Diffusion-Weighted Imaging of the Brain with Isotropic Resolution using *syngo* RESOLVE with GRAPPA and SMS

Thomas Illigen; Christian Söldner, Ph.D.

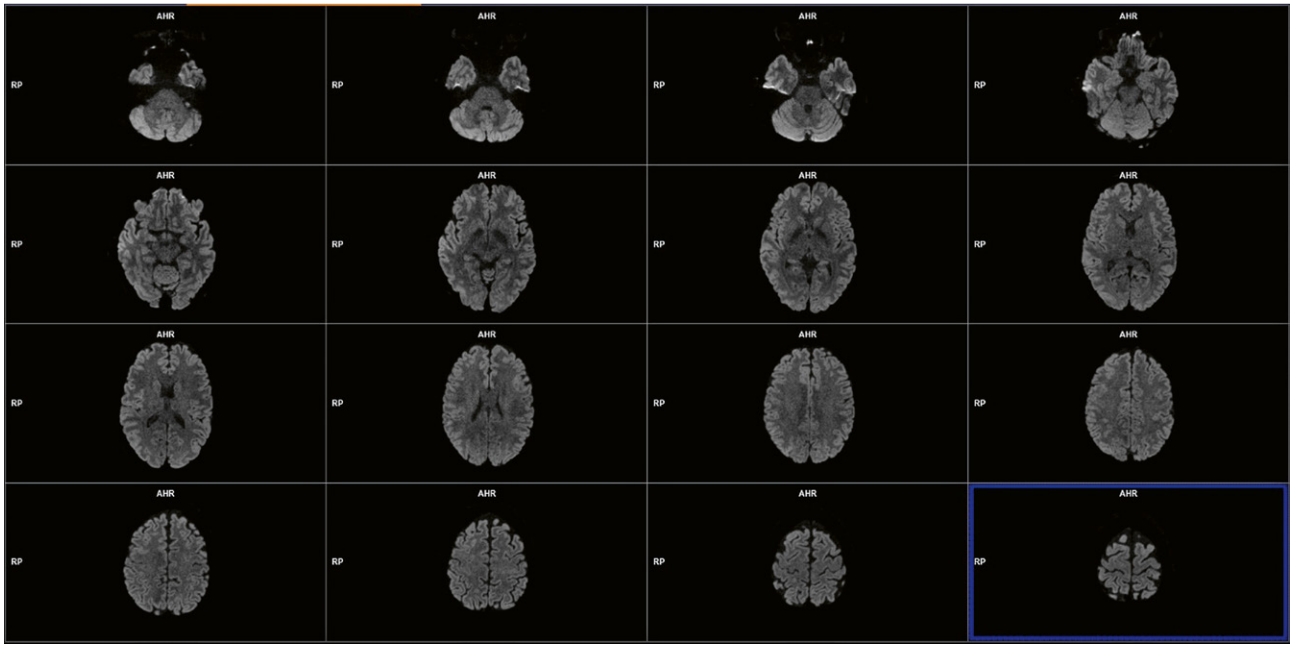
Siemens Healthineers, Erlangen, Germany

Introduction

Readout-segmented echo-planar imaging (RESOLVE) produces sharp diffusion-weighted images with high spatial resolution, while GRAPPA (GeneRalized Autocalibrating Partially Parallel Acquisition) and Simultaneous Multi-Slice (SMS)[1] acquisition significantly reduce scan times in clinical MRI.

The clinical benefit of diffusion-weighted imaging (DWI) with isotropic resolution is the volumetric information, e.g., better grading of the progression of an epidermoid cyst, tumor, or stroke area. High resolution (1.1 mm isotropic) scanning will create severe susceptibility artifacts in single shot EPI. Therefore, RESOLVE is a good alternative, but would require very long scan times on systems with low gradient system configurations. With the 3T MAGNETOM Cima.X[2], the acquisition time for a RESOLVE sequence with an isotropic resolution of 1.1 mm will be reduced to under 10 minutes, making it applicable for clinical examinations.

[1]Simultaneous Multi-Slice (SMS) is part of the Turbo Suite Excelerate package or available as a single chargeable license.
[2]Work in progress: This product is still under development and not yet commercially available. Its future availability cannot be ensured.



1 RESOLVE with isotropic 1.1 mm resolution; b-value 1000 s/mm²; representative transverse slices show a very homogeneous DWI of the brain.

