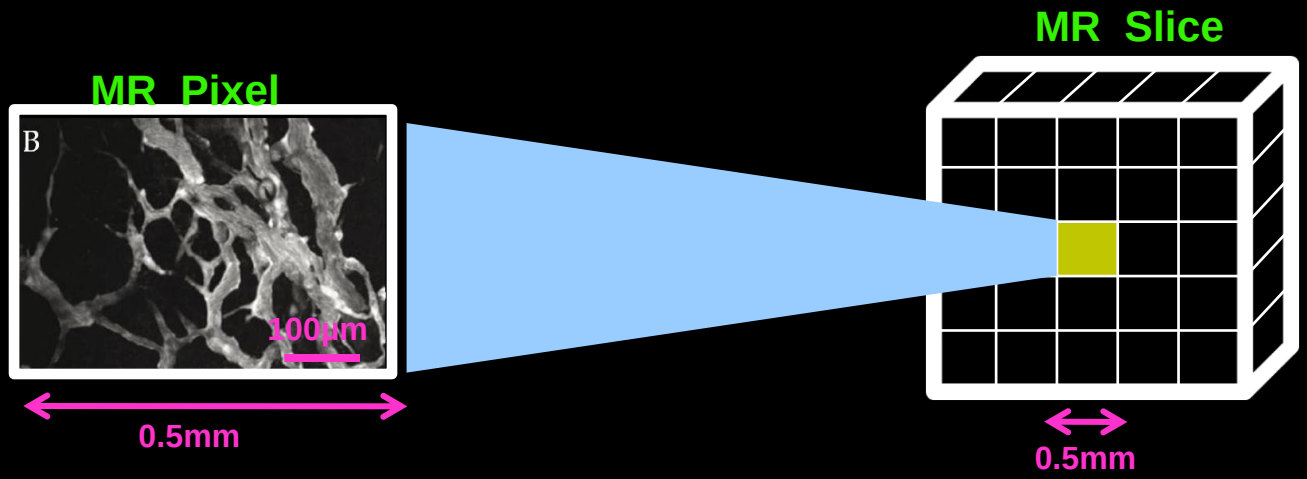




Renal Cell Carcinoma
DCE – MRI

Pharmacokinetic Modeling





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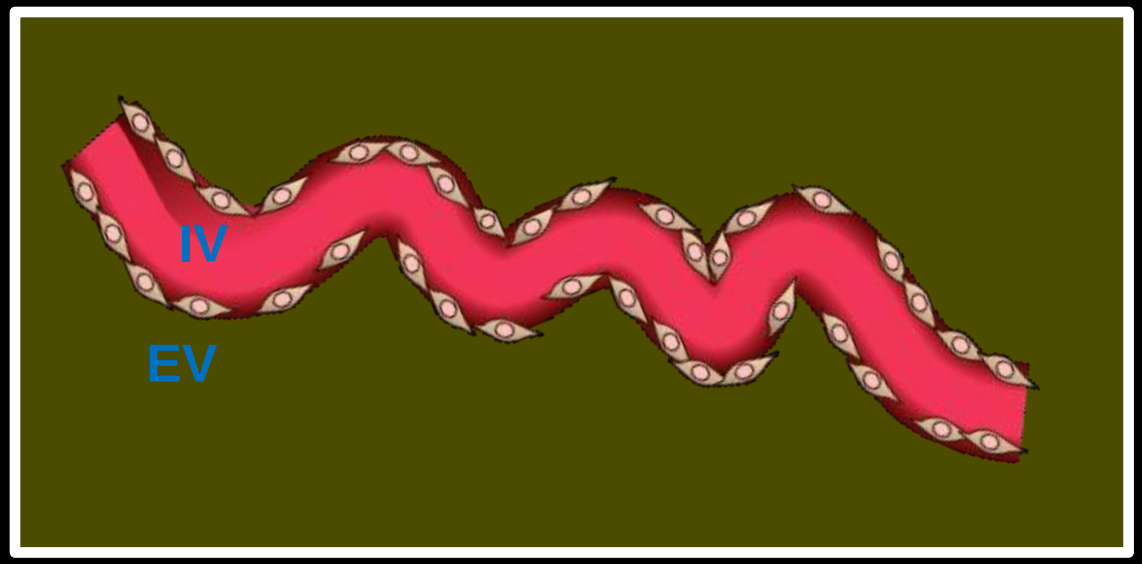
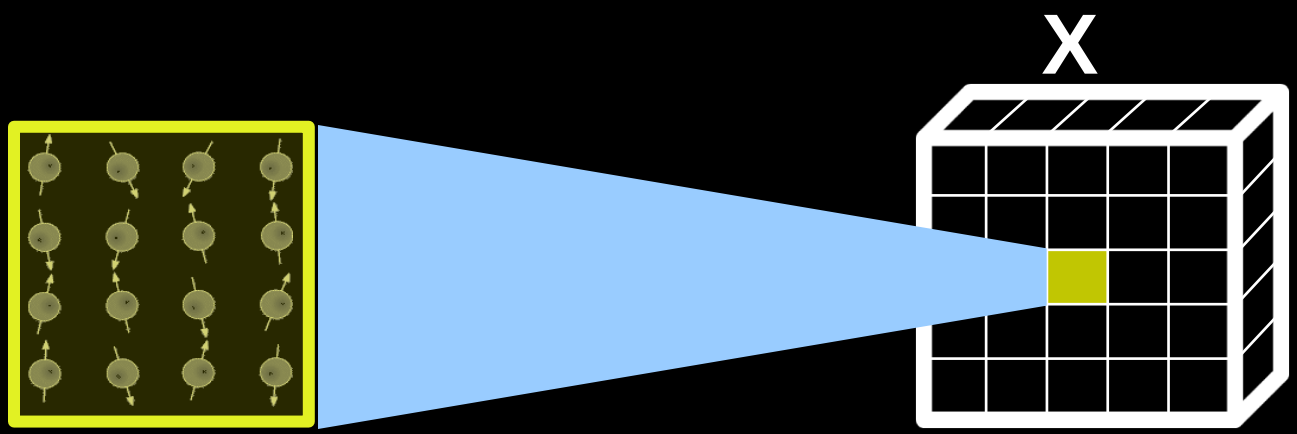
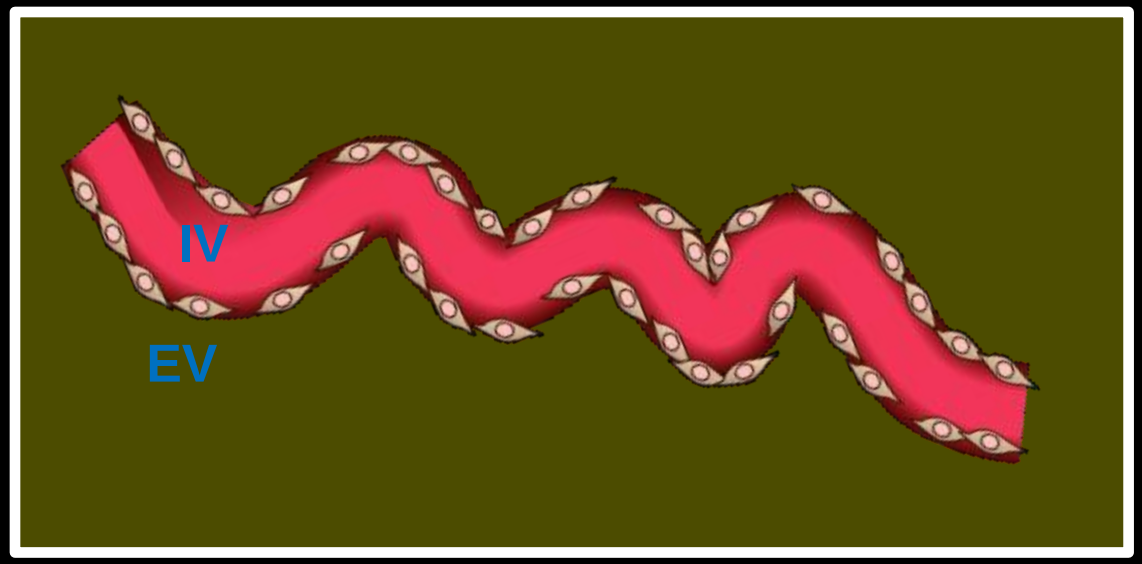
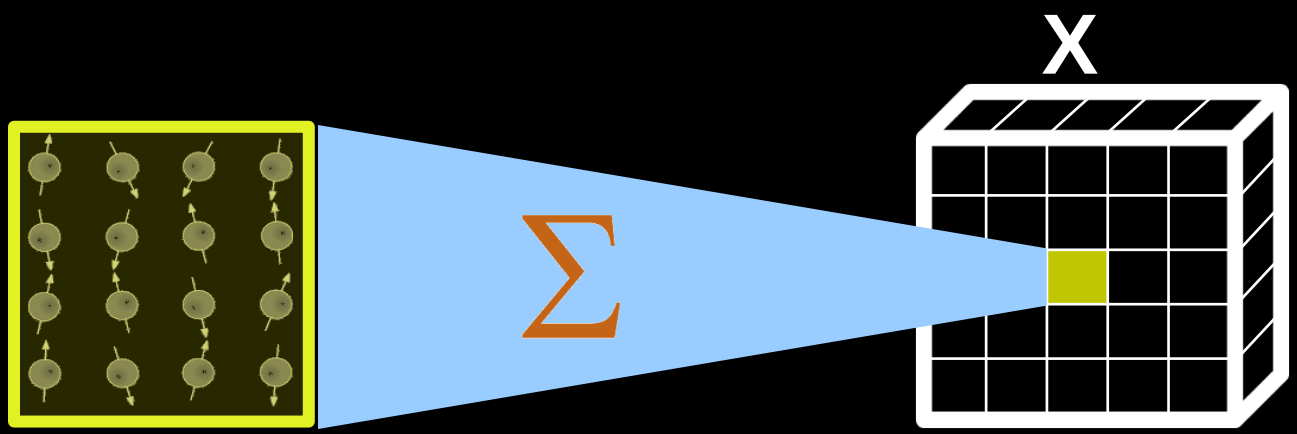
Dynamic Contrast Enhanced MRI



