Simultaneous Multi-Slice RESOLVE for Optimized Diffusion-Weighted Imaging of the Breast at 3 Tesla

Lukas Filli, M.D.[1]; Soleen Ghafoor, M.D.[1]; David Kenkel, M.D.[1]; Wei Liu, Ph.D.[2]; Elisabeth Weiland, Ph.D.[3]; Gustav Andreisek, M.D., MBA[4]; Thomas Frauenfelder, M.D.[1]; Val M. Runge, M.D.[5]; Andreas Boss, M.D., Ph.D.[1]

[1] Institute of Diagnostic and Interventional Radiology, University Hospital Zurich, University of Zurich, Switzerland
[2] Siemens Shenzhen Magnetic Resonance Ltd., Shenzhen, China
[3] Siemens Healthineers, MR Application Development, Erlangen, Germany
[4] Kantonsspital Münsterlingen, Switzerland
[5] Inselspital Bern, Switzerland

Abstract

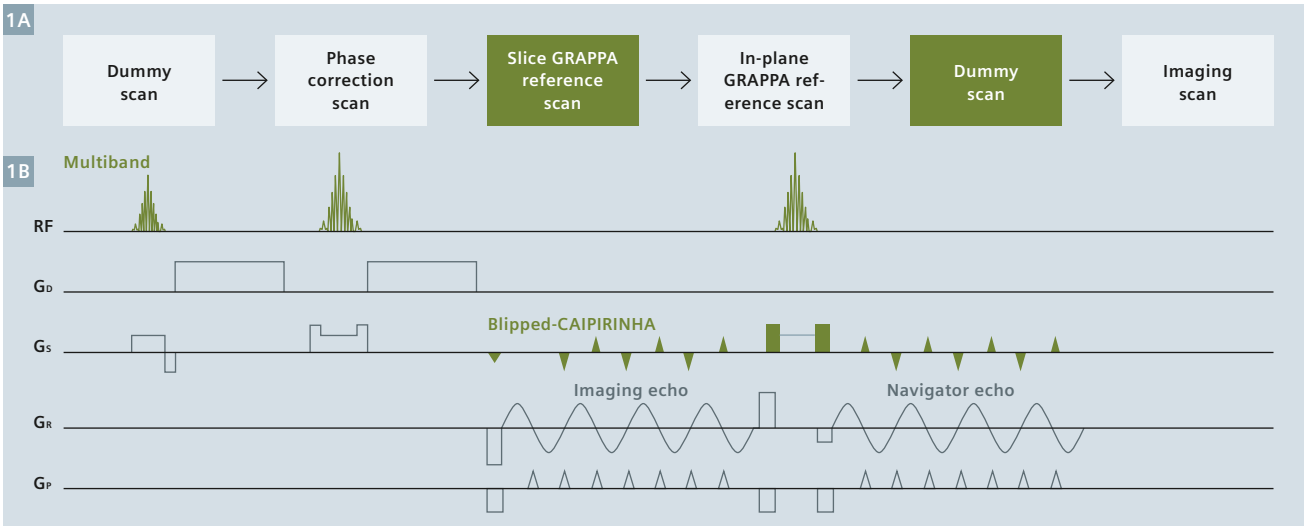
Simultaneous multi-slice (SMS) acquisition significantly reduces scan times in clinical MRI. Readout-segmented echo planar imaging (RESOLVE) is a recently developed sequence which produces sharp diffusion-weighted images with high spatial resolution. In this article, we describe our early experience with SMS RESOLVE[1] for optimized diffusion-weighted imaging of the breast. SMS RESOLVE combines the advantages of high image quality and greatly reduced scan times.

[1] The product is still under development and not commercially available yet. Its future availability cannot be ensured.

Introduction

Diffusion-weighted imaging improves diagnostic accuracy of breast MRI [1-3] and may be used for predicting treatment outcome in breast cancer [4, 5]. Traditionally, diffusion-weighted imaging is based on single-shot echo planar imaging (EPI). With this technique, the entire *k*-space is filled during a single T2* decay, which makes imaging prone to signal blurring and susceptibility artifacts. These technical obstacles can be overcome with readout-segmented EPI (RESOLVE), which divides the *k*-space trajectory into separate segments along the readout direction and allows short echo times [6]. Because the resulting images are very sharp and of high spatial resolution, RESOLVE has superior diagnostic performance compared to single-shot EPI in breast imaging [7].