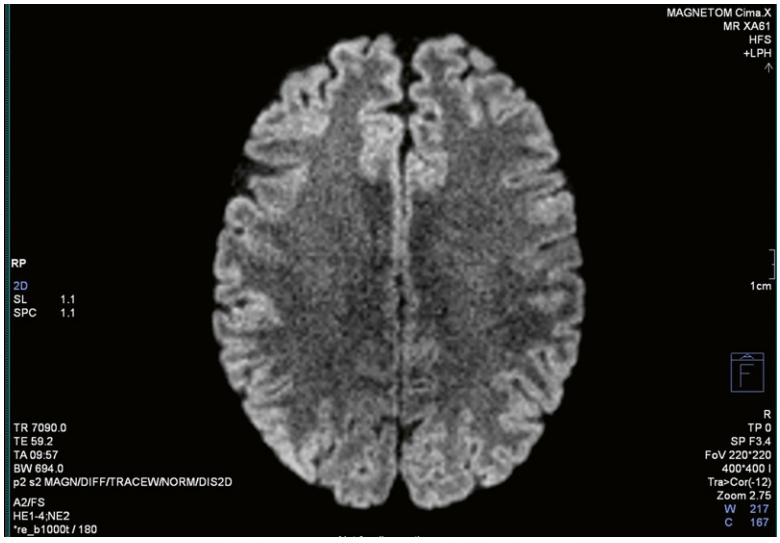
Material and methods

The shown RESOLVE sequence was set up with 7 segments, using GRAPPA (p) and SMS (s), both with an acceleration factor of 2, 100 slices, distance factor (DF) = 0,1 average for b-value 0 s/mm² (b0) and 2 averages for the b-value 1000 s/mm² (b1000), resulting in a scan time of 9:57 min (Fig. 2); acquisition was performed using the BioMatrix Head/Neck 20 coil (BM HN20).

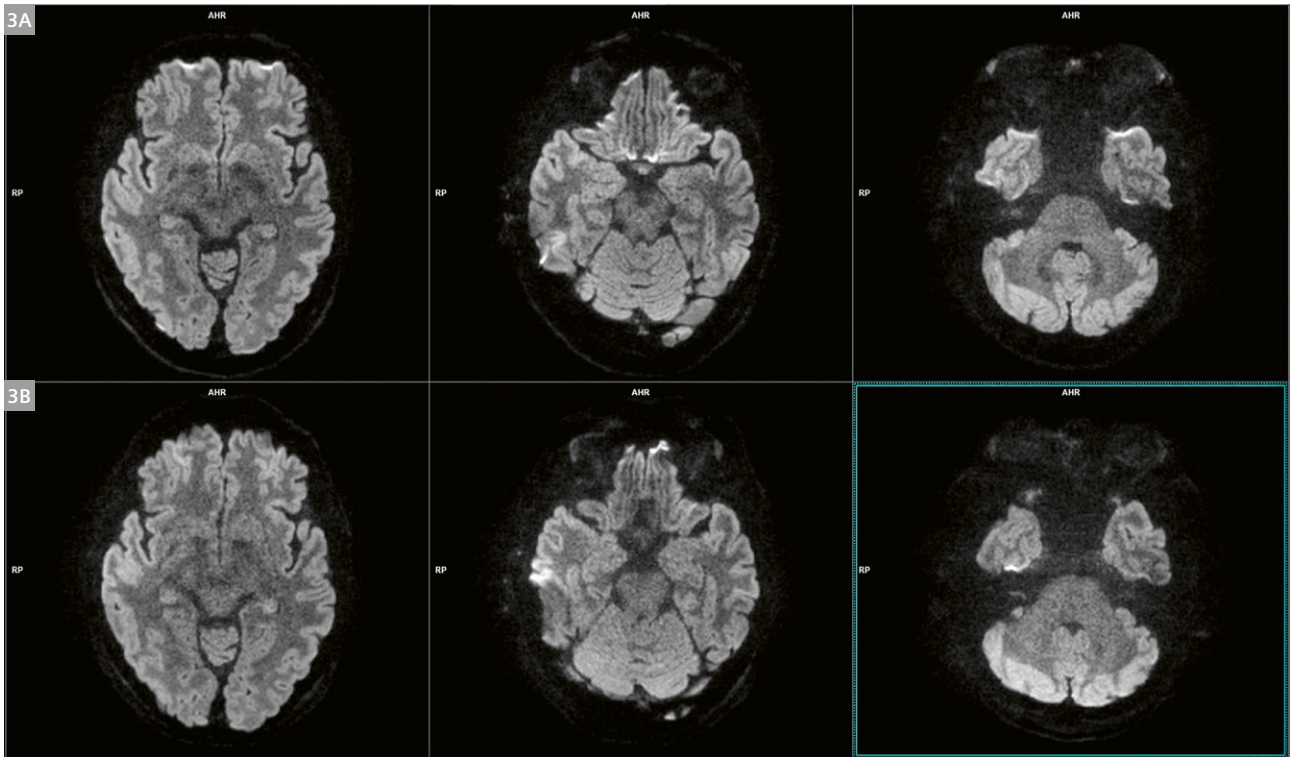
Our preference for the phase-encoding direction is posterior-anterior rather than anterior-posterior, since susceptibility artifacts in the mastoid and sella turcica regions are reduced. Also, the frontal lobe area benefits from this change. In any case, the choice of phase-encoding direction has to be considered (Fig. 3).

The expansion of susceptibility artifacts in the slice direction can be reduced by thinner slices, since this reduces the through-plane effect.