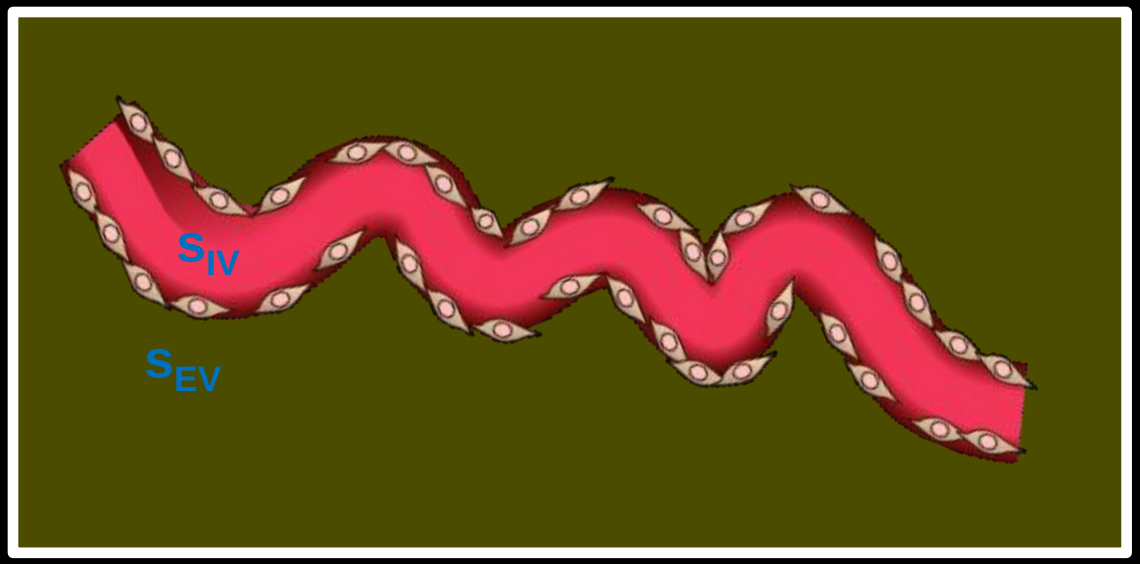


Dynamic Contrast Enhanced MRI





Dynamic Contrast Enhanced MRI



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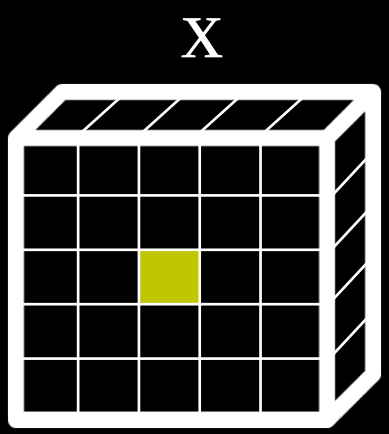

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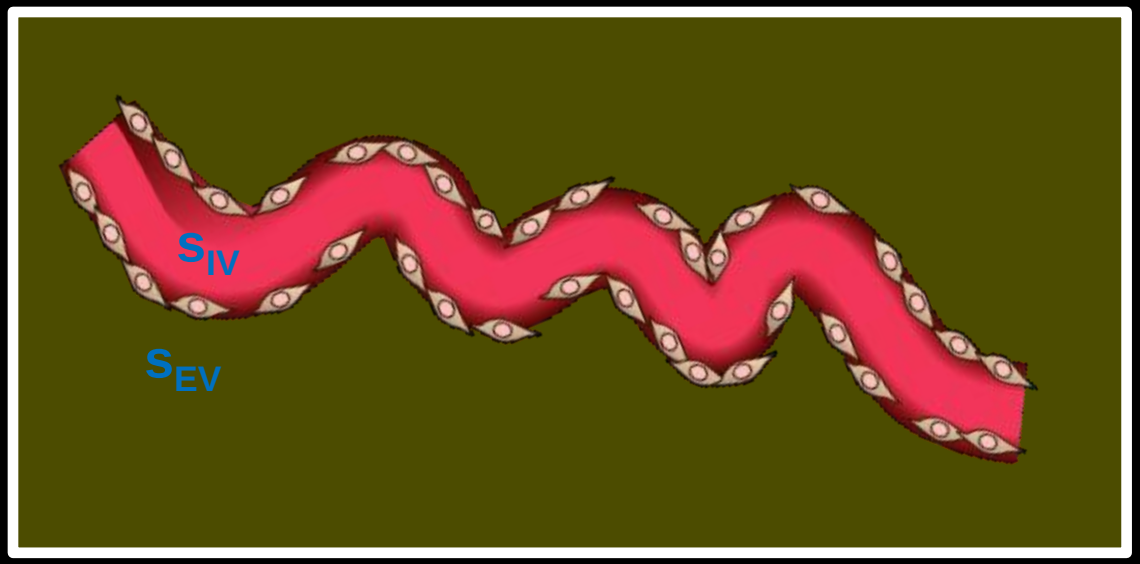
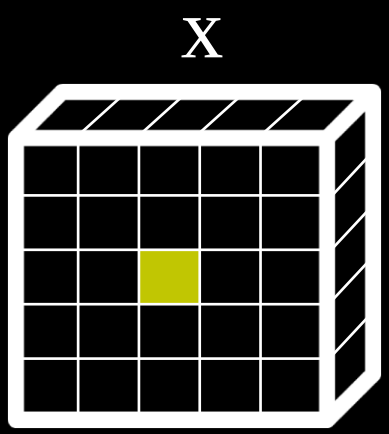


$$X = a_{IV} \times$$

a: contrast Concentration



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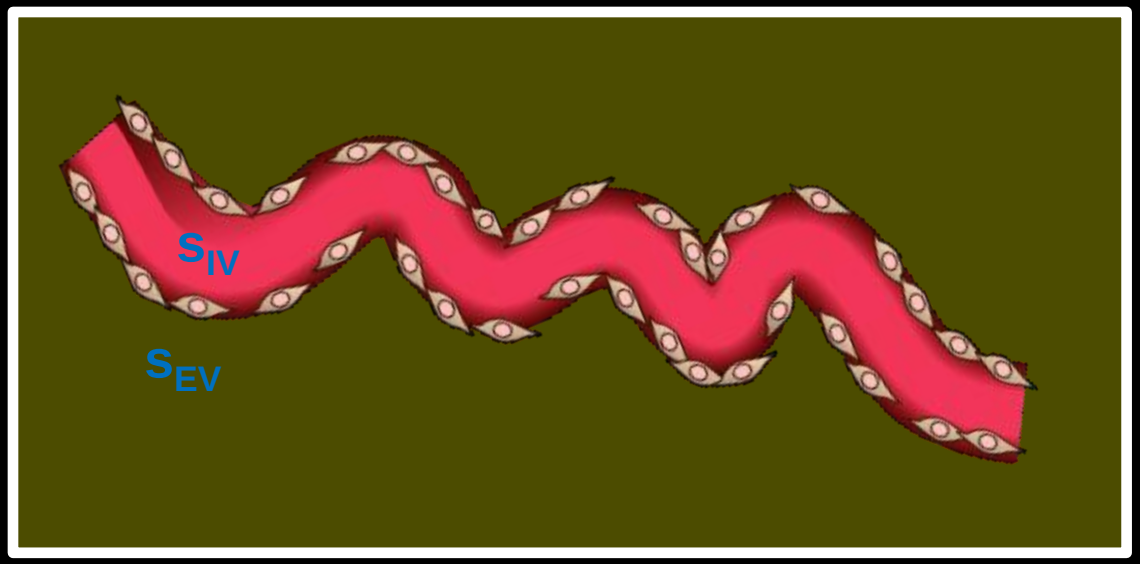
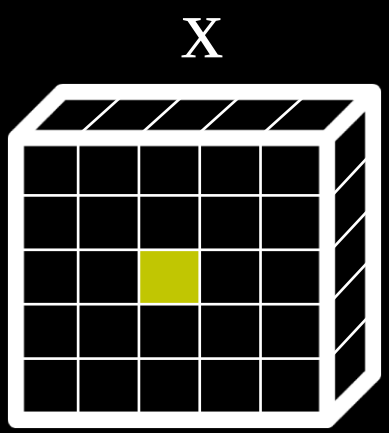


$$X = a_{IV} \times s_{IV} +$$

a: contrast Concentration

s: image



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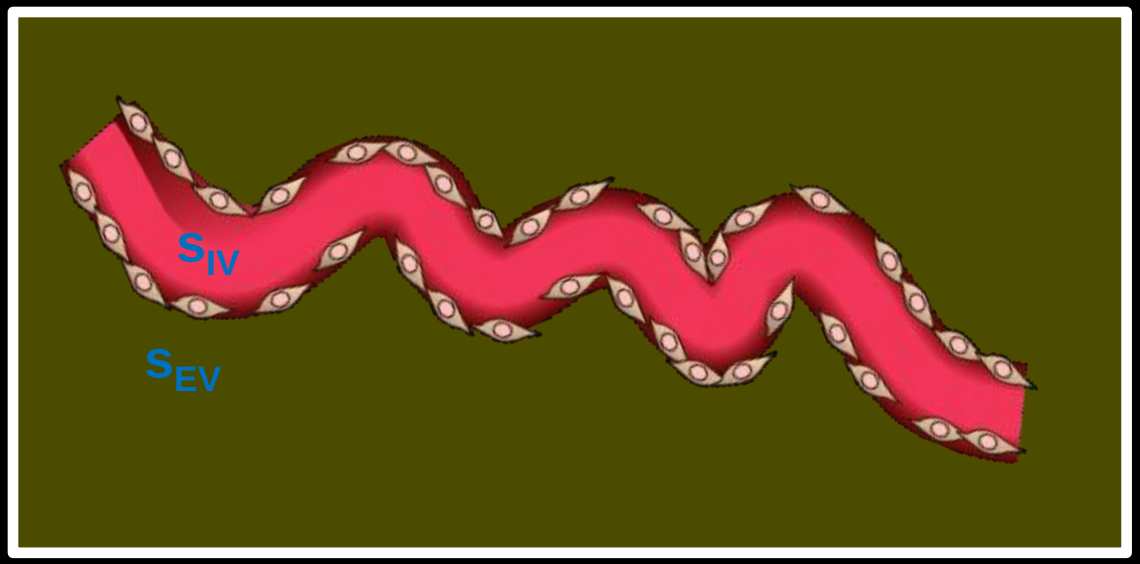
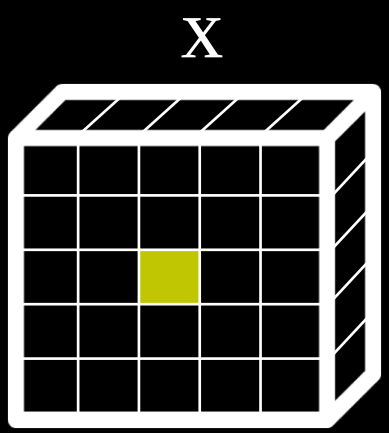


