Using Deep Learning Reconstruction to Support the Clinical Adoption of Submillimeter Neuroimaging at 7 Tesla

Jocelyn Philippe[1,2,3], Gabriele Bonanno[4,5,6], Kevin Battistini[7], Caterina Bernetti[7], Roland Wiest[4,8], Marwan El-Koussy[8], Natalia Pato Montemayor[1,2,3], Dominik Nickel[9], Patrick A. Liebig[9], Robin M. Heidemann[9], Felix T. Kurz[7], Jean-Philippe Thiran[2,3], Tom Hilbert[1,2,3], Tobias Kober[9], Gian Franco Piredda[1], Thomas Yu[1,2,3] *, Piotr Radojewski[4,8] *

[1] Swiss Innovation Hub, Siemens Healthineers International AG, Lausanne, Switzerland
[2] Department of Radiology, Lausanne University Hospital and University of Lausanne, Switzerland
[3] LTS5, École Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland
[4] Translational Imaging Center (TIC), Swiss Institute for Translational and Entrepreneurial Medicine, Bern, Switzerland
[5] Swiss Innovation Hub, Siemens Healthineers International AG, Bern, Switzerland
[6] Magnetic Resonance Methodology, Institute of Diagnostic and Interventional Neuroradiology, University of Bern, Switzerland
[7] Division of Neuroradiology, University Hospitals of Geneva, Switzerland
[8] Support Center for Advanced Neuroimaging, Institute for Diagnostic and Interventional Neuroradiology, Inselspital, University of Bern, Switzerland
[9] Magnetic Resonance, Siemens Healthineers AG, Erlangen, Germany

* Authors contributed equally to the manuscript.

Abstract

Ultra-high-field magnetic resonance imaging (at 7 Tesla and above) enables submillimeter spatial resolution that creates new opportunities for detailed neuroanatomical assessment and lesion characterization. However, long acquisition times are a major barrier to routine clinical use. In this article, we illustrate how deep learning-based reconstruction enables higher acceleration of high-resolution brain imaging while preserving diagnostic image quality and thereby supporting the broader clinical usability of 7T MRI.

Introduction

Ultra–high-field magnetic resonance imaging (UHF MRI) at 7 Tesla (7T) is increasingly transitioning from a research tool to a clinically relevant modality, with specialized centers progressively integrating UHF MRI into routine neuroradiological workflows [1]. This evolution is mainly being driven by substantial improvements in spatial resolution enabled by the increased signal-to-noise ratio at 7T [2]. These improvements have demonstrated clinical value across multiple neurological conditions [1, 3]. Submillimeter-resolution imaging at 7T improves the visualization of cortical and juxtacortical lesions in multiple sclerosis, facilitates the detection of subtle epileptogenic abnormalities, and enhances the assessment of small-vessel pathologies such as cerebral microbleeds and of perivascular spaces [1, 4, 5]. Collectively, these advances have expanded the diagnostic scope of neuroimaging and have motivated the adoption of 7T MRI for targeted clinical indications.

However, the practical use of UHF MRI in routine clinical settings is constrained by long acquisition times, particularly for high-resolution three-dimensional sequences. Achieving submillimeter isotropic resolution often requires five to ten minutes of scanning. This increases sensitivity to patient motion and limits robustness in everyday clinical practice. Even with optimized protocols, scan duration remains a critical bottleneck that restricts broader clinical adoption and complicates the acquisition of larger patient cohorts.

Recent advances in deep learning (DL)-based reconstruction offer new opportunities to address these limitations. By integrating data-driven priors directly into the reconstruction process, DL-based techniques have the potential to enable higher acceleration while preserving image quality [6], which would shorten acquisition times and improve the clinical usability of UHF neuroimaging.

In this article, we illustrate how integrating DL reconstruction into a clinical 7T workflow can help unlock the full potential of submillimeter brain imaging, bringing UHF MRI closer to routine clinical application.

