Highly Accelerated Brain DCE MRI with Direct Estimation of Pharmacokinetic Parameter Maps

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I have no financial interests or relationships to disclose with regard to the subject matter of this presentation.
Introduction

- Sub-optimal coverage and resolution for Dynamic Contrast Enhanced (DCE) MRI by Nyquist sampling.
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• Whole-brain coverage high-resolution enabled by constrained reconstruction from under-sampled kt-space$^{1,2}$.

• Sub-optimal coverage and resolution for Dynamic Contrast Enhanced (DCE) MRI by Nyquist sampling.

• Whole-brain coverage high-resolution enabled by constrained reconstruction from under-sampled kt-space^{1,2}.

• Important pathological information from pharmacokinetic(PK) maps ($K^{\text{trans}}$, $v_p$, $v_e$ etc.).

Reduced dimensionality: from 4D dynamic images to 3D static PK maps.
Goal

• Direct reconstruction of PK maps with PK model integrated in reconstruction process

• This may enable higher acceleration rate and better fidelity of PK maps.
Conventional estimation of PK maps

Under-sampled kt-space data: $k_u(t)$ → Anatomical Images: $S(t)$ → Contrast Agent Concentration: $CA(t)$ → PK Parameters: $K^{\text{trans}}, v_p$

Constrained reconstruction using sensitivity maps, under-sampling pattern, with some sparsity constraints.

Sensitivity Sampling pattern
Under-sampled kt-space data: $k_u(t)$

Anatomical Images: $S(t)$

Contrast Agent Concentration: $CA(t)$

PK Parameters: $K_{\text{trans}}, v_p$

Use T1w signal equation to estimate contrast concentration changes over time with T1 maps and M0 maps.
Under-sampled kt-space data: $k_u(t)$

Anatomical Images: $S(t)$

Contrast Agent Concentration: $CA(t)$

PK Parameters: $K_{trans}$, $v_p$

Use PK model (Patlak model in our study) to estimate PK parameters from contrast concentration changes $C(t)$
Conventional estimation of PK maps

Under-sampled kt-space data: \( k_u(t) \)

Anatomical Images: \( S(t) \)

Contrast Agent Concentration: \( CA(t) \)

PK Parameters: \( K^{\text{trans}}, v_p \)

Reduced dimension!
Conventional estimation of PK maps

Under-sampled kt-space data: $k_u(t)$

Anatomical Images: $S(t)$

Contrast Agent Concentration: $CA(t)$

PK Parameters: $K^{\text{trans}}, v_p$
Under-sampled kt-space data: $k_u(t)$

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PK Parameters: $K^{\text{trans}}, v_p$
Under-sampled 
kt-space data: \( k_u(t) \)

Anatomical 
Images: \( S(t) \)

Contrast Agent 
Concentration: \( CA(t) \)

PK Parameters: 
\( K_{\text{trans}}, v_p \)

If a general function \( f \) is used:

\[
B(t) = f (K_{\text{trans}}, v_p)
\]

Can solve PK maps with an optimization problem:

\[
(K_{\text{trans}}, v_p) = \underset{K_{\text{trans}}, v_p}{\arg\min} \| B(t) - f (K_{\text{trans}}, v_p) \|_2^2
\]
Direct estimation

• Solve: \( (K^{\text{trans}}, v_p) = \arg \min_{K^{\text{trans}}, v_p} \| k_u(t) - f(K^{\text{trans}}, v_p) \|^2 \)

• No constraint is needed, a parameter-free reconstruction!

• Gradient is calculated for the objective function to use a efficient l-BFGS algorithm.

<table>
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<th>Conventional</th>
<th>Direct</th>
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<tr>
<td>Sparsity constraint</td>
<td>Temporal finite difference on anatomic images</td>
<td>None!</td>
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<tr>
<td>Algorithms</td>
<td>Alternating Direction Methods of Multipliers (ADMM)</td>
<td>Limited memory Broyden–Fletcher–Goldfarb–Shanno (l-BFGS)</td>
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<tr>
<td>Reconstruction time (2D case)</td>
<td>265s</td>
<td>296s</td>
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Retrospective study

- Fully-sampled DCE from brain tumor patients
- Randomized golden-angle radial sampling\textsuperscript{1,2}
- Retrospectively down-sampled 10x ~ 100x

\textsuperscript{1}Y Zhu et al. p4365, ISMRM 2014
\textsuperscript{2}Y Zhu et al. p2535, ISMRM, 2015
**K_{trans} maps**

- **Fully sampled**
- **Direct**
- **Conventional**

- **20x**
- **60x**
- **100x**
Zoom-in on tumor, 100x

Fully-sampled

Direct

Conventional
Fully sampled

$v_p$ maps

Direct

Conventional

20x

60x

100x
Zoom-in on vessels, 100x

Fully-sampled  Direct  Conventional
1-rMSE and mSSIM

\(K_{\text{trans}}\)

1-rMSE & mSSIM

\(V_p\)

mSSIM

1-rMSE

Reduction factor

1.0  2.0  3.0  4.0  5.0  6.0  7.0  8.0  9.0  10.0

1.0  0.95  0.9  0.85  0.8  0.75  0.7  0.65  0.6  0.55

Reduction factor

1.0  2.0  3.0  4.0  5.0  6.0  7.0  8.0  9.0  10.0

1.0  0.95  0.9  0.85  0.8  0.75  0.7  0.65  0.6  0.55

Direct 1-rMSE

Conventional 1-rMSE

Direct mSSIM

Conventional mSSIM
• Direct reconstruction from prospective under-sampled data:
  – A whole-brain FOV: 22×22×19cm³
  – Spatial resolution: 0.9×0.9×1.9mm³
  – Temporal resolution: 5s
  – Traditional golden-angle radial sampling
  – Prospective under-sampled in ky-kz plane
  – Reduction factor 30x
Whole-brain $K^{\text{trans}}$ maps
Whole-brain $v_p$ maps
A three-plane view
Summary

• Direct reconstruction of PK maps is feasible.
• Superior accuracy up to reduction factor of 100x.
• No significant difference in reconstruction time.
• Parameter free reconstruction!
• Applied successfully to whole-brain DCE-MRI in brain tumor patients.
Acknowledgement

• Funding source:
  SC CTSI (NIH/NCRR/NCATS) Grant # KL2TR000131

• Magnetic Resonance Engineering Laboratory (MREL)

• Keck Hospital of USC

• Other posters and talks from our DCE group:
  #196, #3050, #3705, #2535, #3052