Kernel SIME: simultaneous estimation of blood input function using a kernel method and its evaluation with total-body PET

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Introduction

- Dynamic PET allows quantification of physiological parameters through kinetic modeling. **Blood input function is essential for accurate kinetic parameter estimation**.
- Image-derived input function (ID-IF) and optimization-derived input function (OD-IF) are two noninvasive input functions. However, **ID-IF suffers from partial volume effect** when major blood pools are not covered in the field of view. **OD-IF from simultaneous estimation (SIME) method is not stable due to the ill-posedness of the problem**.
- In this work, we proposed a kernel SIME method that incorporates ID-IF as a *priori* information for joint estimation of OD-IF and kinetic parameters.

Method

Conventional SIME

- Given time activity curves (TACs) $c(t)$ measured from different regions, SIME seeks to jointly estimate kinetic parameters θ and input function $u(t)$:

$$\hat{\theta}, \hat{u} = \arg\min_{\theta,u} \Phi(\theta, u),$$

$$\Phi(\theta, u) = \sum_{j,m} \left(h_j(t_m, \theta_j) \otimes u(t_m) - c_j(t_m)\right)^2,$$

where $h(t, \theta)$ is the response function of compartment model.

Kernel SIME

- 1D feature maps $\boldsymbol{f}$ are extracted from ID-IF to build a kernel matrix, with (m, n)th element as

$$\kappa_{IDIF}(\boldsymbol{f}_m, \boldsymbol{f}_n) = \exp\left(-\frac{\|\boldsymbol{f}_m - \boldsymbol{f}_n\|^2}{2\sigma}\right).$$

- Input function can be described using kernel representation:

$$u_m = \sum_n \alpha_n \kappa_{IDIF}(\boldsymbol{f}_m, \boldsymbol{f}_n).$$

- Kernel SIME jointly estimates θ and kernel coefficient α

$$\hat{\theta}, \hat{\alpha} = \arg\min_{\theta,\alpha} \Phi(\theta, \alpha).$$

Validation on EXPLORER dataset

- 10 subjects were scanned on uEXPLORER total-body PET/CT with ^{18}F-FDG for an hour.
- Three brain regions of interest (ROIs) were placed, including gray matter (GM), white matter (WM), and cerebrospinal fluid (CSF), to extract TACs for joint estimation.
- ID-IF extracted from carotid artery was used to build the kernel matrix.
- TAC extracted from the descending aorta was used as the reference input function for comparison.
- The activity of the last time point was scaled to the reference IF to overcome the scaling problem.
- Methods for comparison:
  - Kernel SIME
  - Conventional SIME
  - Carotid artery ID-IF

Results

- Kernel SIME generates OD-IF that better matches with the reference IF and more accurate kinetic parameters compared to other two methods.

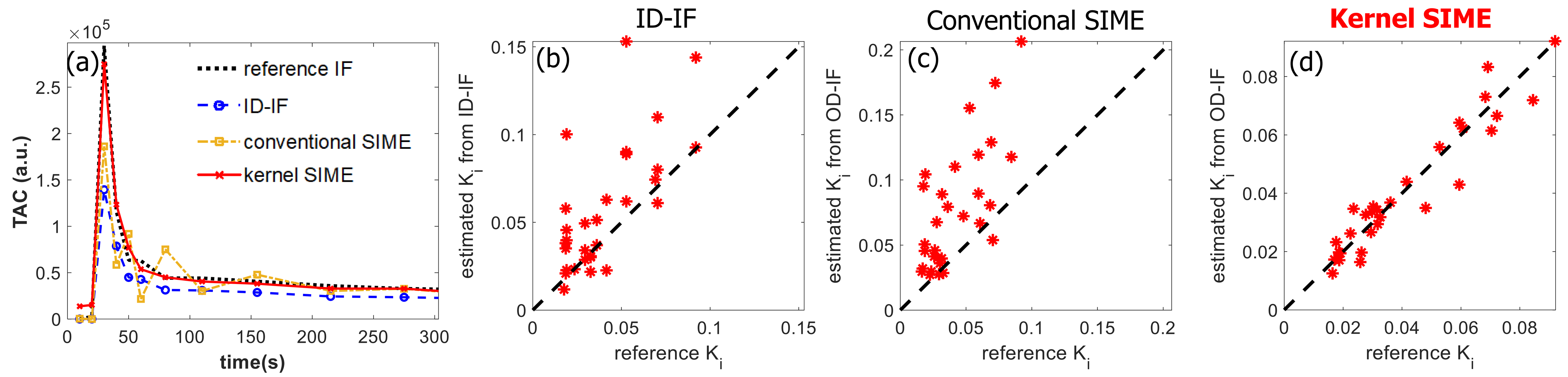

Fig. 1: (a) Example of estimated input functions for different methods. (b)-(d) Plots of estimated K_i for different methods. Black dashed line indicates the idea case that the estimated K_i is equal to reference K_i.

- Quantitative evaluation indicates kinetic parameters from kernel SIME have higher correlation coefficient and lower mean absolute errors.