Materials and methods

Forty-five patients with various pathologies (e.g., multiple sclerosis, tumor, epilepsy) were scanned at 7T using a MAGNETOM Terra system (Siemens Healthineers, Erlangen, Germany) with a 1Tx32Rx head coil (Nova Medical, Wilmington, MA, USA). As part of the clinical protocol at the enrolled institution, a 0.6 mm isotropic three-dimensional T1-weighted MP2RAGE sequence [7, 8] (matrix size, 384 × 256 × 384; repetition time, 6000 ms; inversion times, 800 ms and 2700 ms; echo time, 2.06 ms; acquisition time, 7:40 min) was acquired with a sparse undersampling pattern and an acceleration factor of R = 4.

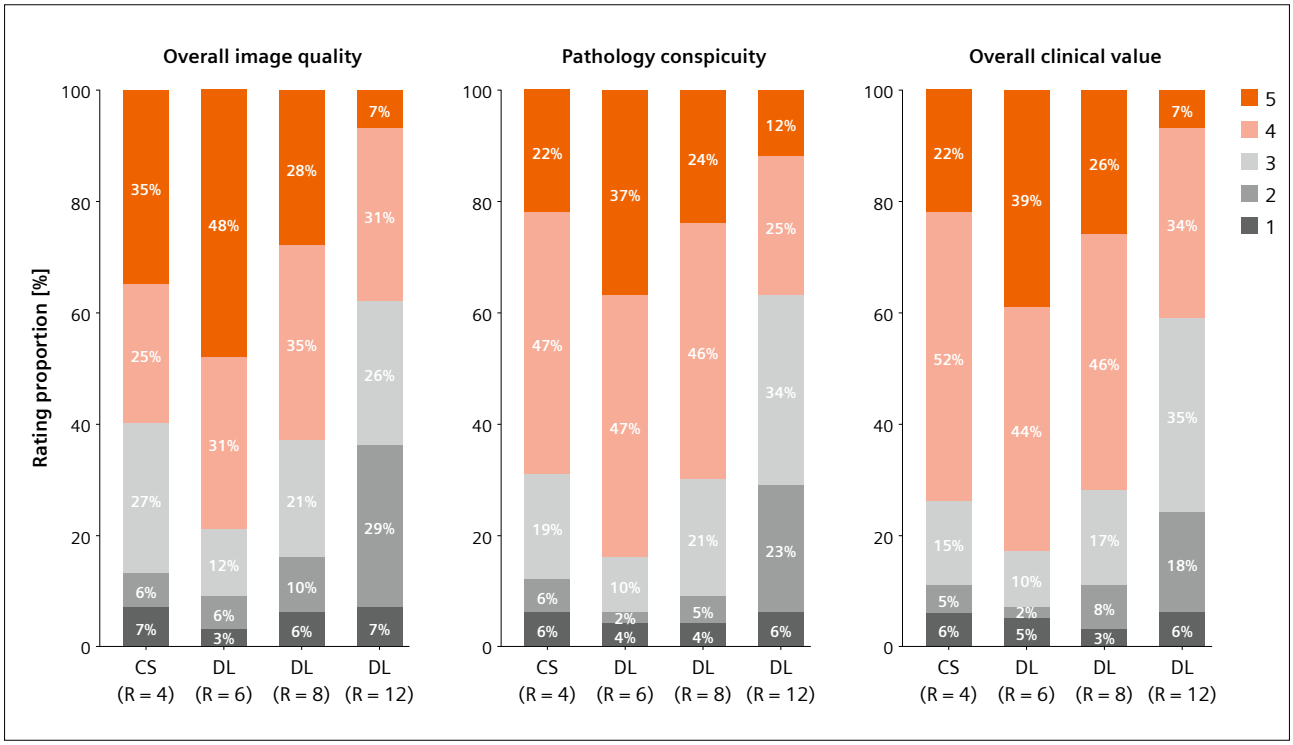
Each acquisition was retrospectively undersampled to simulate acceleration factors of R = 6 (5:06 min), R = 8 (3:50 min), and R = 12 (2:33 min). The original acquisition was reconstructed with compressed sensing (CS) [9] following the institution's clinical protocol. The retrospectively undersampled datasets were reconstructed with a DL-based method [10]. Three radiologists (P.R., K.B., and C.B., with seven years, two years, and one year of experience with UHF brain images, respectively) used a five point Likert scale (1 = very poor, 2 = poor, 3 = adequate, 4 = good, 5 = very good) to rate all the images for overall image quality, pathology conspicuity, and overall clinical value.

