MRI-PET joint kinetic model-driven reconstruction

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Overview

PET: Kinetic model driven reconstruction
MRI: Kinetic model driven reconstruction
PET-MRI: Opportunities for joint kinetic model driven reconstruction
PET: KINETIC MODEL DRIVEN RECONSTRUCTION
PET kinetic data

Muzi et al. MRI 2012; 30: 1203.

QIN: Quantitative assessment of dynamic PET imaging data in Cancer Imaging.

Dynamic PET Data Analysis

- Segment Dynamic Data
- Parametric Imaging
- Segmented sub-TACs (cluster by similar profile)
- VOIs from PET and Co-registered MRI
- Tissue Curves
- Blood AIFs
- Parameter Estimation
- Kinetic Parameters from Residue Analysis
  \[ C_f(t) = \bar{V}_b C_p (t - \Delta) + K_i \int_0^t R(t-s) C_p (s - \Delta) ds \]
- Parametric Volumes by Mixtures (recombine pixel level parameters)

Results: Parameter Sets with Units

<table>
<thead>
<tr>
<th>Region</th>
<th>( K_i ) (transport)</th>
<th>( K_i ) (flux)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CE Gloma</td>
<td>0.047</td>
<td>0.018</td>
</tr>
<tr>
<td>NCE Gloma</td>
<td>0.021</td>
<td>0.001</td>
</tr>
<tr>
<td>Brain</td>
<td>0.024</td>
<td>0.002</td>
</tr>
</tbody>
</table>

"Compartmental models express the residue in a parametric form"
PET AIF

Muzi et al. MRI 2012; 30: 1203.

QIN: Quantitative assessment of dynamic PET imaging data in Cancer Imaging.

**A**
Arterial Blood Sampling
“Gold Standard”, Invasive

- 20-30 Samples per Study
- PET : $\gamma$ Cross-Calibration

**B**
Historical Data
Scalable Templates

- Camouflaged Deconvolution
- Variance Representation

**C**
Image Based (IDIF)
Automated, Objective

- Segmentation, Curve Recovery, Spillover Adjustment
- Scale by late Venous Blood Sample

- Radial Artery
- Image Extracted
PET kinetic models

Muzi et al. MRI 2012; 30: 1203.
QIN: Quantitative assessment of dynamic PET imaging data in Cancer Imaging.

B. Metabolites of FLT (Liver to Blood)

\[ \beta-G \]

\[ ^{18}\text{F}-\text{FLT} \rightleftharpoons ^{*^{18}}\text{F}-\text{FLT-Glucuronide (in blood)} \]

\[ \text{UDP-GT} \]

C. Kinetic Model of FLT Metabolism

Blood

- \( C_{p\text{FLT}} \)
- \( C_{\text{met}} \)

Tissue Compartments

- \( Q_e \): Exchangeable \( ^{18}\text{F}-\text{FLT} \)
- \( Q_m \):
  - \( ^{18}\text{F}-\text{FLTMP} \)
  - \( ^{18}\text{F}-\text{FLTDP} \)
  - \( ^{18}\text{F}-\text{FLTTP} \)

\( K_1 \), \( K_2 \), \( K_3 \), \( K_4 \)
Direct Estimation of Kinetic Parametric Images for Dynamic PET

Guobao Wang and Jinyi Qi

Department of Biomedical Engineering, University of California

The development of algorithms that are suitable for large-scale direct estimation began to attract more and more attention with the recent advances in computing technology. In 2005, a parametric iterative co-
PET - Direct reconstruction

- Dynamic Data (Sinograms): $S(\theta,ti); i=1,...,200$
- Dynamic Images (Concentrations): $C(r,ti); i=1,...,200$
- Parametric Maps: $K_1(r), k_2(r), k_3(r), ...$
- Direct Reconstruction
- Compartment Model
Direct reconstruction of parametric images in cardiac PET imaging: in-vivo studies

Yoann Petibon², Yothin Rakhongthai¹¬², Georges El Fakhri² and Jinsong Ouyang²
MRI: KINETIC MODEL DRIVEN RECONSTRUCTION
Dynamic MRI (1984)

Precontrast

6min

16min

67min

1984: first direct recon in PET!

MRI kinetic models

- CBF (ml/100ml/min)
- CBV (ml/100ml)
- PS (ml/100ml/min)
- EEV
- AIF
- CBF
  - CBV
  - PS
  - EEV
MRI Signal modelling

FLASH with FA from 10° to 90°

Signal change (a.u.)

Concentration (/100 mM)
MRI AIF measurement

Arterial Input Function
Reference concentration for quantitative analysis
(“Virtual” blood sampling)
AIF & partial-volume correction

Partial-volume Correction
AIF measurement errors

**Problem:** Inflow effects (velocity sensitive signal)

**Possible solutions**
- Sequence optimisation (in 2D: lower FA, in 3D: increase FA)
- In 3D: distal AIF / saturation slabs / heart in FOV
- Reduce peak concentration (lower dose/flow rate)
- Correct using flow measurements
MRI direct reconstruction

Direct parametric reconstruction from undersampled \((k, t)\)-space data in dynamic contrast enhancement