$$X = a_{IV} \times S_{IV} + a_{EV} \times S_{EV}$$

a: contrast Concentration

s: image



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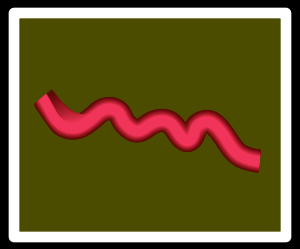
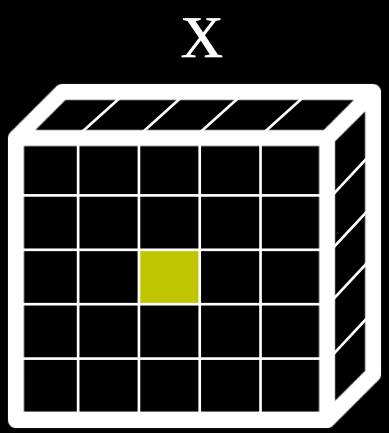


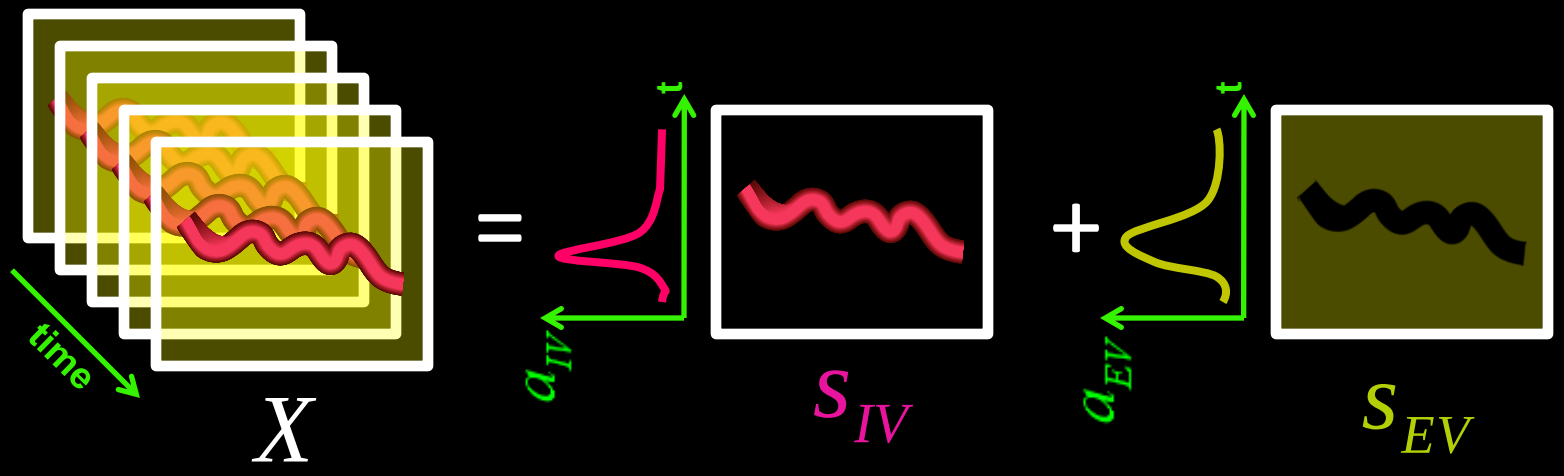
$$X = a_{IV} \times s_{IV} + a_{EV} \times s_{EV}$$

a: contrast Concentration

s: image



Independent Component Analysis



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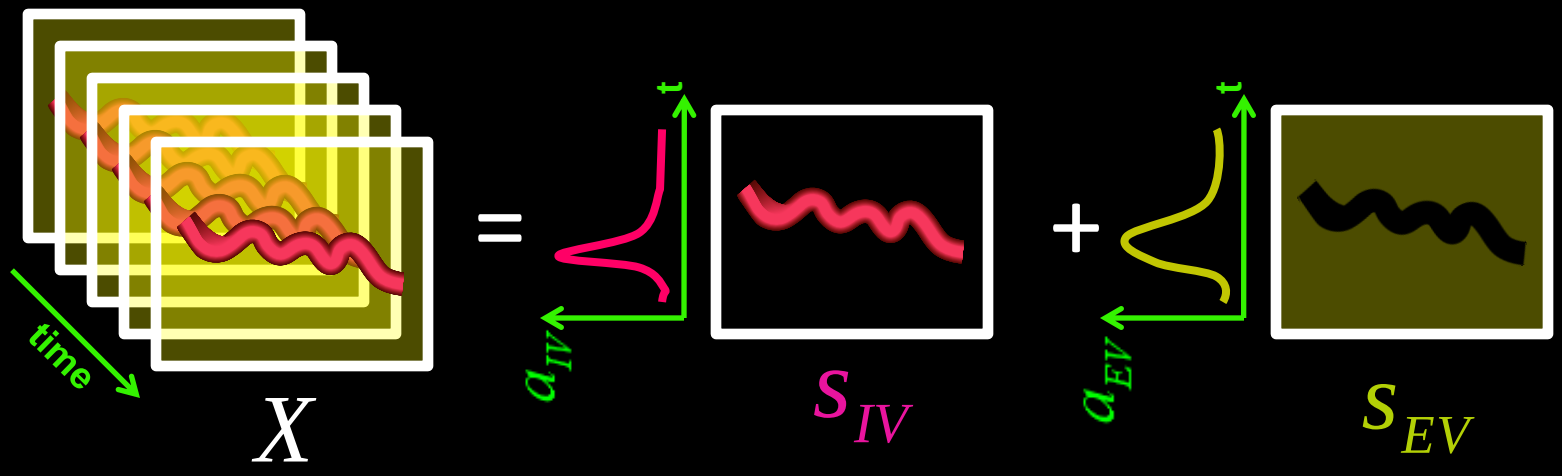


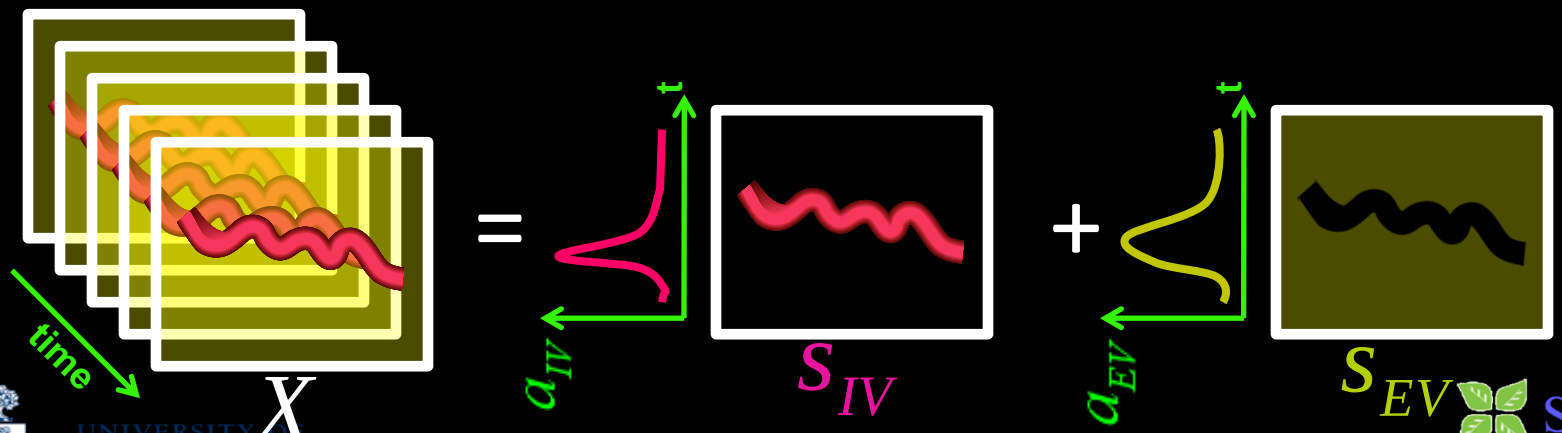
$$X = AS$$

$$X = [x_1, x_2, \ldots, x_N]^T$$

$$A = [a_{IV}, a_{EV}]$$

$$S = [s_{IV}, s_{EV}]$$

Estimator: $F(X \mid A) = [s_{IV}, s_{EV}]$

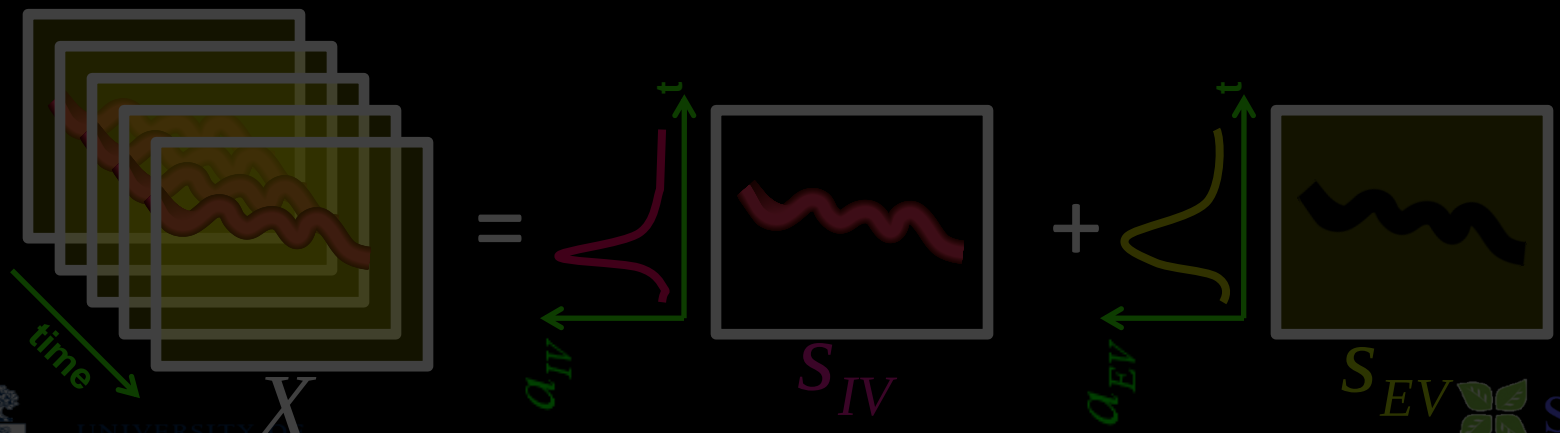


Maximum Likelihood Estimation

Estimator: $F(X \mid A) = [s_{IV}, s_{EV}]$

Maximum likelihood estimator corresponds to the value θ_{ML} that makes the obtained measurements more likely.