Results

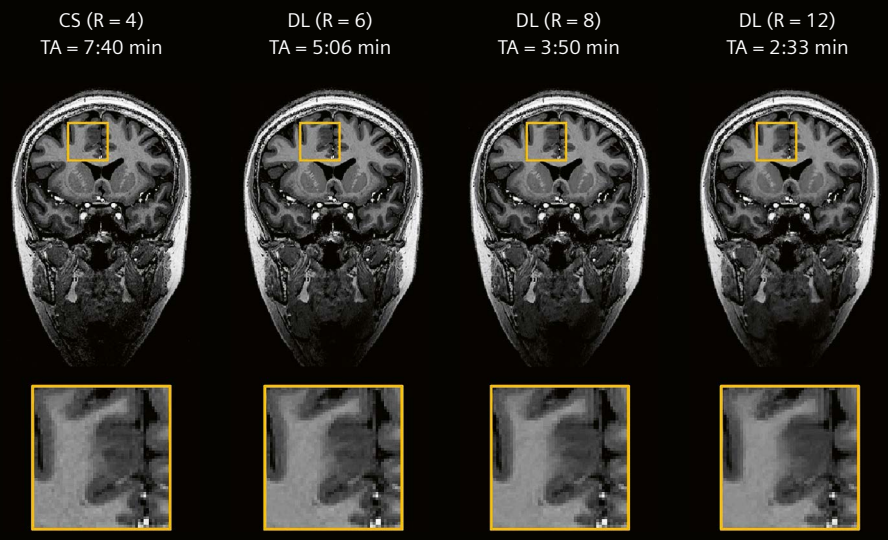
Figure 1 presents the distribution of ratings in the four reconstructions (CS with R = 4, and DL with R = 6, 8, and 12) pooled across radiologists. Images reconstructed with DL at R = 6 exhibit statistically significant improvements over the clinical CS reconstruction in all three evaluation criteria. At R = 12, DL performs significantly worse in the three criteria. No statistically significant differences were found between DL reconstruction at R = 8 and CS at R = 4.

Figures 2–6 display representative patient cases, each with four reconstructions. These examples highlight the range of clinical appearances encountered in routine neuroimaging, including cases with subtle cortical abnormalities and fine structural detail. At moderately higher acceleration (R = 6 and R = 8), DL reconstruction consistently preserves anatomical detail, tissue contrast, and lesion morphology, closely matching the clinical reference reconstruction.

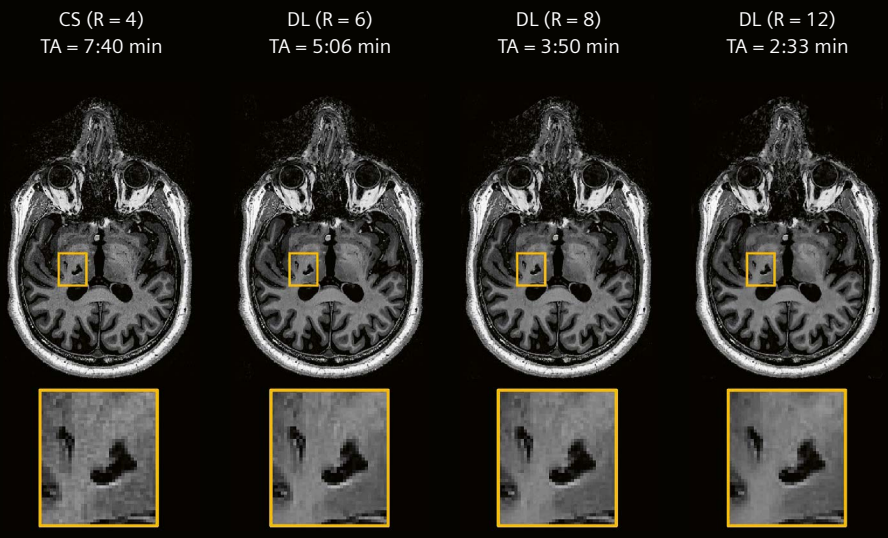
At the highest acceleration factor evaluated here (R = 12), image degradation can become apparent, underscoring the importance of balancing acceleration with diagnostic robustness. Collectively, these cases illustrate that DL-based reconstruction enables substantially higher acceleration than conventional compressed sensing and preserves clinically meaningful image quality for submillimeter 7T neuroimaging.



