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Parallel Transmission for Improved Multishot Diffusion Weighted MRI at 7 Tesla

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Introduction:

Clinical and neuroscience applications of 7 tesla MRI have increased in recent times with the greater SNR allowing improved spatial resolution and image quality. Nevertheless, certain MRI sequences remain particularly challenging at 7T due to the reduced RF wavelength homogeneity and shortened T2 and T2* decay times. Parallel-transmit (pTx) MRI is seen as a critical development for 7T as a means to mitigate RF nonuniformity (Ibrahim 2000). Meanwhile, multishot sequences allow a shorter echo time (TE) and echo-train length to accommodate the reduced T2 and T2* values. This abstract presents a solution to 7T diffusion MRI with a pTx implementation of a 2D readout-segmented, diffusion-weighted echo- planar imaging (EPI) sequence (Heidemann and Porter 2010).

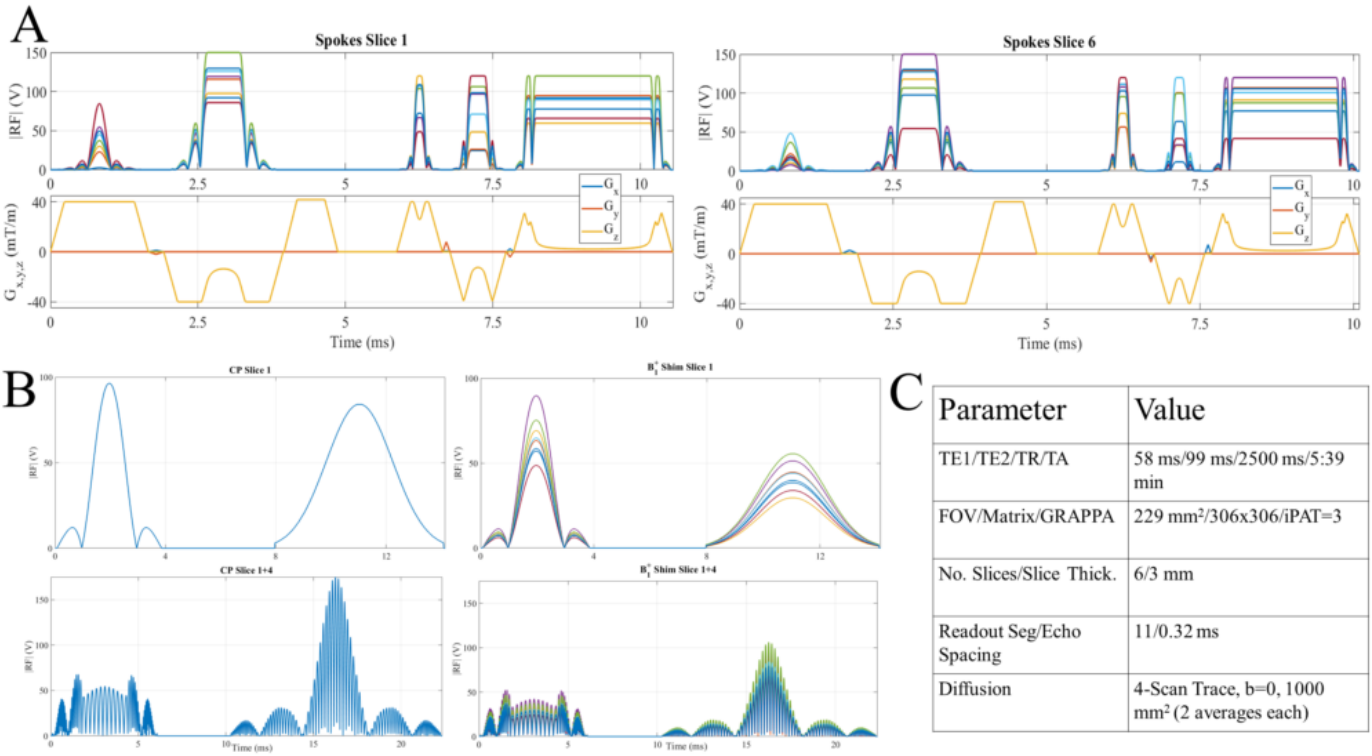
Methods:

Experiments were conducted on a MAGNETOM Terra 7T Scanner (Siemens Healthineers, Erlangen, Germany) using Siemens' RESOLVE sequence with a modification to support slice-selective pTx excitation and refocusing pulses.