Since every readout segment in the *k*-space is preceded by a separate radiofrequency pulse, RESOLVE is limited by relatively long acquisition times. An interesting method to compensate for this is simultaneous multi-slice (SMS) imaging, which is a three-dimensional parallel imaging method. In brief, SMS utilizes the different elements of a phased-array coil to acquire signal from multiple slices at once, thereby enabling accelerated image acquisition. The concept of SMS has been elucidated in detail in the MAGNETOM Flash (63) 3/2015 edition. That edition also includes an



1 SMS RESOLVE sequence diagram for a complete acquisition **(1A)** and for a single readout segment **(1B)**. SMS modifications are colored green.

article by Frost et al., who developed SMS RESOLVE in 2014 [8]. Here, we present our initial experience with this novel pulse sequence for optimized diffusion-weighted imaging of the breast.

Image acquisition

We routinely perform breast MRI on a clinical 3 Tesla scanner (MAGNETOM Skyra with TimTX TrueShape) using an 18-channel breast coil (Siemens Healthcare). We can acquire SMS RESOLVE images of the breast with a dedicated work-in-progress package running on the *syngo* MR VE11A platform. The sequence applies a conventional phase-encoding direction blip for EPI readouts along with an additional blip in the slice direction ("blipped CAIPIRINHA") [9]. Furthermore, like the conventional RESOLVE sequence, it contains two-dimensional navigator correction [6] (Fig. 1).

Parameter	RESOLVE (no slice acceleration) 4 min 21 sec	SMS RESOLVE (2-fold acceleration) 2 min 35 sec	SMS RESOLVE (3-fold acceleration) 1 min 44 sec
Repetition time [ms]	5410	2250	1450
Echo time [ms]	56	55	55
Slices	28	28	27 (28 not possible)
Distance factor	20%		
Voxel size [mm³]	1.2 x 1.2 x 5.0		
Readout segments	5		
Readout partial Fourier	5/8		
Field-of-view [mm²]	340 x 136		
Bandwidth [Hz/Pixel]	829		
Echo spacing [ms]	0.38		
iPAT (GRAPPA) factor	2		
Averages	b=50 (1), b=800 (4)		

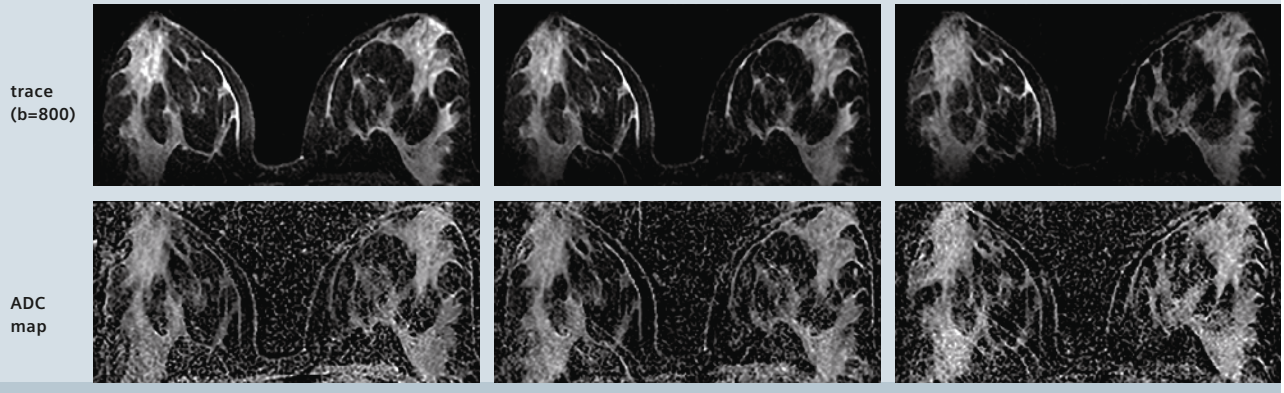
Table 1: Imaging parameters of conventional RESOLVE and SMS RESOLVE at our institution.