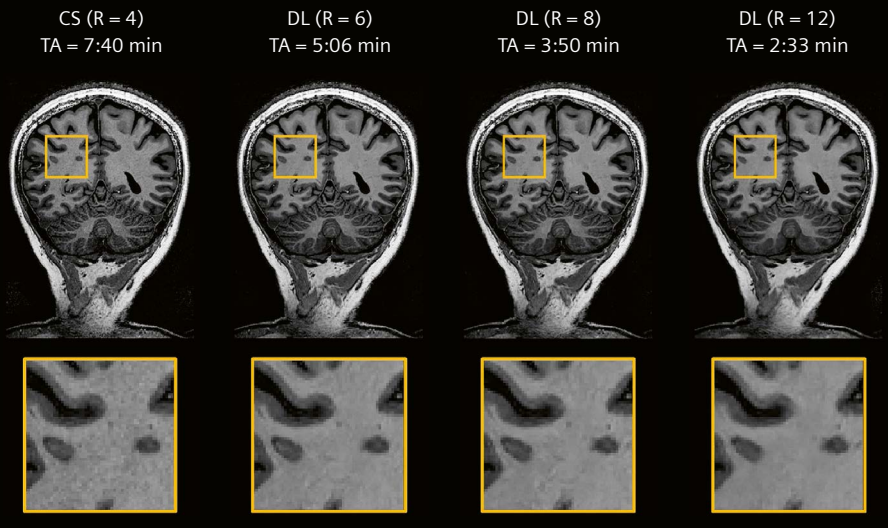
1 Distribution of ratings across reconstruction methods for the three evaluation criteria. Ratings from the three radiologists were pooled. CS = compressed sensing; DL = deep learning



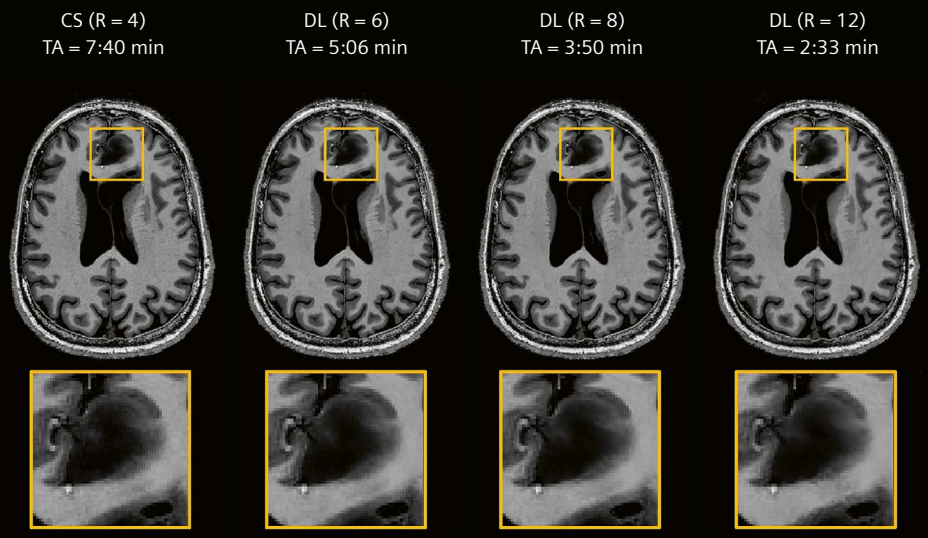
2 T1-weighted MP2RAGE reconstructed images in coronal view of a patient with epilepsy caused by a suspected glioneuronal tumor (WHO Grade 1). DL reconstruction at R = 6 and 8 exhibits a similar level of detail as the compressed sensing image (CS at R = 4).