A few slice-selective pTx methods were explored in the context of the RESOLVE sequence for diffusion imaging. Firstly, a comparison was made between single-transmit (CP) imaging, slice-by-slice static pTx (B1+ shimming), and slice-by-slice dynamic (full-waveform) pTx. With CP excitation, the same voltage amplitudes with fixed phase relationships are played out from each transmit channel for each 2D slice. With B1+ shimming, the relative voltage amplitude and phase of each transmit channel are optimized for each slice. With full-waveform pTx, a set of "spokes" waveforms (Saekho 2006) are optimized for each slice. For both forms of pTx, a magnitude least-squares problem (Setsompop 2008) was solved to optimize RF homogeneity. With the spokes pulses, 2 spokes were used for excitation and 3 spokes were used for refocusing. VERSE (Conolly 1988) was used to reduce peak pulse voltage. A plot of the slice-selective spokes RF waveforms is shown in Figure 1A.

Secondly, a study was made between conventional single-band (SB) and multiband (MB) pTx pulses for B1+ shimming using the method of simultaneous multislice (SMS) (Müller 1988). To make a matched comparison with CP excitation, the conventional slice-selective RF pulse waveforms were used for pTx SB B1+ shimming and the product VERSE'd waveforms were used for MB B1+ shimming. In Figure 1B, the SB RF waveforms are compared with MB waveforms for imaging two slices simultaneously (MB factor 2); results are shown for both CP and B1+ shimming.

Following informed consent and local ethics committee approval, a healthy volunteer was scanned using an in-house pTx coil with 8-transmit and 32-receive elements (Williams 2021). The RESOLVE sequence protocol is listed in Figure 1C.



Parameter	Value
TE1/TE2/TR/TA	58 ms/99 ms/2500 ms/5:39 min
FOV/Matrix/GRAPPA	229 mm^2/306x306/iPAT=3
No. Slices/Slice Thick.	6/3 mm
Readout Seg/Echo Spacing	11/0.32 ms
Diffusion	4-Scan Trace, b=0, 1000 mm^2 (2 averages each)

Figure 1. Plots of RF and gradient waveforms and RESOLVE sequence protocol. A) Dynamic pTx spokes pulses and their gradients used in single-band experiments at two different slice locations (Slice 1 and Slice 6). The top row shows multiple RF waveforms from 8 transmit elements, the bottom row shows gradient waveforms for the three axes. Both 2-spoke excitation and 3-spoke refocusing are shown plotted together for illustration, although the time gap between them used experimentally was in reality longer to achieve the required TE. B) CP (left) and pTx B1+ shimming (right) pulses for multiband experiments, again with excitation and refocusing plotted together for illustrative purposes. The top row shows single-band pulses and the bottom row, MB pulses. C) Sequence parameters used for all RESOLVE diffusion acquisitions in this study.

(https://files.aievolution.com/prd/hbm2201/abstracts/abs_1122/rf-waveforms-phantom.png)

·Figure 1.

Results:

Figure 2A shows the single-band diffusion-weighted images (b=1000 s/mm^2) comparing CP excitation, static B1+ shimming, and dynamic pTx spokes. B1+ shimming provides clear improvement to RF inhomogeneity seen in the CP images, and is even further improved with spokes pulses.

Figure 2B shows T2-weighted (low b-value) images comparing SMS RESOLVE for CP and B1+ shimming with a MB factor of 2. As in the single-band case, B1+ shimming substantially improves the shading caused by RF inhomogeneity in the CP SMS image.

