Deep learning improves the quality of IVIM-derived microstructural integrity, interstitial fluid and microvascular perfusion images

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Introduction

Intravoxel incoherent motion (IVIM) MRI can measure several cerebral diffusion components, such as the parenchymal diffusivity (D_{par}, a measure for microstructural integrity), the interstitial fluid diffusivity (D_{int}) and microvascular perfusion (D_{mv}). Previous studies demonstrated the potential of estimating these diffusion components in the brain, as their region-averaged values were found to be associated with both cerebrovascular and neurodegenerative diseases.[1-3] However, voxel-wise estimation of these diffusion components using the conventional least-squares (LSQ) fitting approach is highly susceptible to image noise and results in poor quality of the diffusivity-related maps. To derive repeatable and high-quality diffusivity-related maps, we explored physics-informed neural networks (PI-NNs) – an emerging type of deep learning – as a novel IVIM fitting approach.[4]

Methods

IVIM imaging was performed twice on sixteen patients with cerebrovascular disease. The IVIM model was fitted to the voxel-wise IVIM signal curves to obtain D_{par}, D_{int}, D_{mv} (and the corresponding volume fractions f_{int} and f_{mv}, respectively) using the novel PI-NN approach and the LSQ method as baseline for comparison. The quality of the IVIM parameter maps was assessed by the IVIM parameter-contrast-to-noise-ratio (PCNR) between normal-appearing white matter (NAWM) and white matter hyperintensities (WMHs). The test-retest repeatability of brain-averaged IVIM parameters was quantified using the within-subject coefficient of variation (CV).

We used paired Wilcoxon signed-rank tests to test statistical differences in PCNR of the PI-NN maps versus the LSQ maps, and in CV using PI-NN versus CV using LSQ.

Results

The PI-NN parameter maps appeared smoother and had significantly higher PCNR compared to LSQ parameter maps (all p=0.001). Furthermore, the PI-NN method achieved higher test-retest repeatability than LSQ, as PI-NN CVs were lower for all IVIM parameters compared to LSQ CVs (D_{par}: p=0.039, D_{int}: p=0.039, D_{mv}: p=0.001, f_{int}: p=0.008, and f_{mv}: p=0.039).

Conclusion

The PI-NN fitting approach outperforms the conventional LSQ fitting approach in terms of IVIM parameter map quality and test-retest repeatability. The high-quality parameter maps generated with PI-NNs allow for visual evaluation of neurodegenerative (D_{par}), neuroinflammatory (D_{int}, f_{int}), and neurovascular (D_{mv}, f_{mv}) processes within the brains of patients. Retrieving these tissue features precisely on a voxel-wise basis brings IVIM imaging closer to clinical implementation.

References

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