MP-RAGE acquisitions are used for high-resolution $T_1$-weighted imaging because of their high gray and white matter contrast properties, but they suffer from long scan times due to the long inversion and recovery period.

Methods to reduce acquisition time have included homodyne and partial-Fourier techniques and parallel imaging in one and two directions (1D and 2D SENSE or GRAPPA). More recently 2D-CAIPIRINHA was introduced to mitigate noise amplification inherent to parallel imaging. Further extending the ideas of 2D-CAIP, wave-CAIPI fully exploits the 3D coil sensitivity variations by combining corkscrew k-space trajectories with CAIPIRINHA sampling (see Figure 1a)). A fast 3D MP-RAGE wave-CAIPI sequence tailored for ultra-high field was implemented.

For the parallel imaging reconstruction, a GRAPPA-based wave-CAIPI algorithm was developed. As schematically shown in Figure 1b), multiple GRAPPA reconstruction kernels along the readout direction are needed for the reconstruction of the wave-CAIPI dataset. The required number of different GRAPPA reconstruction kernels depends on the number of k-space points acquired during one wave cycle. The GRAPPA reconstructed images still show spreading in readout direction due to the non-Cartesian wave trajectory (cf. Figure 1a), right). The remaining wave spreading is removed by deconvolution with a point spread function which depends on the sinusoidal k-space trajectories and on the spatial location in the phase and partition encoding directions. The applied gradient shape during a wave-CAIPI readout deviates from the nominal shape due to hardware imperfection, eddy currents and field inhomogeneities. This results in blurring and image artifacts. The actual corkscrew k-space trajectory was measured employing the Clip-on Camera.

![GRAPPA RECONSTRUCTED WAVE-CAIPI MP-RAGE](image)

**Figure 1**: a) Schematic description of an acquisition with wave sampling. Oscillating phase encoding gradients during the readout process (left) result in corkscrew k-space trajectories (middle) and wave spreading in the readout direction of the image (right). b) For the GRAPPA-based wave-CAIPI reconstruction, multiple reconstruction kernels are required along the readout direction.
Results
The necessity of a k-space measurement is depicted in Figure 2. A part of a phase encoding trajectory during the readout is plotted. The PSF was determined for the nominal, the delay-corrected nominal and the measured trajectory and applied to a fully sampled wave dataset. Image reconstruction based on the measured k-space trajectory provides a strongly improved image quality compared to reconstruction utilizing the (delay-corrected) nominal trajectory. In comparison to Cartesian CAIPIRINHA, the wave-CAIPI MP-RAGE images show a strongly improved image quality and reduced noise enhancement. Exemplary, the results for R=4x4(2) retrospectively accelerated CAIPIRINHA and wave-CAIPI acquisitions with 1 mm isotropic voxel size are shown in Figure 3. While the CAIPIRINHA images show aliasing artifacts, the wave-CAIPI images do not. Further, the g-factor is reduced.

Conclusion
A GRAPPA reconstruction for wave-CAIPI acquisitions is presented in this work. The wave-CAIPI reconstruction can be formulated as a Cartesian problem and allows an efficient GRAPPA-based image reconstruction when the actual k-space trajectory is known by parallel measurement using NMR field probes. The combination of the fast wave-CAIPI MP-RAGE implementation and the GRAPPA-based wave-CAIPI reconstruction enables ultra-fast high-resolution MP-Rage imaging at 7T.

Figure 2: a) Section of the trajectory with 32 wave cycles during a 7680μs readout for the phase encoding gradient. b) The corresponding reconstructions of a fully sampled wave dataset.

Figure 3: 16-fold retrospectively accelerated wave-CAIPI MP-RAGE images plus CAIPIRINHA images and the corresponding g-factor maps.

Clip-on Camera
Know the image encoding during your MR scan.
- Captures field perturbations regardless of their origin
- Delivers the requisite input to remove phase errors in images
- Offers real-time field feedback for field stabilization