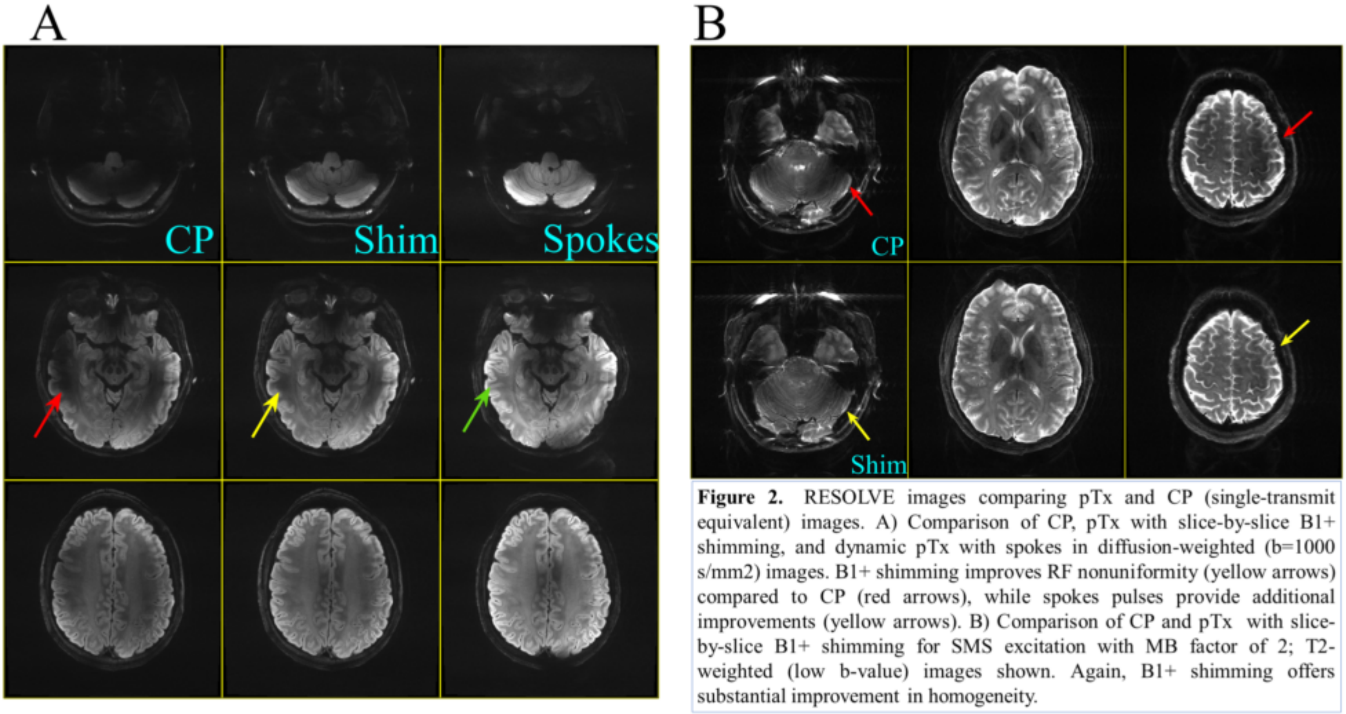


Figure 2. RESOLVE images comparing pTx and CP (single-transmit equivalent) images. A) Comparison of CP, pTx with slice-by-slice B1+ shimming, and dynamic pTx with spokes in diffusion-weighted (b=1000 s/mm2) images. B1+ shimming improves RF nonuniformity (yellow arrows) compared to CP (red arrows), while spokes pulses provide additional improvements (yellow arrows). B) Comparison of CP and pTx with slice-by-slice B1+ shimming for SMS excitation with MB factor of 2; T2-weighted (low b-value) images shown. Again, B1+ shimming offers substantial improvement in homogeneity.

(https://files.aievolution.com/prd/hbm2201/abstracts/abs_1122/resolve-images.png)

·Figure 2.

Conclusions:

We present a solution to the challenges of 7T diffusion imaging by: (1) using multishot imaging to achieve shorter TEs and readout times to compensate for the faster T2 and T2* relaxation; and (2) using parallel transmission to mitigate RF field inhomogeneity. Dynamic pTx spokes pulses performed the best at correcting RF nonuniformity for SB imaging, yet also have drawbacks such as greater static field (B0) sensitivity, longer pulse design time, and higher RF specific absorption rate (SAR). Meanwhile, B1+ shimming provided substantial homogeneity improvements for both SB and MB. Future work on the sequence will seek to incorporate pTx in the fat suppression pulse and to increase the number of slices within the scan.

Novel Imaging Acquisition Methods:

Anatomical MRI
Diffusion MRI [1]
Imaging Methods Other [2]

Keywords:

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MRI
MRI PHYSICS
STRUCTURAL MRI

[1|2]Indicates the priority used for review

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No

Please indicate below if your study was a "resting state" or "task-activation" study.

Other

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Was any human subjects research approved by the relevant Institutional Review Board or ethics panel? NOTE: Any human subjects studies without IRB approval will be automatically rejected.

Yes

Was any animal research approved by the relevant IACUC or other animal research panel? NOTE: Any animal studies without IACUC approval will be automatically rejected.

Not applicable

Please indicate which methods were used in your research:

Structural MRI
Diffusion MRI

For human MRI, what field strength scanner do you use?

7T

Provide references using author date format

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