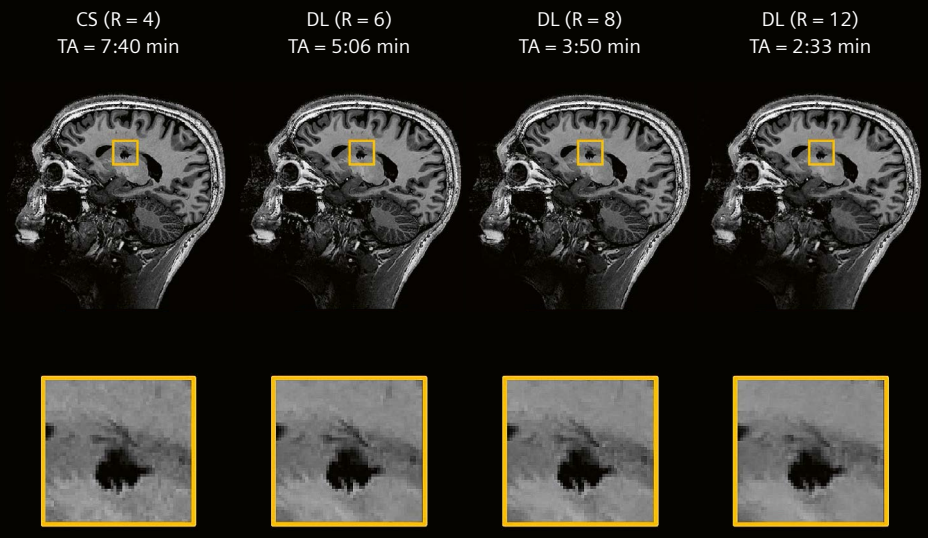
3 T1-weighted MP2RAGE reconstructed images in axial view of a patient with brain hemorrhages. DL-reconstructed images show similar levels of hemorrhage delineation as the compressed sensing image (CS at R = 4).



4 T1-weighted MP2RAGE reconstructed images in coronal view of a patient with multiple sclerosis (MS). Lesion conspicuity in images reconstructed with the DL method at R = 6 or 8 is similar to the compressed sensing image (CS at R = 4), while fine structures start to be smoothed out at R = 12.



5 T1-weighted MP2RAGE reconstructed images in axial view of a patient with a tumor in the frontal lobe. At the three acceleration factors, the images reconstructed with DL achieve similar image quality and sharpness in the tumor's border as the compressed sensing image (CS at R = 4).



6 T1-weighted MP2RAGE reconstructed images in sagittal view of a patient with vasculitis. At R = 6 and 8, DL reconstruction preserved the sharpness of the ischemic lesion and its surroundings.

Discussion

Submillimeter-resolution imaging is one of the defining strengths of 7T MRI, yet its clinical impact is often limited by long scan times and sensitivity to motion. By enabling higher acceleration without sacrificing diagnostic confidence, DL reconstruction directly addresses a key bottleneck in translating high-resolution imaging into routine clinical practice.

The evaluation presented here demonstrates that DL reconstruction maintains lesion conspicuity and image quality at acceleration levels beyond those typically used in clinical 7T protocols. By reducing the practical barriers associated with long acquisitions, DL-based reconstruction methods may facilitate larger clinical studies, improve patient tolerance, and ultimately broaden access to submillimeter UHF neuroimaging.

Conclusion and outlook

Deep learning (DL) reconstruction enables higher acceleration of submillimeter 7T brain imaging while preserving clinical image quality and diagnostic confidence. By reducing acquisition time constraints, DL-based reconstruction techniques support the broader clinical usability of UHF neuroimaging and help unlock its full diagnostic potential.

Looking ahead, integrating DL reconstruction into routine clinical protocols will be a promising step toward making high-resolution neuroimaging more accessible and practical. As AI-based reconstruction technology continues to evolve, such approaches are poised to play a central role in the development of the next generation of clinical 7T MRI systems.

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Jocelyn Philippe, M.Sc.

Thomas Yu, Ph.D.

Piotr Radojewski, M.D.

Contact

PD Dr. Piotr Radojewski, M.D.
Translational Imaging Center (TIC)
Swiss Institute for Translational and Entrepreneurial Medicine
Freiburgstrasse 3
3010 Bern
Switzerland
piotr.radojewski@insel.ch