Comparison between RESOLVE and SMS RESOLVE

In a recently published study, we compared the image quality of conventional RESOLVE with SMS RESOLVE (with twofold and threefold slice acceleration) for axial diffusion-weighted imaging of the breast [10]. All imaging parameters were kept constant except for the slice acceleration factor and resulting adjustments of repetition time (lowest possible value as determined by the scanner console) and echo time. Details of imaging parameters are provided in Table 1.

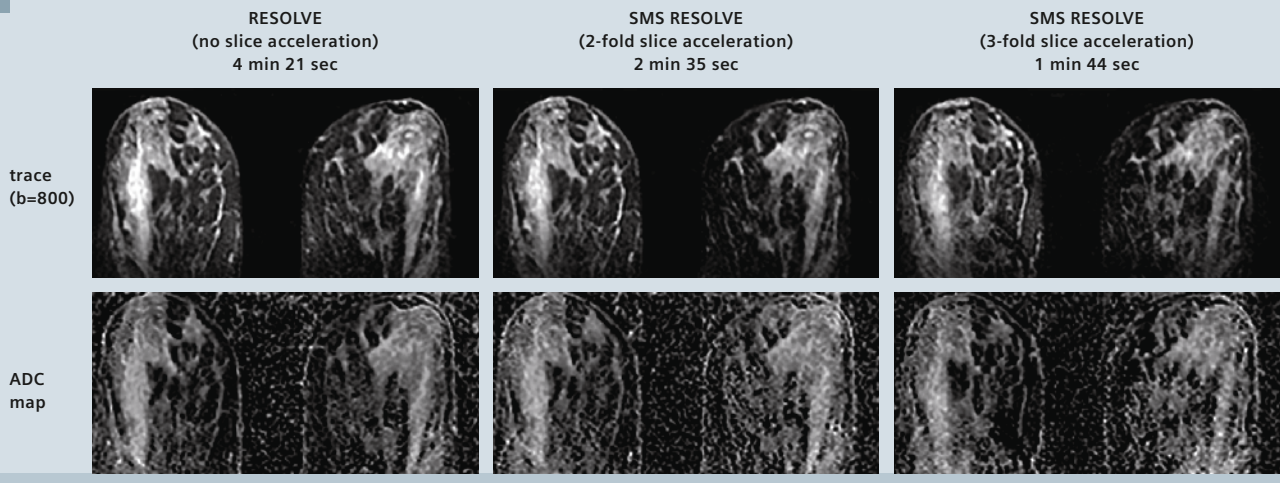
With twofold and threefold slice acceleration, we found a slight decline in signal-to-noise ratio compared to conventional RESOLVE, which however was not statistically significant ($p = 0.83$). In other words, SMS RESOLVE offers a substantial gain in signal-to-noise ratio per unit of time. Mean ADC values in fibroglandular breast tissue were $1.62 \pm 0.29 \times 10^{-3}$ mm²/s, with almost no differences found among the sequences ($p = 0.99$) (Figs. 2, 3). Image quality was rated similarly high between RESOLVE and twofold accelerated SMS RESOLVE. With threefold accelerated SMS RESOLVE, we perceived more shading in the prepectoral region, which may be reduced by changing over from 5/8 to 6/8 readout partial Fourier acquisition in the future. The results of our study suggest that SMS can be applied to RESOLVE for optimized breast imaging, with an optimal slice acceleration factor of 2 or potentially 3.

2



2 Example 3T diffusion-weighted images from a 26-year-old healthy volunteer with corresponding ADC maps. The in-plane resolution is 1.2 x 1.2 mm². There is almost no visible difference between RESOLVE and 2-fold accelerated SMS RESOLVE. With 3-fold acceleration, the image is still sharp and most parts of the breast can be depicted very well, whereas the prepectoral region is slightly affected by shading.

3



3 Example diffusion-weighted images from a 38-year-old healthy volunteer with large breasts. Except for the prepectoral shading artifact at 3-fold acceleration, there is almost no visible difference between the sequences despite substantial differences regarding acquisition time.