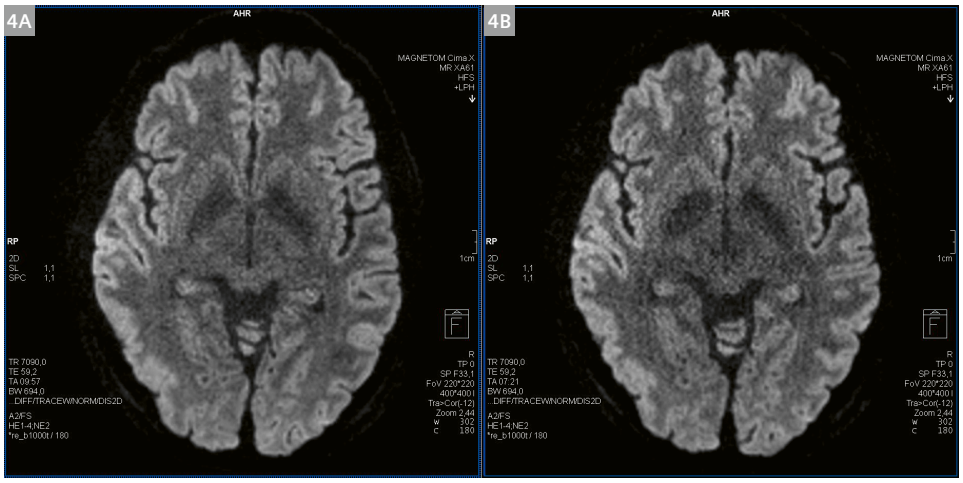
It might be tempting to further shorten the measurement time by using higher acceleration factors, such as p3 and/or s3, or readout partial Fourier, or the acquisition



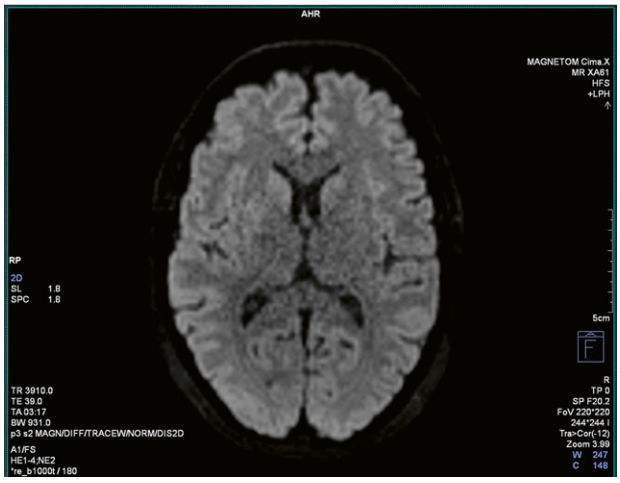
2 RESOLVE with isotropic 1.1 mm resolution; b1000 with TR 7090 ms and TE 59 ms, with an acquisition time of 9:57 minutes.



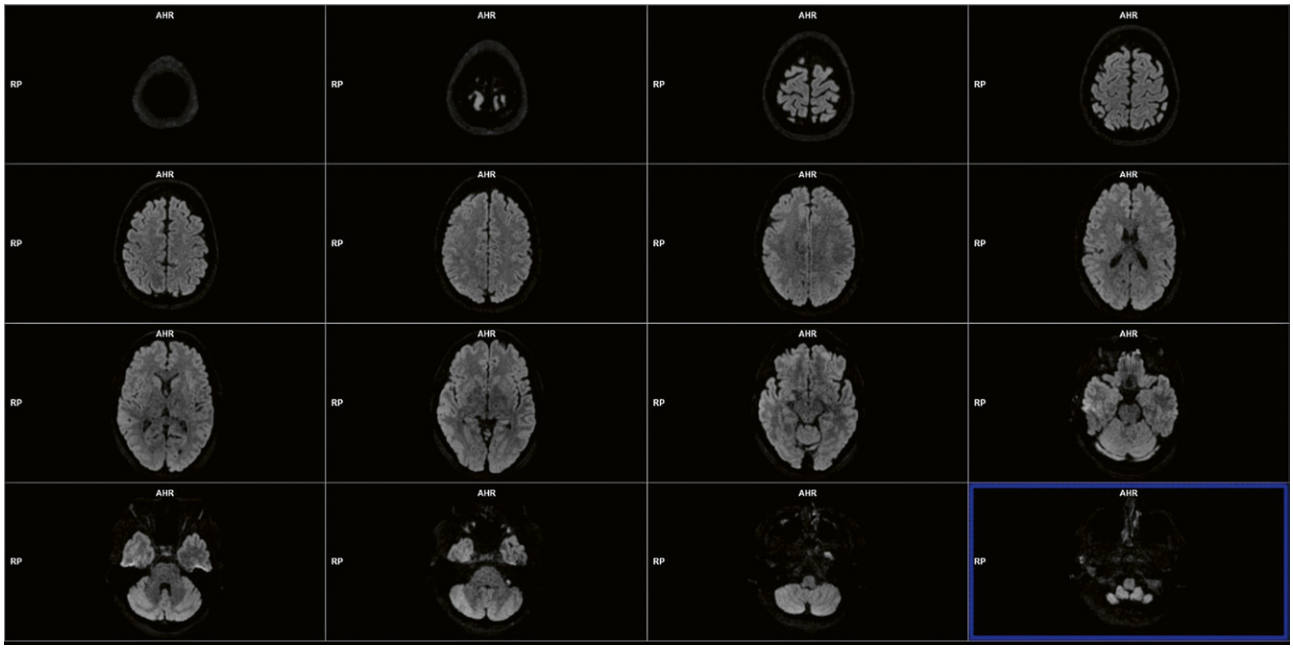
3 RESOLVE with isotropic 1.1 mm resolution, b-value 1000 s/mm², **(3A)** AP encoded; **(3B)** PA encoded – the areas most affected by susceptibility artifacts can be compared.