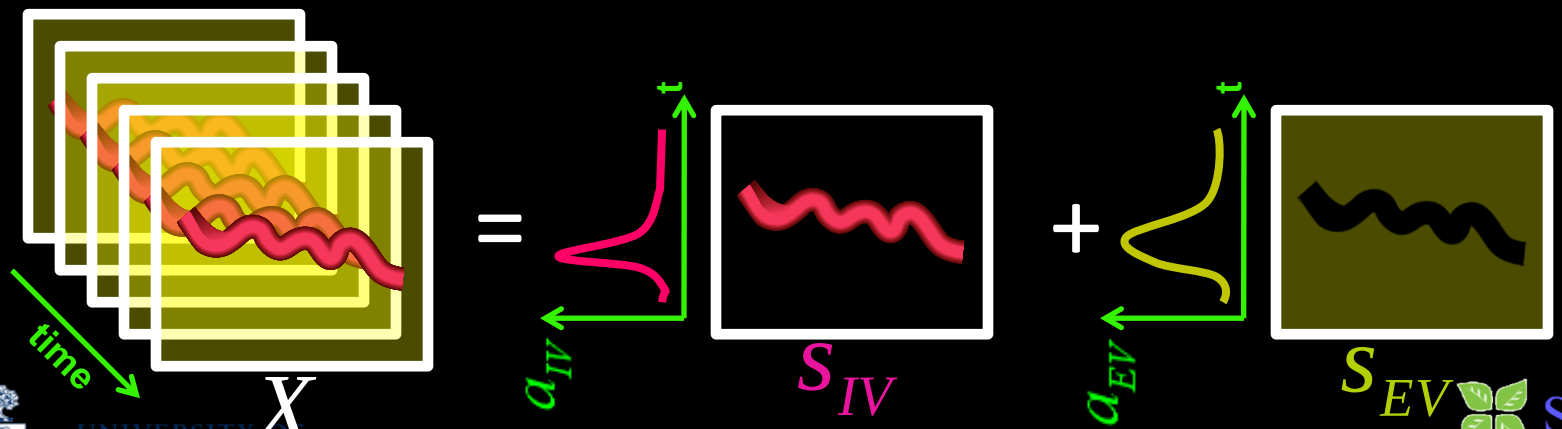
$$ML\{(X \mid \theta)\} = \arg\max_{\theta}\{p(x_1, x_2, ..., x_N \mid \theta)\}$$



Maximum Likelihood Estimation

Estimator: $F(X \mid A) = [s_{IV}, s_{EV}]$

$$ML\{(X \mid A)\} = \arg\max_{A}\left[\, p\left(\left[x_1, x_2, \ldots, x_N\right]^T \mid A\right)\right]$$



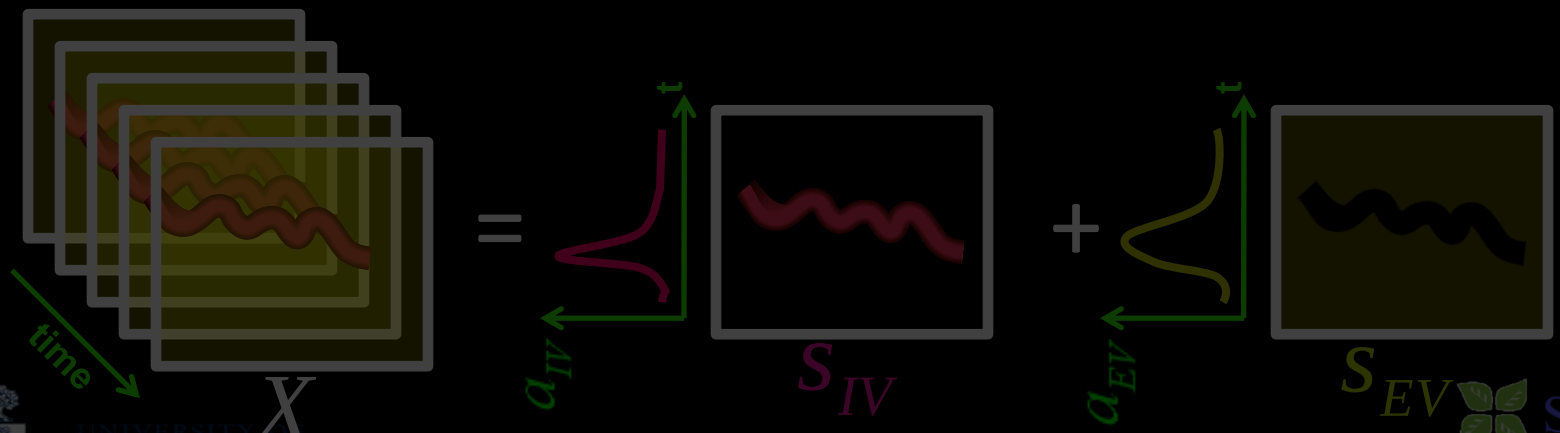
Maximum Likelihood Estimation

Estimator: $F(X \mid A) = [s_{IV}, s_{EV}]$

$$ML\{(X \mid A)\} = \arg\max_{A} \left[p\left([x_1, x_2, \ldots, x_N]^T \mid A \right) \right]$$

$$X = AS$$

$$p(X) = p(AS) = \left|\det(A^{-1})\right| \times p(S)$$



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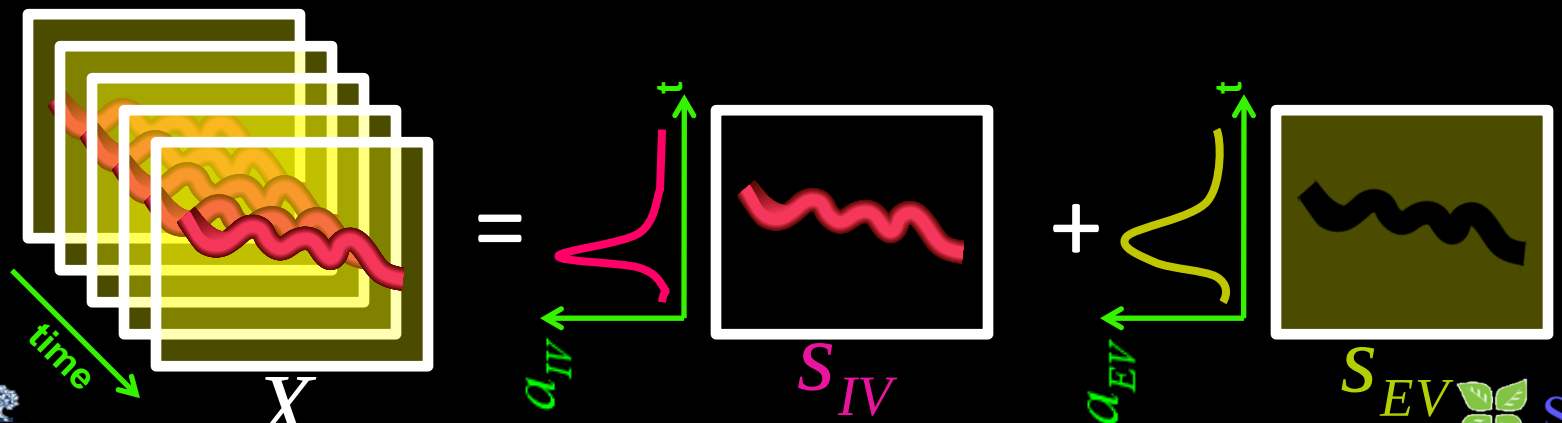
$$= \arg\max_{A}\left[\left|\det\left(A^{-1}\right)\right| \times p(S \mid A)\right]$$



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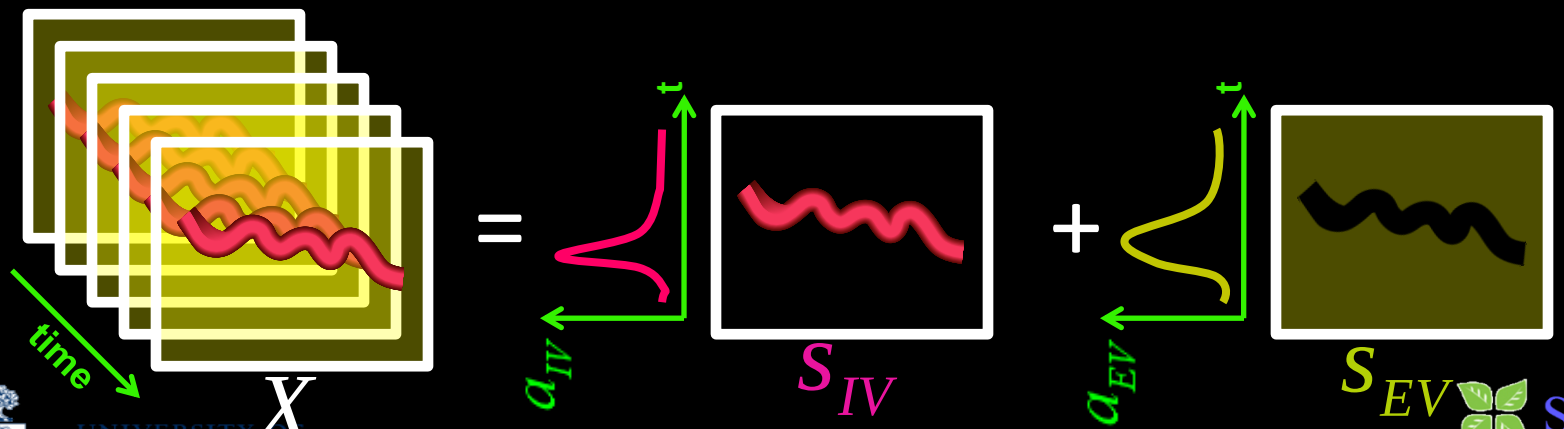