Discussion

In a recent study, RESOLVE showed many advantages over single-shot EPI for diffusion-weighted imaging of the breast. These included reduced blurring, reduced geometric distortions, better depiction of breast lesions, and improved discrimination between benign and malignant lesions [7]. SMS RESOLVE drives this image optimization one step forward: It reduces the acquisition time while maintaining similar image quality and ADC accuracy compared to conventional RESOLVE as long as a moderate acceleration factor is applied.

With regard to SMS RESOLVE of the breast, the main advantage of SMS acquisition lies in the reduction of acquisition time. Alternatively, depending on the application or body region, the gain in SNR efficiency offered by SMS may be reinvested in extended slice coverage or to increase spatial resolution while keeping the acquisition time constant.

In conclusion, SMS RESOLVE enables the acquisition of high-quality diffusion-weighted images at greatly reduced scan times. Our initial experience with SMS RESOLVE for breast imaging is very promising for the future.

References

1 Bickel H, Pinker-Domenig K, Bogner W, Spick C, Bago-Horvath Z, Weber M, et al. Quantitative apparent diffusion coefficient as a noninvasive imaging biomarker for the differentiation of invasive breast cancer and ductal carcinoma in situ. Invest Radiol. 2015;50(2):95-100.

2 Bogner W, Gruber S, Pinker K, Grabner G, Stadlbauer A, Weber M, et al. Diffusion-weighted MR for differentiation of breast lesions at 3.0 T: how does selection of diffusion protocols affect diagnosis? Radiology. 2009;253(2):341-51.

3 Pinker K, Bogner W, Baltzer P, Karanikas G, Magometschnigg H, Brader P, et al. Improved differentiation of benign and malignant breast tumors with multiparametric 18fluorodeoxyglucose positron emission tomography magnetic resonance imaging: a feasibility study. Clin Cancer Res. 2014;20(13):3540-9.

4 Iacconi C, Giannelli M, Marini C, Cilotti A, Moretti M, Viacava P, et al. The role of mean diffusivity (MD) as a predictive index of the response to chemotherapy in locally advanced breast cancer: a preliminary study. Eur Radiol. 2010;20(2):303-8.

5 Liu S, Ren R, Chen Z, Wang Y, Fan T, Li C, et al. Diffusion-weighted imaging in assessing pathological response of tumor in breast cancer subtype to neoadjuvant chemotherapy. Journal of magnetic resonance imaging : JMRI. 2015;42(3):779-87.

6 Porter DA, Heidemann RM. High resolution diffusion-weighted imaging using readout-segmented echo-planar imaging, parallel imaging and a two-dimensional navigator-based reacquisition. Magnetic resonance in medicine. 2009;62(2):468-75.

7 Bogner W, Pinker-Domenig K, Bickel H, Chmelik M, Weber M, Helbich TH, et al. Readout-segmented echo-planar imaging improves the diagnostic performance of diffusion-weighted MR breast examinations at 3.0 T. Radiology. 2012;263(1):64-76.

8 Frost R, Jezzard P, Douaud G, Clare S, Porter DA, Miller KL. Scan time reduction for readout-segmented EPI using simultaneous multislice acceleration: Diffusion-weighted imaging at 3 and 7 Tesla. Magnetic resonance in medicine. 2014.

9 Setsompop K, Gagoski BA, Polimeni JR, Witzel T, Wedeen VJ, Wald LL. Blipped-controlled aliasing in parallel imaging for simultaneous multislice echo planar imaging with reduced g-factor penalty. Magnetic resonance in medicine. 2012;67(5):1210-24.

10 Filli L, Ghafoor S, Kenkel D, Liu W, Weiland E, Andreisek G, et al. Simultaneous multi-slice readout-segmented echo planar imaging for accelerated diffusion-weighted imaging of the breast. Eur J Radiol. 2016;85(1):274-8.

Contact

Lukas Filli, M.D.
Institute of Diagnostic and Interventional Radiology
University Hospital Zurich, University of Zurich
Raemistrasse 100
CH-8091 Zurich
Switzerland
Phone: +41 44 225 11 11
lukas.filli@usz.ch