4 RESOLVE with isotropic 1.1 mm resolution; b-value 1000 s/mm²; without **(4A)** and with **(4B)** readout partial Fourier 6/8, respectively. 5 instead of 7 readout segments; TA: 9:57 minutes vs. 7:21 minutes.



5 RESOLVE with an isotropic resolution of 1.8 mm; b1000 image with TR 3910 ms, TE 39 ms, and an acquisition time of 3:17 minutes.

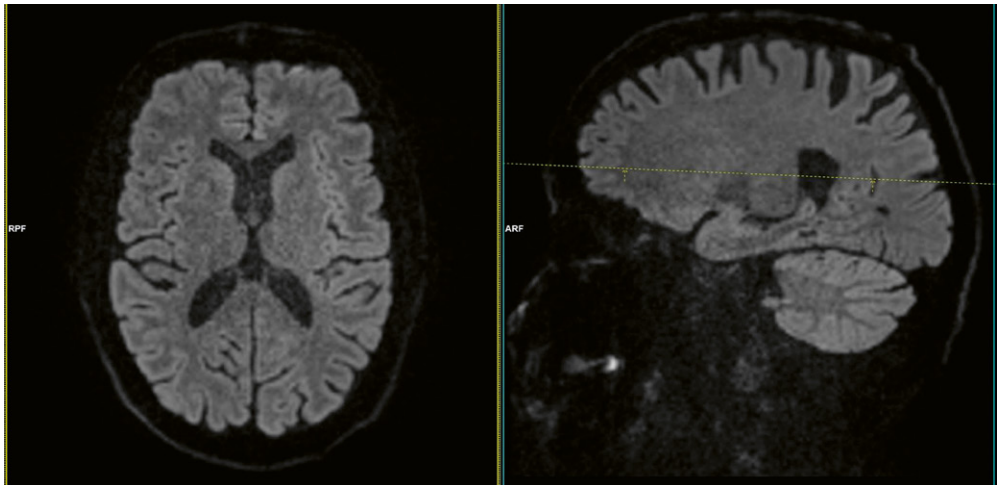


6 RESOLVE with an isotropic resolution of 1.8 mm; representative transversal slices of b1000 s/mm².

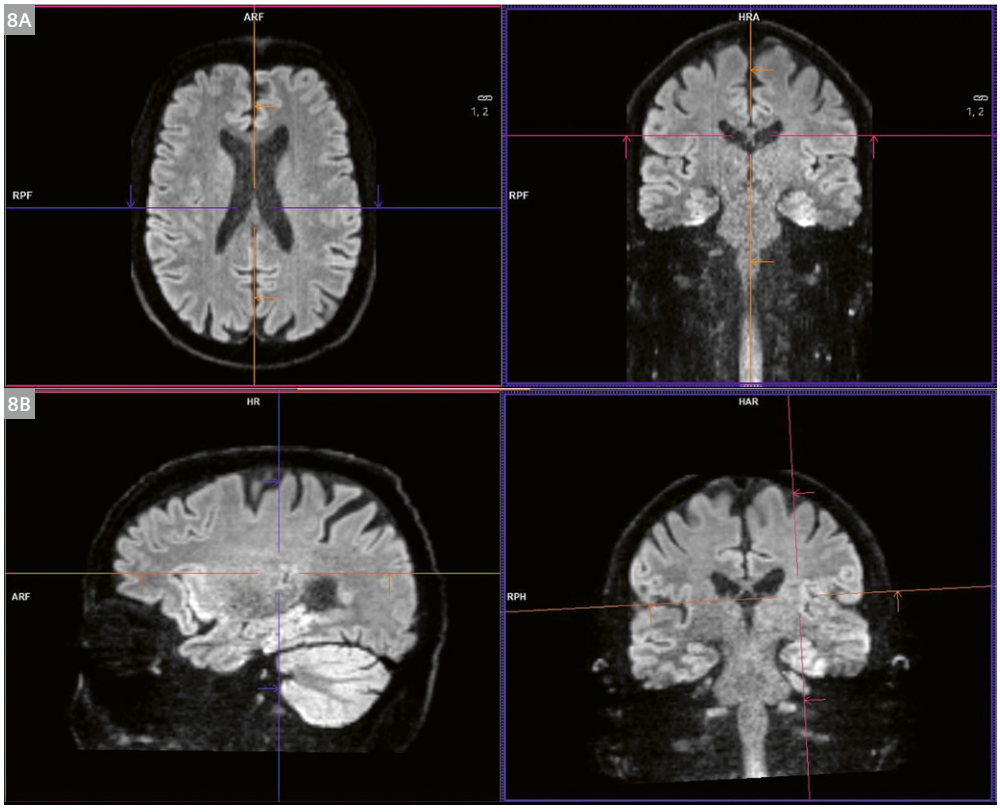
of fewer segments. All these methods reduce the scan time, indeed – but the resulting images suffer from less SNR (Figure 4 shows a comparison of 7 vs. 5 readout segments, using phase partial Fourier 6/8). Our preferred choice for the high isotropic resolution of 1.1 mm^3 is p2s2.