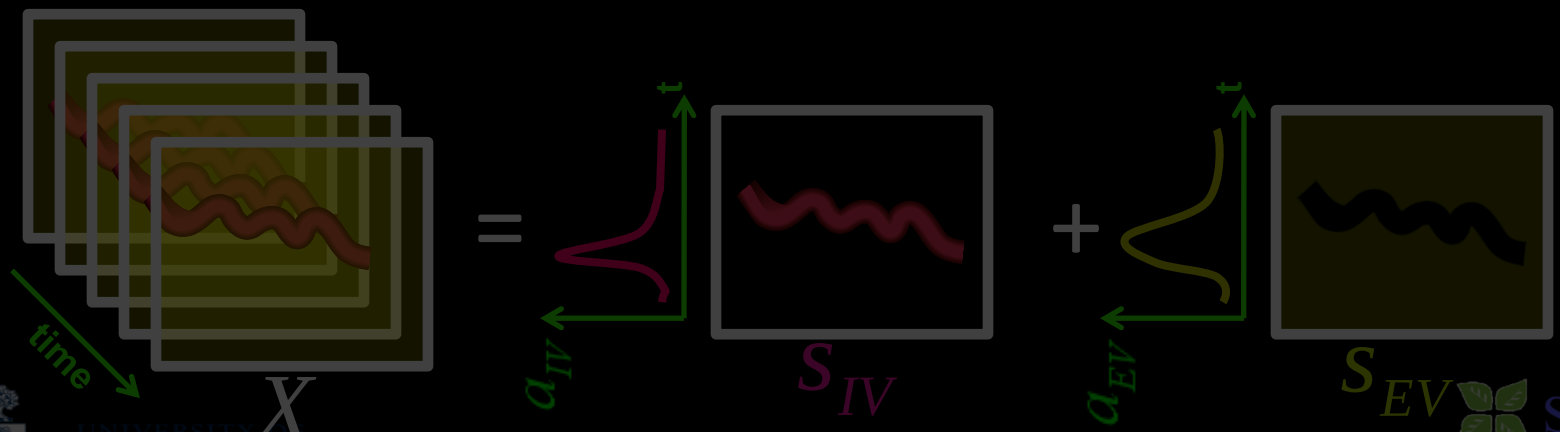
Maximum Likelihood Estimation

Estimator: $F(X \mid A) = [s_{IV}, s_{EV}]$

$$ML\{(X \mid A)\} = \arg\max_{A} \left[p\left([x_1, x_2, \ldots, x_N]^T \mid A \right) \right]$$

If s_1 & s_2 are independent

$$p(s_1, s_2) = p(s_1) \times p(s_2)$$



Maximum Likelihood Estimation

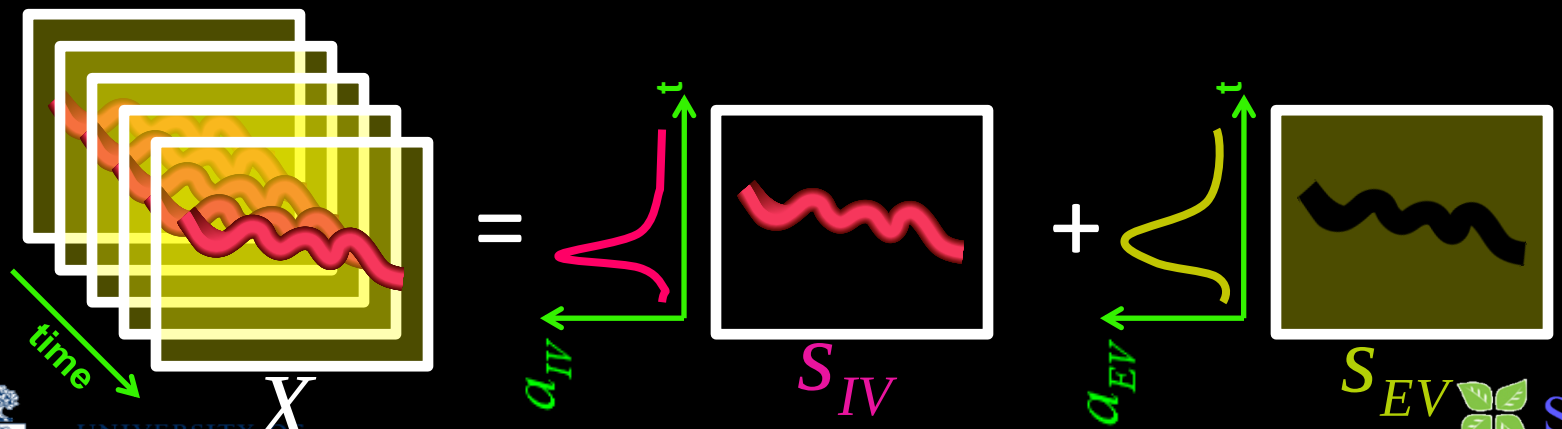
Estimator: $F(X \mid A) = [s_{IV}, s_{EV}]$

$$ML\{(X \mid A)\} = \arg\max_{A}\left[p\left(\left[x_1, x_2, \ldots, x_N\right]^T \mid A\right)\right]$$

$$= \arg\max_{A}\left[\left|\det\left(A^{-1}\right)\right| \times p(S \mid A)\right]$$

$$= \arg\max_{A}\left[\left|\det\left(A^{-1}\right)\right| \times p\left(\left[s_{IV}, s_{EV}\right] \mid A\right)\right]$$

$$= \arg\max_{A}\left[\left|\det\left(A^{-1}\right)\right| \times p(s_{IV} \mid A) \times p(s_{EV} \mid A)\right]$$



Independent Component Analysis

$$ML\{(X \mid A)\} = \arg\max_{A}\left[\left|\det\left(A^{-1}\right)\right| \times p\left(s_{IV} \mid A\right) \times p\left(s_{EV} \mid A\right)\right]$$

Independent Component Analysis

$$ML\{(X \mid A)\} = \arg\max_{A}\left[\left|\det\left(A^{-1}\right)\right| \times p\left(s_{IV} \mid A\right) \times p\left(s_{EV} \mid A\right)\right]$$

$$p(s_i) = ?$$

Probability Density Function (pdf)

$$p(s_i) = ?$$

$$p(s_i, s_j) = p(s_i) \times p(s_j)$$

$$\mu = E\{s_i\} = 0$$

$$\sigma^2 = E\{(s_i)^2\} = 1$$

Probability Density Function (pdf)

$$p(s_i) = ?$$

$$E\left\{ s_i \times \frac{\partial p(s_i)}{\partial s_i} - \frac{\partial^2 p(s_i)}{\partial {s_i}^2} \right\} > 0$$

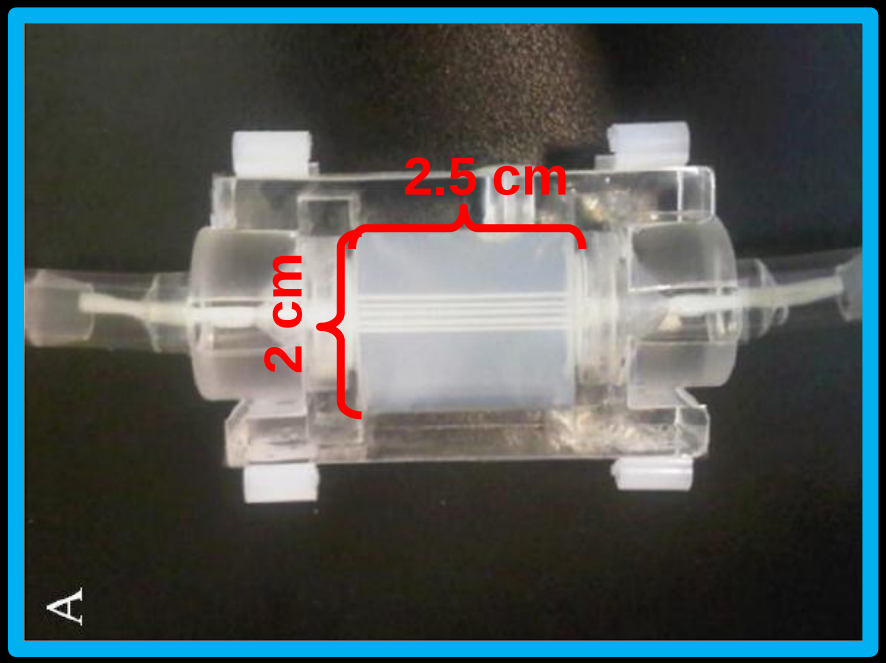
Independent Component Analysis (ICA)

$$ML\{(X \mid A)\} = \arg\max_{A}\left[\left|\det\left(A^{-1}\right)\right| \times p\left(s_{IV} \mid A\right) \times p\left(s_{EV} \mid A\right)\right]$$

$$p(s_i) = \exp\left\{\alpha_1 - 2\log\left(\cosh\left(s_i\right)\right)\right\}$$

