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Parametrised Dynamic Contrast-Enhanced MRI through Implicit Neural Representations

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Introduction

Dynamic contrast-enhanced MRI (DCE MRI) enables non-invasive assessment of tissue perfusion and vascular permeability through kinetic modelling of contrast agents. The extended Tofts model describes tissue microvasculature via kinetic parameters: volume transfer constant, rate constant, intravascular volume fraction, and extracellular volume fraction. Conventional curve fitting (CF) is computationally intensive and noise-sensitive, while deep neural networks require large datasets. We hypothesise that implicit neural representations (INRs) achieve equivalent accuracy to CF with improved spatial coherence, without population-level training data.

Methods

A light-weight neural network (SIREN, Gaussian Fourier Features encoding) maps spatial coordinates to voxel-wise Tofts parameters by minimising MSE between model-predicted and measured concentration-time curves, requiring no ground-truth parameter maps. Iliac artery (for image-derived input function), prostate and tumour segmentations were obtained from co-registered PET/CT images and refined by a medical expert, with DCE MRI volumes aligned to the CT via a multi-stage deformable registration pipeline. Retrospective evaluation data included 13 patients with histopathologically confirmed prostate cancer (local ethics committee approved).

Results

INR-based estimation achieved reconstruction accuracy equivalent to CF in both prostate and tumour regions ($p \gg 0.05$). Despite CF yielding numerically lower mean MSE (prostate INR: 0.0071 ± 0.005 vs. CF 0.0052 ± 0.004; tumour: INR 0.0090 ± 0.008 vs. CF 0.0063 ± 0.005), parameter maps were smoother for INR in the prostate ($p \leq 0.003$) with Laplacian energy reduced by 3–70× and consistently higher Moran's I across all parameters (range: INR 0.84–0.86 vs. CF 0.70–0.79). INR inference was ~7 times faster than CF (INR: 39.4 ± 14.0 s; CF: 293.2 ± 163.0 s).

Conclusion

Our findings demonstrate the potential of INRs for personalised, data-efficient, spatially coherent kinetic modelling in DCE MRI. The proposed framework operates on single-patient acquisitions, producing high-resolution smooth kinetic parametric images, and offers a computationally tractable alternative to CF.

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