From a practical point of view, and to find the best compromise between resolution and acquisition time, our recommendation for clinical routine examinations would be a protocol with an isotropic resolution between 1.5 and 2 mm. With MAGNETOM Cima.X, the acquisition time for a RESOLVE with an isotropic resolution of 1.8 mm can be reduced to 3:17 minutes with p3s2, b0 and b1000, with one average each and 80 slices for whole-brain coverage (Figs. 5, 6).

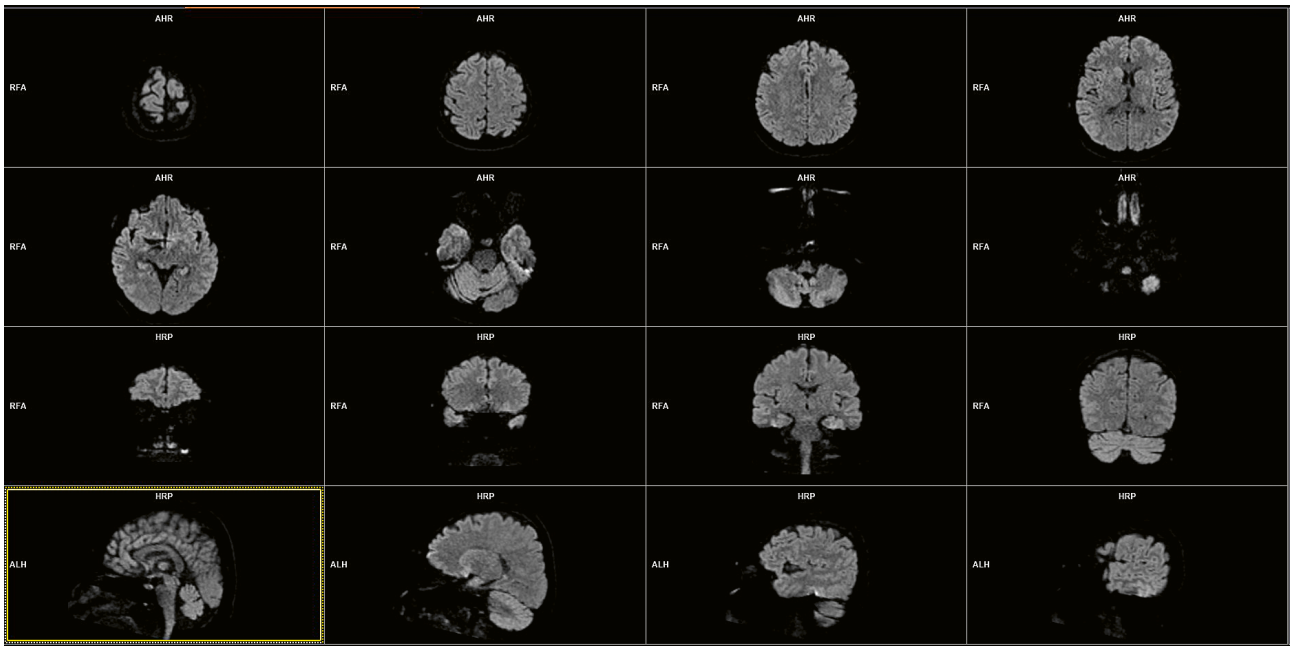
A possible approach might be to acquire the brain sagittally instead of transversally, since sagittal acquisition has the advantage that probably fewer slices are needed for whole-brain coverage. And as far as isotropic resolution is concerned, there should be no significant difference. Due to the weaker susceptibility effects at 1.5T the MRP reconstructions of the 1.5T scans show slightly better image quality than those of the 3T scans. However, the image quality of the acquired slices is very comparable (Figs. 7, 8).