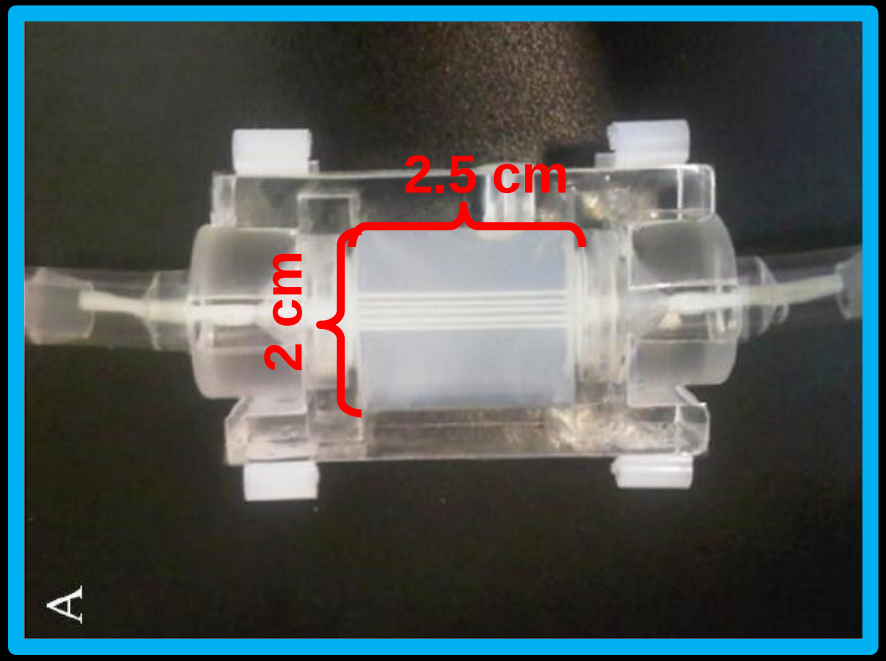
Phantom Study

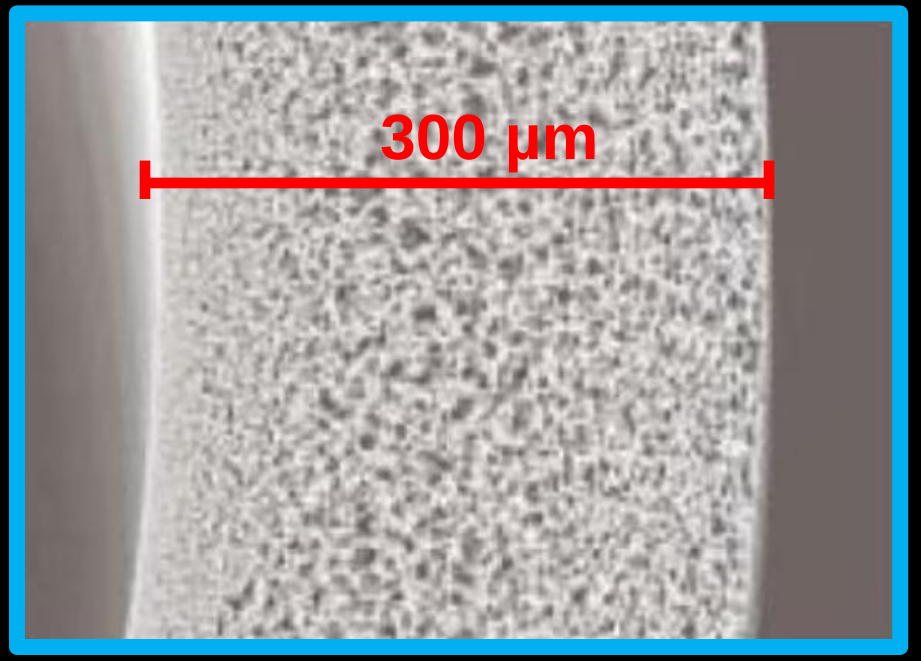
- Dialysis Tubing



Phantom Study

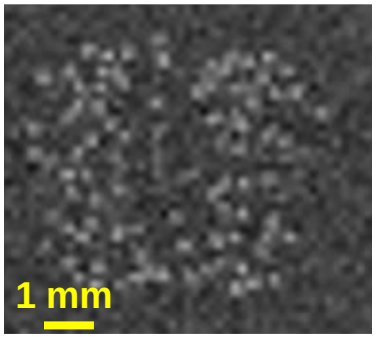
- Dialysis Tubing
- Pore size: 90-970 nm





Phantom Study

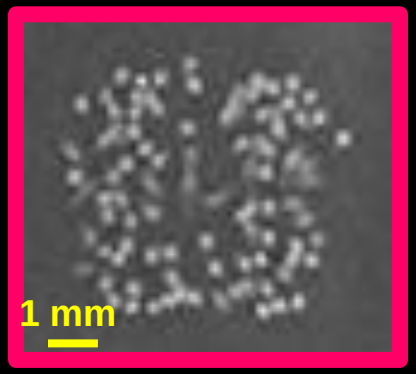
Raw Data



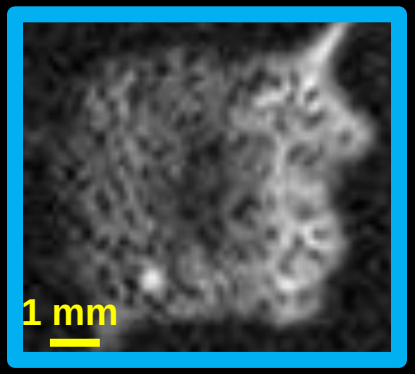
in-plane resolution=300μm

Phantom Study

Intravascular



Extravascular



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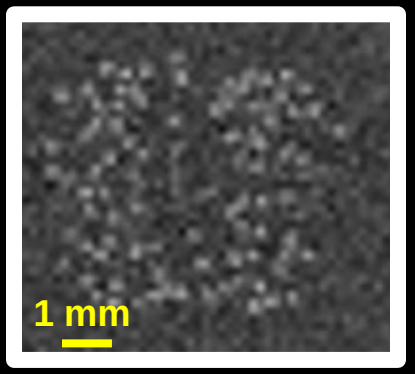
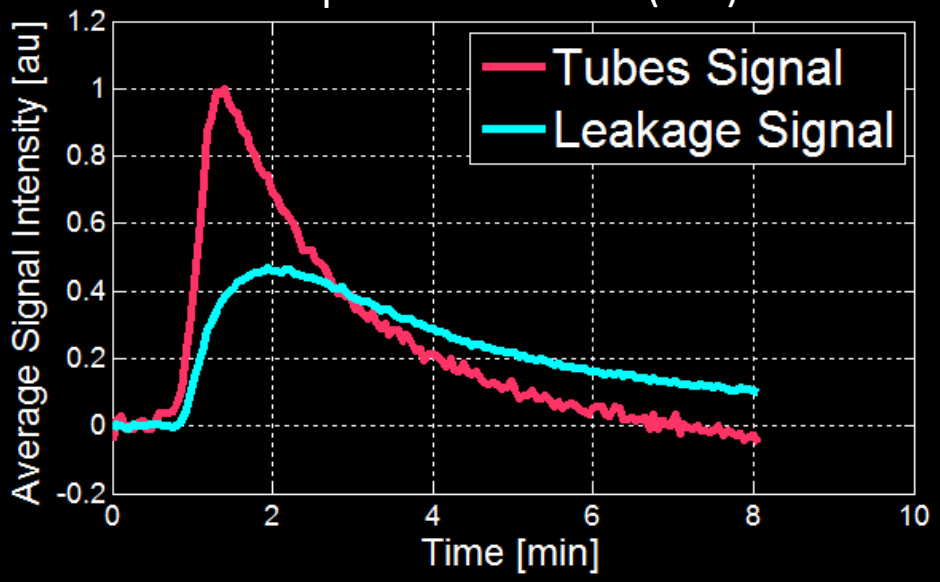


Separation Results (ICA)



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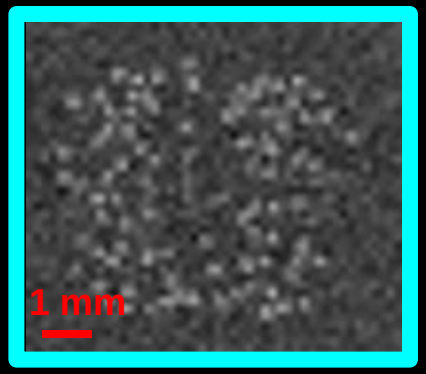
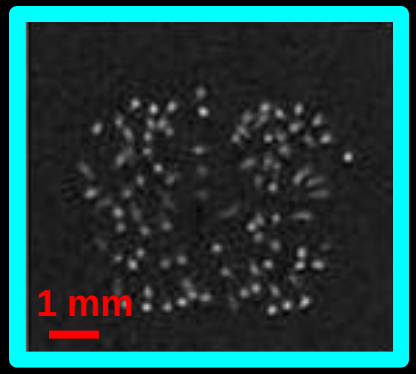
Validation

- High resolution pre-contrast MR image



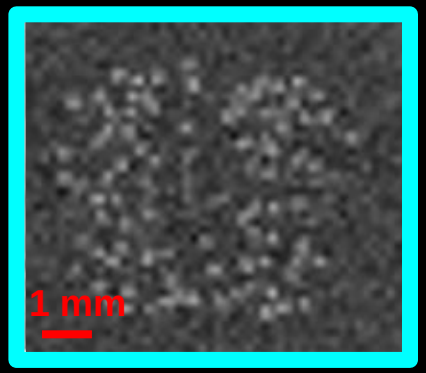
DCE MRI Dataset



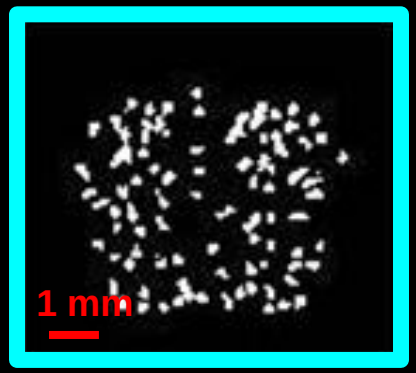
High Resolution (Pre-contrast)