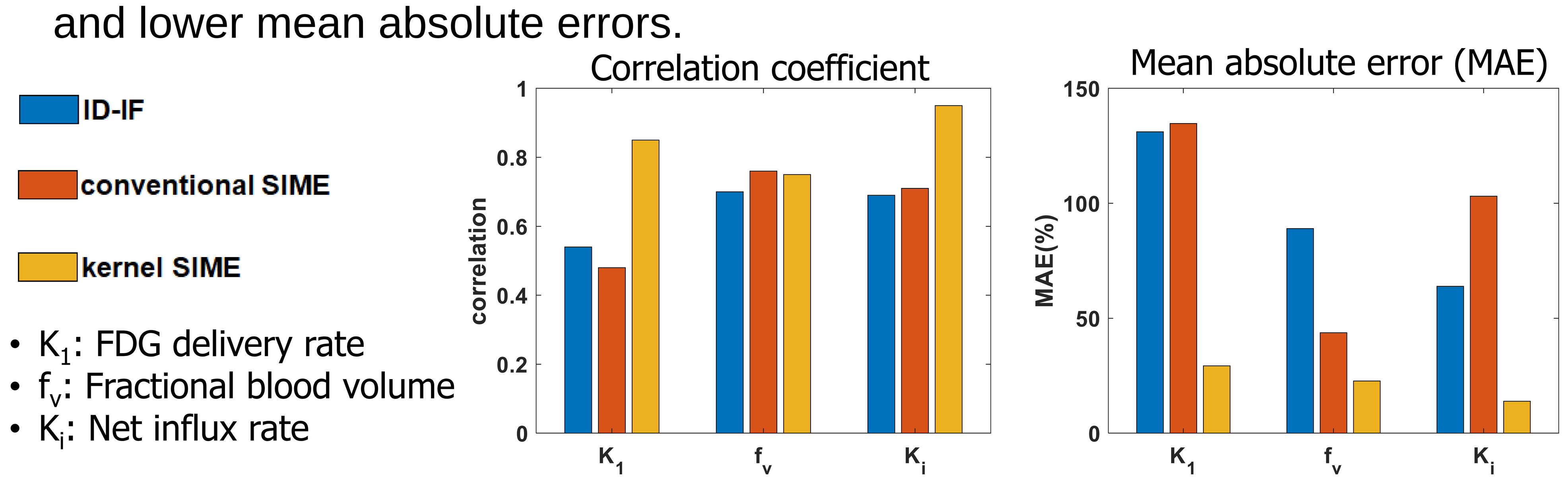

Fig. 2: Correlation coefficients (left) and mean absolute errors (right) of estimated kinetic parameters.

- OD-IF from kernel SIME generates similar parametric images as those from reference IF.

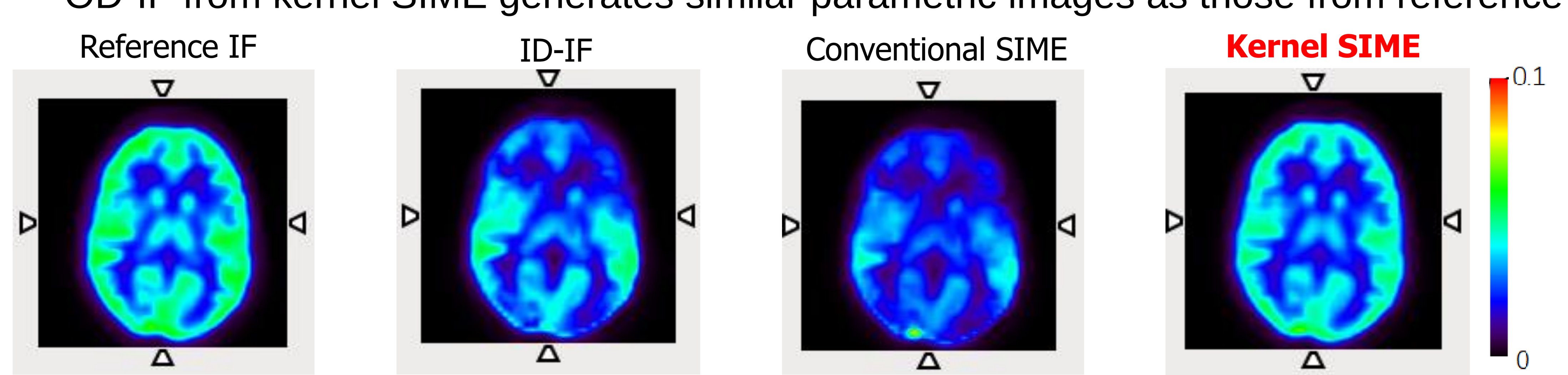

Fig. 3: Estimated Ki images with input functions from different methods.

Summary

For estimated input function:

- Compared to carotid artery ID-IF, OD-IF by our proposed kernel SIME shows improved peak estimation and matches better with reference IF.
- Compared to conventional SIME, kernel SIME generates a more stable OD-IF.

For estimated kinetic parameters:

- Kernel SIME shows more accurate estimation on kinetic parameters compared to conventional SIME and carotid artery ID-IF.

Conclusions/Further Study

Conclusion:

We developed and investigated a kernel SIME method to obtain OD-IF. Evaluation on total-body patient datasets indicate the method enables more accurate estimation of input function and kinetic parameters. Our method could be potentially applied on dynamic imaging for brain, head & neck and rectal cancer that major blood pools are not covered using conventional short PET scanner.

Future study:

- We will study the influence of temporal resolution and number of TACs for joint estimation on the performance of the proposed kernel SIME.
- We will validate the proposed method on different tracers other than ^{18}F-FDG.

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