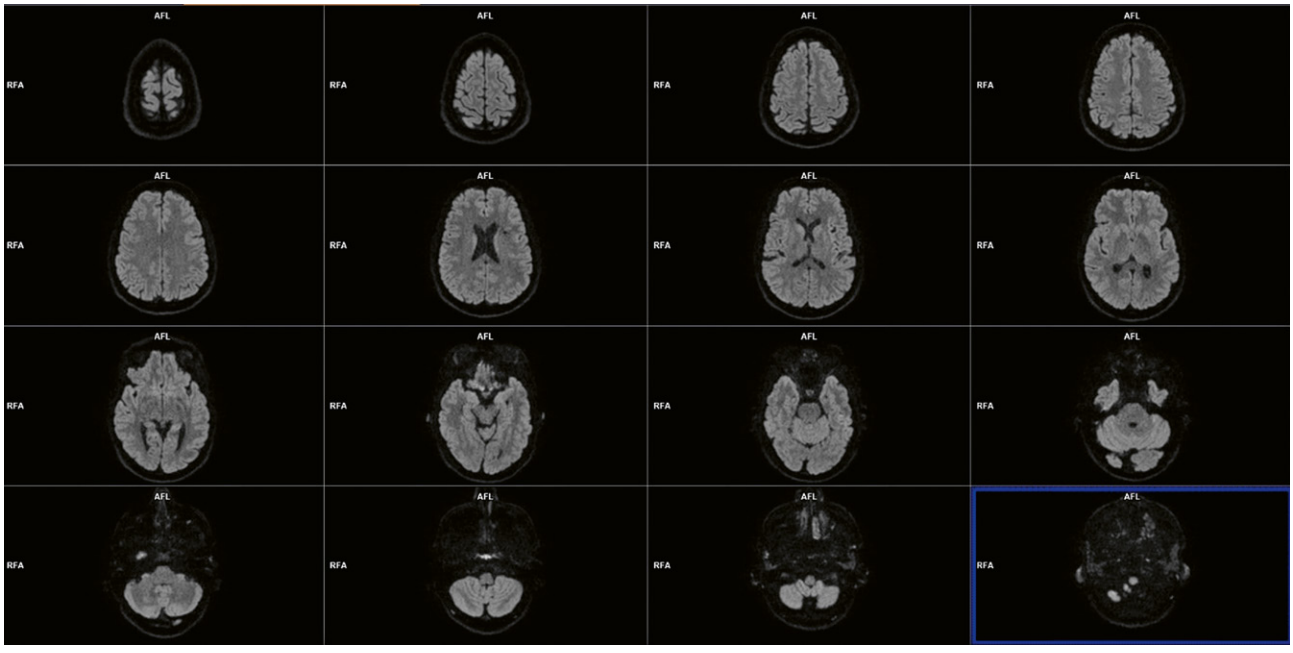
7 RESOLVE with an isotropic resolution of 1.5 mm; b-value 1000 s/mm^2 from 3T MAGNETOM Vida; representative transversally and sagittally acquired slices.



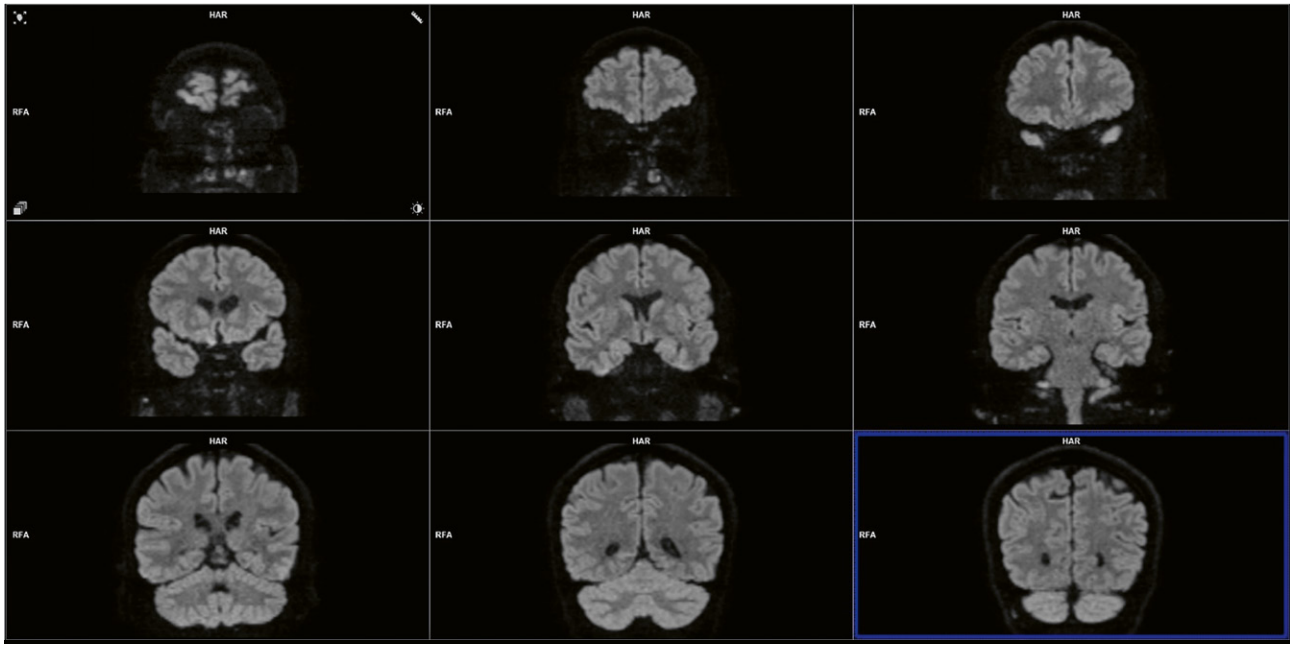
8 **(8A)** Transversal and coronal multiplanar reconstructions (MPR) from sagittal acquisition show impairing stripes. **(8B)** Sagittal and coronal MPRs from transversal acquisition do not show stripes.