Validation

- High resolution pre-contrast MR image
  - Thresholding → Binary mask



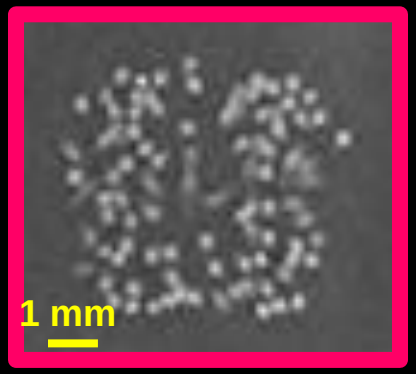
DCE MRI Dataset



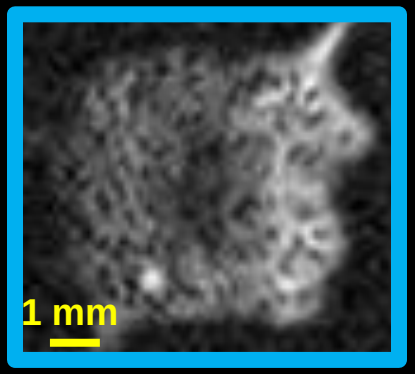
Mask

Phantom Study

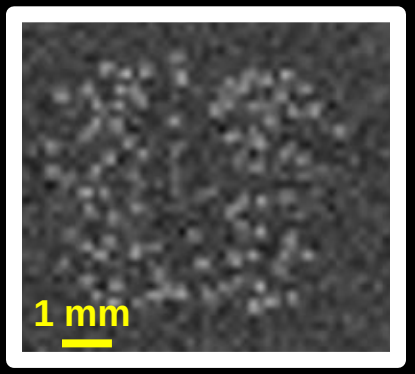
Intravascular



Extravascular



Raw Data



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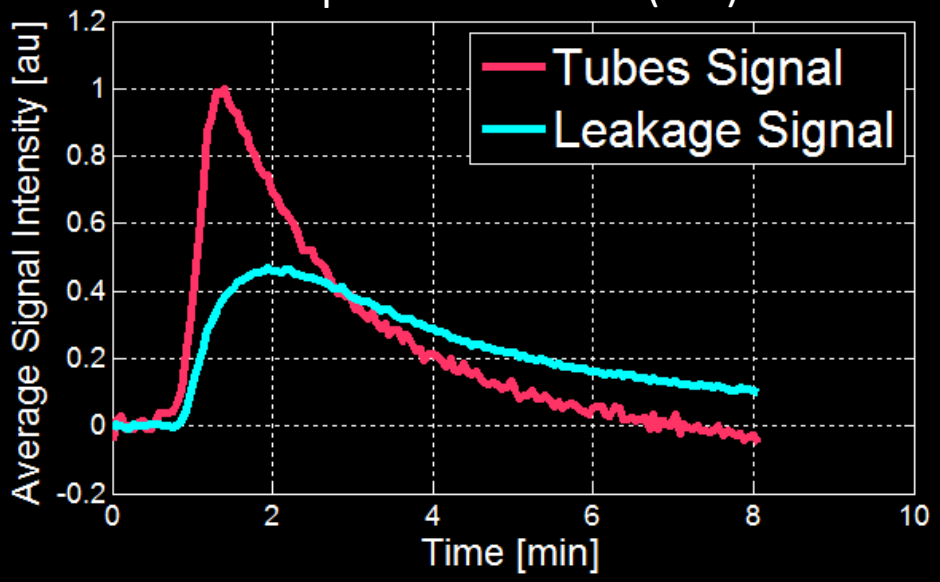
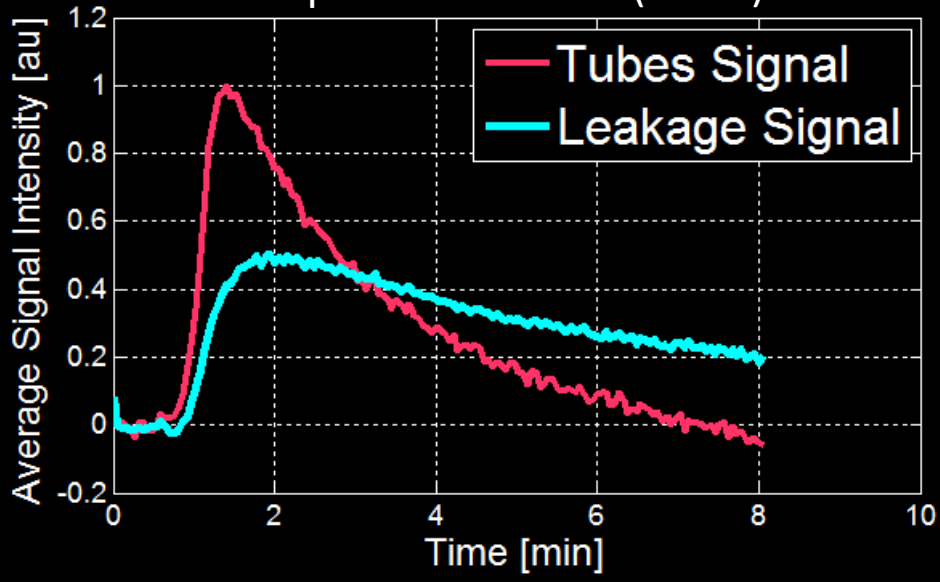


Separation Results (Mask)



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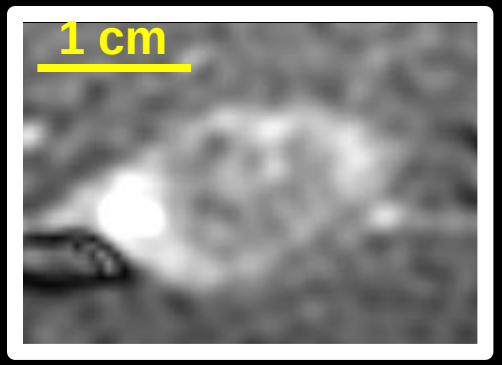
In-vivo Experiment (MR data)

- Tumor in the Thigh muscle
- Imaged with US and MRI



Raw Data

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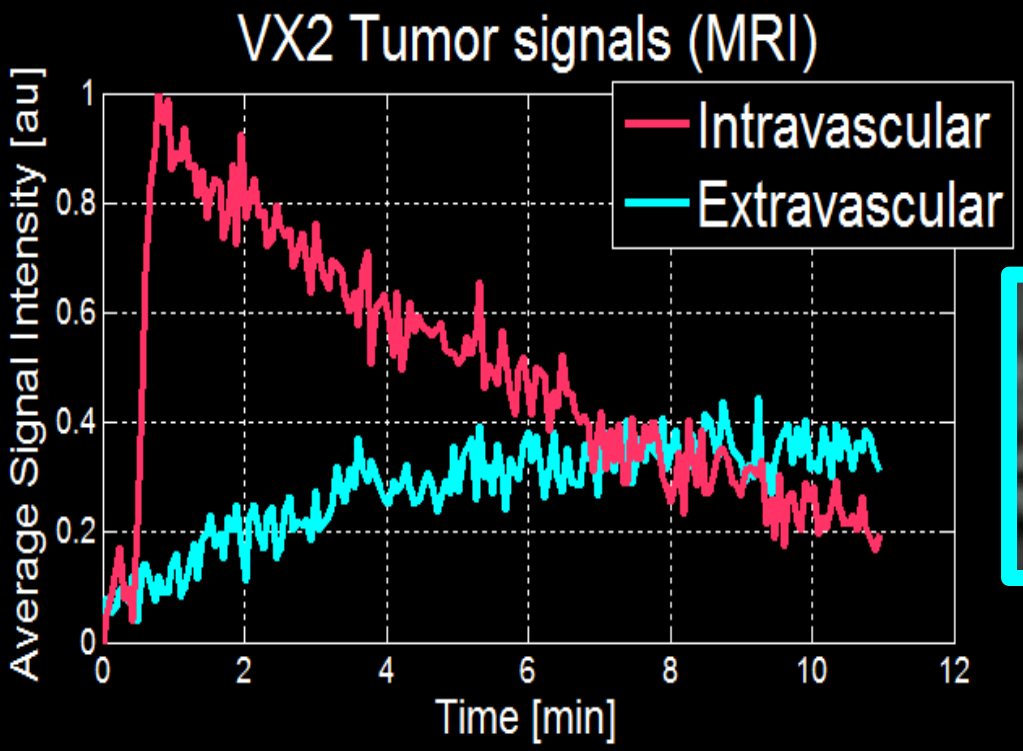
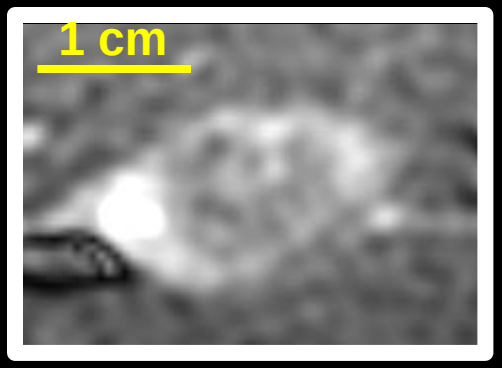
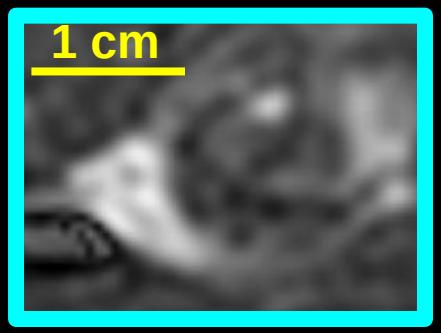
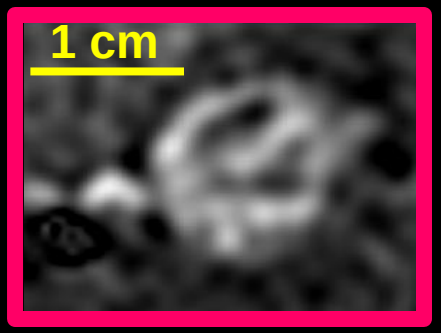




Raw Data



Extravascular



Intravascular

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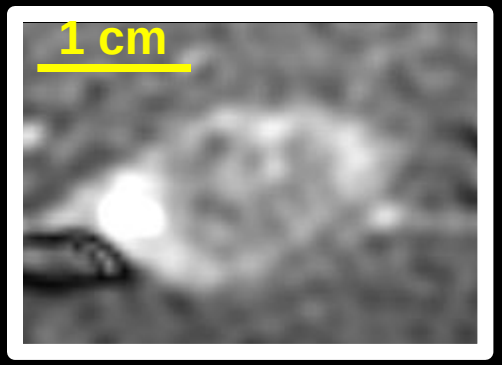
Ultrasound Contrast Agent (µBubbles)