Nikolaos Dikaios \(^{a,b,*}\), Simon Arridge

\(^{a}\) Centre for Medical Imaging, University College London
\(^{b}\) Centre for Medical Image Computing, University College London

\[ S(k, t; w) = \int x(r, t; w) \cdot \exp(-j2\pi k \cdot r) dr \]

\[ = \int S_0(r) \frac{\sin(\theta) \cdot \left(1 - \exp\left(-\frac{TR}{T1(r, t; w)}\right)\right)}{1 - \cos(\theta) \cdot \exp\left(-\frac{TR}{T1(r, t; w)}\right)} \cdot \exp(-j2\pi k \cdot r) dr \]

\[ \frac{1}{T1(r, t; w)} = \frac{1}{T10(r)} + r_1 \cdot C(r, t \geq t_0; w) \]

\[ C(r, t; w) = \nu_p(r) \cdot C_p(r, t) + K_{\text{trans}}(r) \cdot \int_0^t C_p(r, \tau - t_0) \]

\[ \otimes e\left(\frac{K_{\text{trans}}(r)}{\nu_e(r)}(t - \tau)\right) d\tau \]
PET-MRI: JOINT KINETIC MODEL DRIVEN RECONSTRUCTION
Opportunities (I)
Exploiting AIF similarities

B. Metabolites of FLT (Liver to Blood)

\[ ^{18}\text{F-FLT} \leftrightarrow \text{*}^{18}\text{F-FLT-Glucuronide (in blood)} \]

\[ ^{18}\text{F-FLT} \leftrightarrow \text{UDP-GT} \]

C. Kinetic Model of FLT Metabolism

Blood

- \( C_{p\text{FLT}} \) (\(^{18}\text{F-FLT}\))
- \( C_{\text{met}} \) (\(^{18}\text{F-FLT-gluc}\))

Tissue Compartments

- \( Q_e \) (Exchangeable \(^{18}\text{F-FLT}\))
- \( Q_m \) (\(^{18}\text{F-FLTMP}\), \(^{18}\text{F-FLTDP}\), \(^{18}\text{F-FLTTP}\))

K₁, K₂, K₃, K₄

Graph showing signal over time.
Incorporation of MRI-AIF Information For Improved Kinetic Modelling of Dynamic PET Data

Hasan Sari, Student Member, IEEE, Kjell Erlandsson, Kris Thielemans, Senior Member, IEEE, David Atkinson, Sebastien Ourselin, Simon Arridge, and Brian F. Hutton, Senior Member, IEEE

Abstract—In the analysis of dynamic PET data, compartmental kinetic analysis methods require an accurate knowledge of the arterial input function (AIF). Although arterial blood sampling is the gold standard of the methods used to measure the AIF, it is usually not the part of a nuclear medicine examination. In this work, we try to improve SIME, by utilizing an input function derived from a simultaneously obtained DSC-MRI scan. With the assumption that the true value of one of the six-parameter PET-AIF model can be derived from an MRI-AIF, the method is tested using simulated data. The results indicate that SIME can yield more robust results when the MRI information is included with a significant reduction in absolute bias of $K_i$ estimates.

Index Terms—Arterial input function, magnetic resonance imaging, noninvasive measurement, positron emission tomography.

$C_P(t) = (A_1 t - A_2 - A_3)e^{-\lambda_1 t} + A_2 e^{-\lambda_2 t} + A_3 e^{-\lambda_3 t}$

highly invasive and labour intensive. For this reason, a number of alternative methods have been proposed to accurately measure the input function. One method is the use of standardized, normalized, and input functions of volunteer, which is obtained from a group taking one injection-based input function, which may not always be valid. Input functions of different individuals, or different groups, will always have some shape discrepancies, which may cause errors in parameter estimation. In addition, to our knowledge, this method has only been applied to 2-deoxy-2-[\textsuperscript{18}F] fluoro-D-glucose (FDG) studies, so has limited usage with other tracers. A third method is to obtain image-derived input functions (IDIF) [5] where the voxels corresponding to arteries, or heart, are defined on PET images, and the mean concentration within that region is computed over
Opportunities (II)
Exploiting tissue similarities

MRI: Vp, CBF, PS, EEV

PET: Vp, K1, k2, k3, k4

PET-MRI: Vp, CBF, PS, EEV, K1, k2, k3, k4

4+5 = 8!
Developing a combined contrast kinetic model in heart failure using hybrid PET/MRI

Benjamin Wilk², Jonathan Thiessen¹, Jane Sykes¹, Gerald Wisenberg¹, John Butler¹, Michael Kovacs¹, Robert Thompson¹ and Frank Prato¹

Abstract

Objectives A kinetic model for combined contrast with a constant infusion of Gd-DTPA and 18F-FDG might help determine the extent of fibrosis and inflammation in the heart after myocardial infarction, and overcome of lack of penetration of tracer following bolus injection into zones of very compromised flow. We followed the progression of inflammation after cardiac infarction from baseline to 40+ days in a well-characterized large animal model wherein 18F-FDG uptake by macrophages serves as a surrogate marker of inflammation [1,2]. Initial attempts to model both Gd-DTPA and 18F-FDG-PET have been limited to either separate acquisitions [3] or static analysis [4] of late gadolinium enhancement and 18F-FDG uptake in MI.

Methods To study the early stages of heart failure, the left anterior descending coronary artery was permanently occluded in four bred-for-research hounds. Using 20% lipid infusion, the normal myocardial uptake of 18F-FDG was
A Joint Estimation Method for Kinetic Modeling of Simultaneously Acquired PET/MRI Signals

Moses Q. Wilks, Xiaomeng Zhang, Jinsong Ouyang, Georges El Fakhri, Nathaniel M. Alpert, Quanzheng Li.

At the IEEE Medical Imaging Conference, a method was developed to use simultaneously acquired PET and MRI data to improve kinetic modeling in cases of tumor growth. A 4×4×5 cm region of interest was used, and imaging was done with a 1.5 T scanner using standard techniques (PET Alone, PET ADMM, H2O). A 5×5×5 cm region of interest was also used, and a H2O scan was performed. PET alone was not sufficient to retrieve all the necessary biological information.
MRI-PET joint kinetic model-driven reconstruction