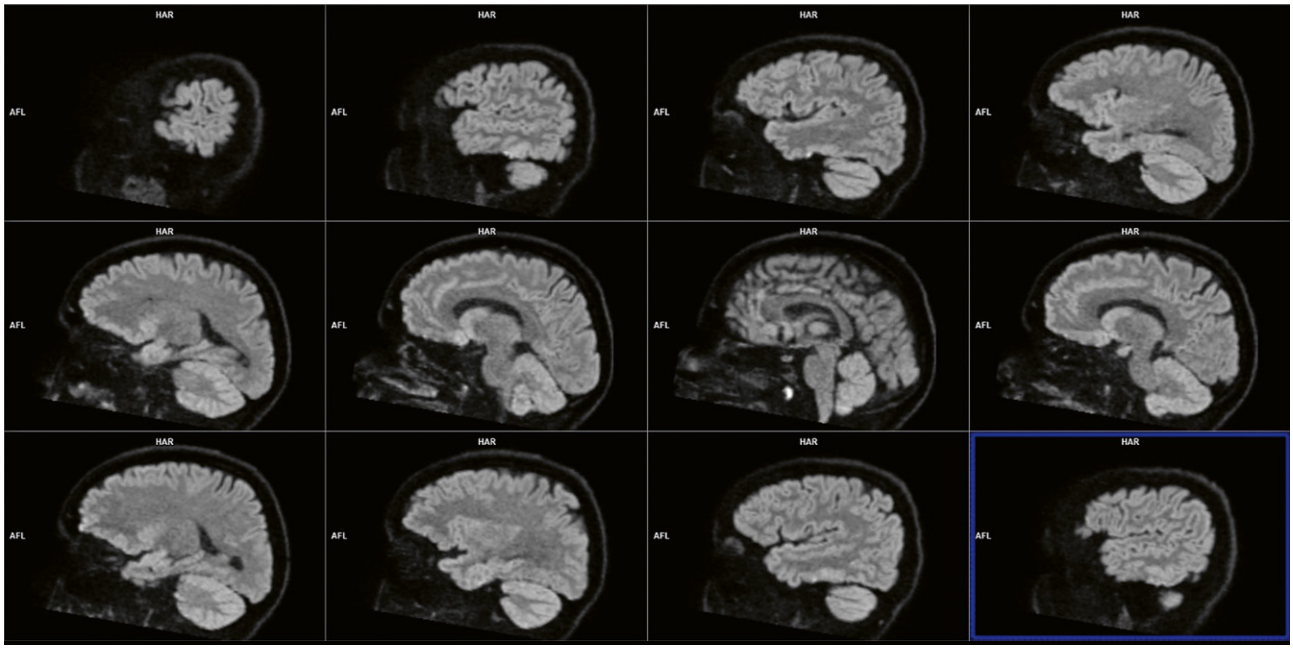
9 1.5T MAGNETOM Altea; RESOLVE with an isotropic resolution of 1.8 mm; b-value 1000 s/mm²; representative transversal slices with coronal and sagittal MPRs.



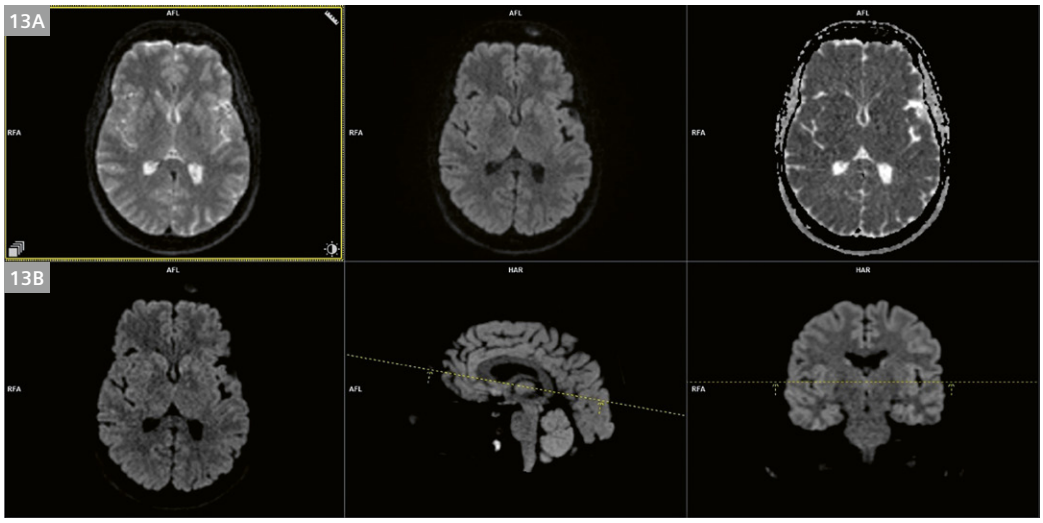
10 1.5T MAGNETOM Sola with XQ gradient system; RESOLVE with an isotropic resolution of 1.8 mm; b-value 1000 s/mm², p2s2, 90 slices, DF = 0, TA: 5:36 minutes; representative transversal slices.