- Tumor in the Thigh muscle
- Imaged with US and MRI



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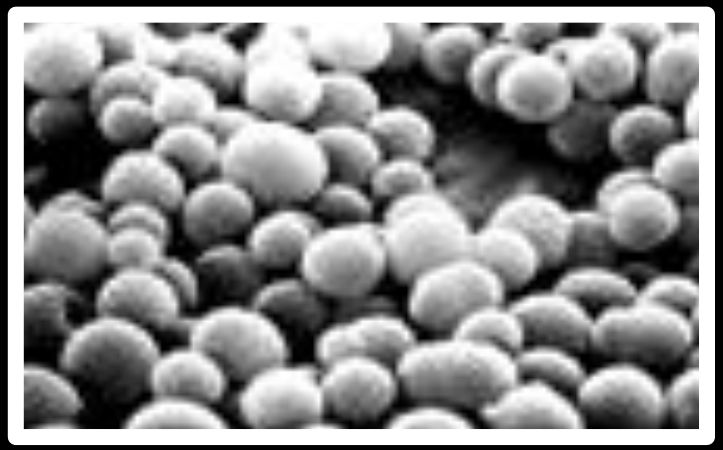

Ultrasound Contrast Agent (µBubbles)

- Tumor in the Thigh muscle
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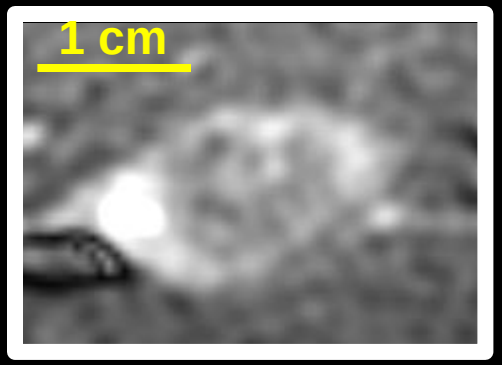
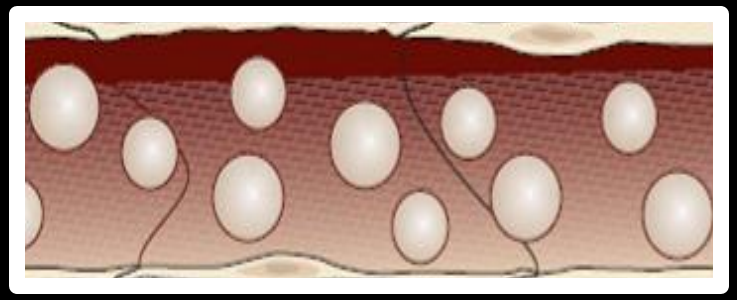
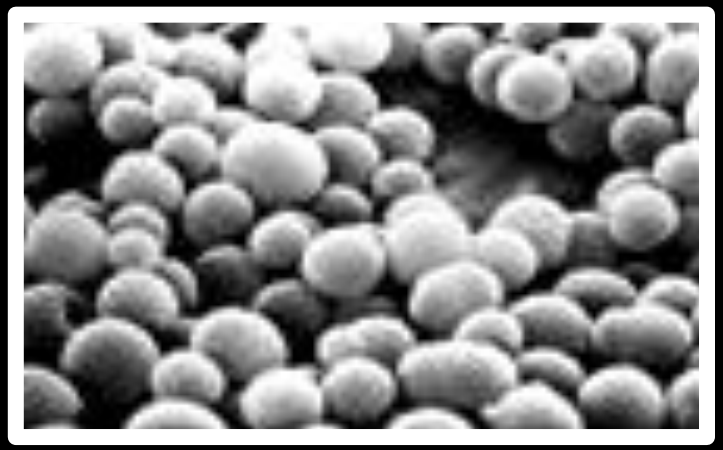


Raw Data

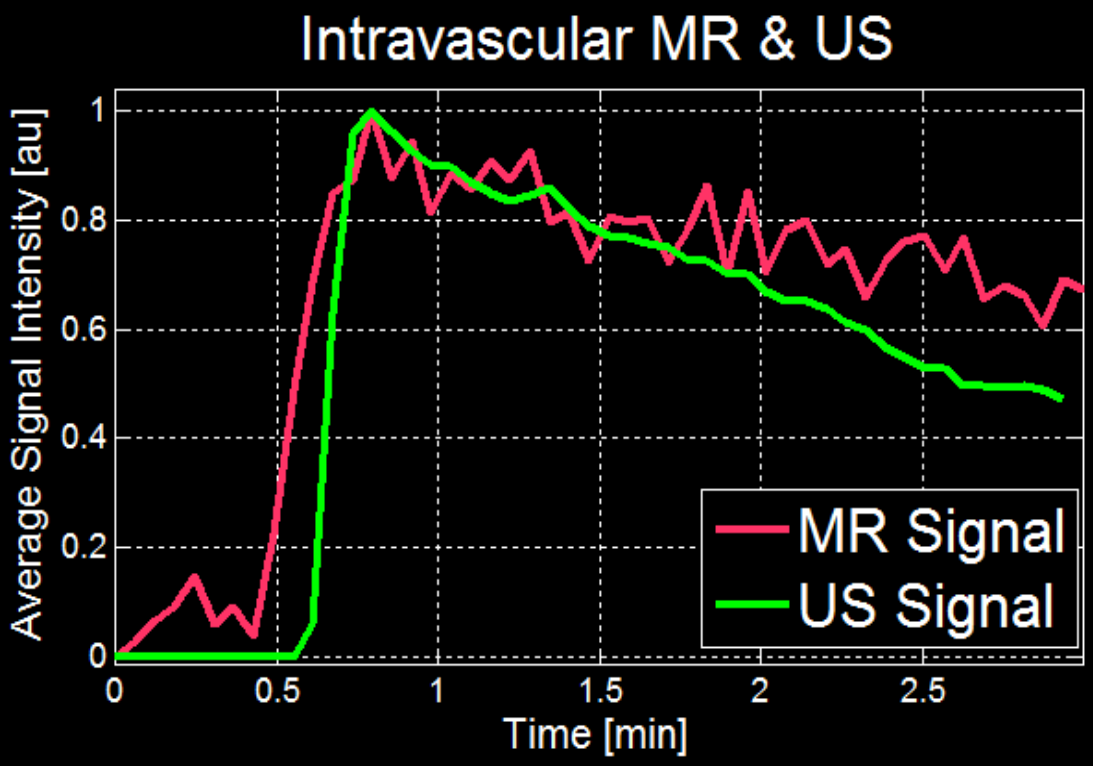
Circulating µbubbles



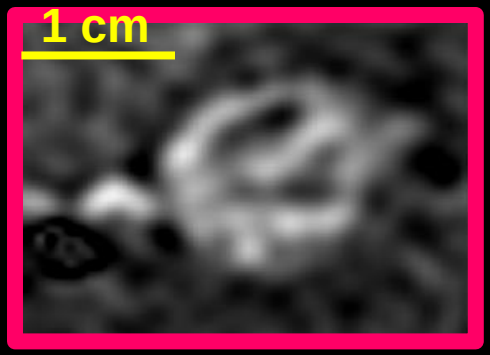


In-vivo Experiment (MRI vs. US)

- Ultrasound Imaging
- µBubbles stay intravascular



Raw Data- US



Intravascular-MR

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Summary & Conclusions

- Tumor vasculature is heterogeneous and leaky
- MRI contrast agent is capable of leaking
- Tumor is characterized based on the tracer dynamics
- ICA is capable of separating the intravascular and extravascular compartments and identifying arterial input function
- Results of phantom and in-vivo experiment studies were promising

Acknowledgements


Ontario Institute for Cancer Research


NSERC CRSNG

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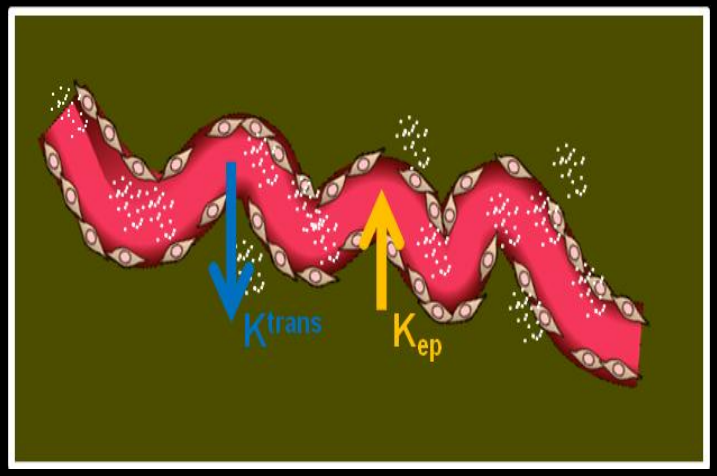
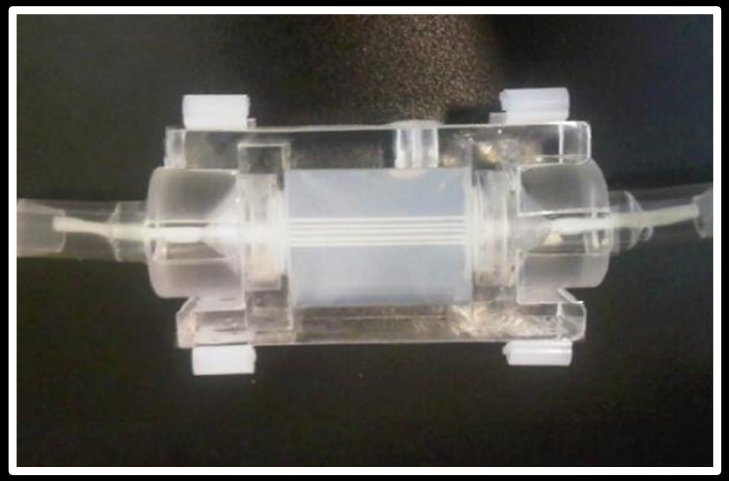
Thank You





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