11 1.5T MAGNETOM Sola with XQ gradients; RESOLVE with an isotropic resolution of 1.8 mm; b-value 1000 s/mm²; representative slices from coronal MPR.



12 1.5T MAGNETOM Sola with XQ gradient system; RESOLVE with an isotropic resolution of 1.8 mm; b-value 1000 s/mm²; representative slices from sagittal MPR.



13 1.5T MAGNETOM Sola with XQ gradient system; **(13A)** shows b0 and b1000 s/mm² and the ADC map; **(13B)** shows the calculated b1500 s/mm², sagittal and coronal MPRs of b1000 s/mm².

Diffusion-weighted imaging at 3 Tesla is affected to a greater or lesser extent by susceptibility, as seen above. By comparison, a 1.5 Tesla scanner reduces this effect significantly. The image gallery (Figs. 9–13) shows examples of isotropic RESOLVE-scans acquired on the 1.5 Tesla scanners MAGNETOM Altea and MAGNETOM Sola. It is remarkable that almost no susceptibility artifacts occur. We acquired the isotropic RESOLVE sequence typically with b0 and b1000, an ADC map, a calculated b1500 and, in addition, inline generated MPRs (Fig. 13) using the add-ins "MPR Planning" and "MPR Assignment" to obtain consistent results.

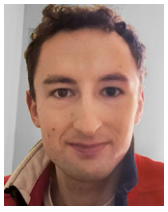
Conclusion

A diffusion-weighted measurement with isotropic voxel-sizes at high resolution and convincing image quality – also for the multiplanar reformations (MPR) – in an acceptable acquisition time can be achieved with the RESOLVE sequence using GRAPPA and SMS.

Contact

Thomas Illigen
SHS EMEA CWE DI MR
Karlheinz-Kaske-Str. 2
91052 Erlangen
Germany
thomas.illigen@siemens-healthineers.com

Christian Söldner, Ph.D.
Application Developer
SHS DI MR R&D CCC&CIT AIQ
Allee am Röthelheimpark 2
91052 Erlangen
Germany
christian.soeldner@siemens-healthineers.com



Acknowledgments

We would like to thank Katrin Schmidt-Kaiser for her generous scanning support and especially Dr. Andreas Bartsch from Radiologie Bamberg for the meaningful discussion.

References

1 McNab J A. 3D vs. 2D Diffusion acquisition. Presented at: ISMRM & SMRT Annual Meeting & Exhibition 2014; Milan, Italy. ↗ https://cds.ismrm.org/protected/14MProceedings/SearchResults.php?Session=Advanced%20Diffusion%20Acquisition

2 Cohen-Adad J. High-Resolution DWI in Brain and Spinal Cord with *syngo* RESOLVE. MAGNETOM Flash – SMS Supplement to the RSNA Edition. 2012;50(2):16–23. ↗ https://marketing.webassets.siemens-healthineers.com/1800000001345165/aa18a0a08ddb/MRI_52_Cohen-Adad_1800000001345165.pdf

3 Filli L, Ghafoor S, Kenkel D, Liu W, Weiland E, Andreisek G, et al. Simultaneous Multi-Slice RESOLVE for Optimized Diffusion-Weighted Imaging of the Breast at 3 Tesla. MAGNETOM Flash. 2016;66(3):126–128. ↗ https://cdn0.scrvt.com/39b415fb07de4d9656c7b516d8e2d907/1800000003527429/894bad0bc7c6/siemens_mri_magnetom-world_hot-topics_simultaneous-multi-slice_sms-resolve_filli_18000000003527429.pdf

4 Jiang JS, Zhu LN, Wu Q, Sun Y, Liu W, Xu XQ, et al. Feasibility study of using simultaneous multi-slice RESOLVE diffusion weighted imaging to assess parotid gland tumors: comparison with conventional RESOLVE diffusion weighted imaging. BMC Med Imaging. 2020;20(1):93.

5 Bartsch A. Case Report: High-Resolution Simultaneous Multi-Slice (SMS) RESOLVE Diffusion Neurography for Evaluation of Peripheral Nerve Entrapment Syndrome and Neuropathy. MAGNETOM Flash. 2016;65(2): 63–67. ↗ https://uploads-ssl.webflow.com/5db282fd014ef8f7bb8ce927/5db282fd014ef865bf8ceb26_Neurografia%20com%20Difusao%20Resolve%20SIEMENS%20REVIEW.pdf