# Hybrid MP-RAGE Trajectory with FID Motion Detection and Self-Navigated Motion Correction (MoCoRAGE)

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## Introduction

Featuring an excellent grey-white matter contrast, the Magnetisation-Prepared Rapid Acquisition Gradient Echo (MP-RAGE) sequence is widely used in clinical practice and research. Optimal brain tissue contrast, however, requires long repetition times (TRs) and resulting acquisition times of 5-10 minutes render MP-RAGEs susceptible to motion artefacts. The present work aims at mitigating the motion susceptibility of MP-RAGE acquisitions by exploring a concept of complementary motion detection and intrinsic correction ("MoCoRAGE") without increasing the total scan time. While a free-induction-decay (FID) navigator is used for detection [1], the self-navigating [2] properties of a hybrid acquisition scheme are exploited to quantify the occurred motion directly from the imaging data.

## Materials and Methods

A standard MP-RAGE sequence was modified to sample k-space in a hybrid trajectory scheme, i.e. spirally arranged in-centre-out groups of Cartesian readouts in the phase encoding plane (Fig. 1a). The spirals, modelled as described in [3], were repeated at each TR after a rotation by the golden angle (137.51°, Fig 1b-f). Nearest-neighbour interpolation was performed to fit the Cartesian grid at acquisition, while readouts that were acquired more than once were averaged in the final reconstruction. This sampling scheme results in a highly oversampled area around the centre of k-space, while the corners are omitted. Moreover, the golden angle rotation provides a uniform spatial distribution of the readouts at any point over time. For these reasons, image volumes with reduced resolution can be reconstructed from any subset of TRs and used for motion parameter quantification or "self-navigation". To detect head motion in the first place, an extra FID readout was inserted 20 msec after the inversion pulse (128 points/non-selective/4°), similarly to [1]. To test the self-navigating capabilities of this approach, datasets from five healthy subjects were acquired on a 3T clinical MRI scanner (MAGNETOM Trio, Siemens AG, Healthcare Sector, Erlangen, Germany) after obtaining written consent. Each measurement session included three MoCoRAGE sequences (3x9:23 min). Protocol parameters were set as follows: TI/TR/TE=900ms/2300ms/2.98ms, flip angle 7°, voxel size (1x1x1.2) $mm^3$, and receiver bandwidth 238 Hz/px. Matrix size was (240x240x240) in a (240x240x288) $mm^3$ FOV. While the first scan was performed without intended motion (reference), during the following two scans, the subject was instructed to change his head position once upon verbal command, given at around 4:40 min after start. The first position change was to be a "head shaking", the second a "nodding" motion. In a post-processing step, FID navigator signals were analysed to precisely detect the TR when the head position changed (Fig. 2A). Consecutively acquired portions of the k-space data after the occurrence of motion were reconstructed offline for time intervals of 4 min (green), 2 min (white), 1 min (orange), 30 sec (black), 20 sec (red) and 10 sec (yellow) (Fig. 2B). These undersampled image volumes were then registered to a reference volume reconstructed from a 4-min portion of the acquisition prior to motion (cyan), using the co-registration tool of SPM8 [4] (Fig. 2C). The registration error was computed comparing the transformation parameters obtained from the registration of each undersampled volume to those obtained from the 4-min-to-4-min (green to cyan) registration. To characterise the worst-case scenario, the error was expressed as displacement on a point at 10 cm distance from the centre of the image (roughly the size of the skull). Motion correction was performed applying the 3D rigid transformation derived from each registration to the k-space of the second half of the measurement. The two halves were then put together by performing the same averaging of the reference. The final image quality was qualitatively compared to that of the motionless acquisition.

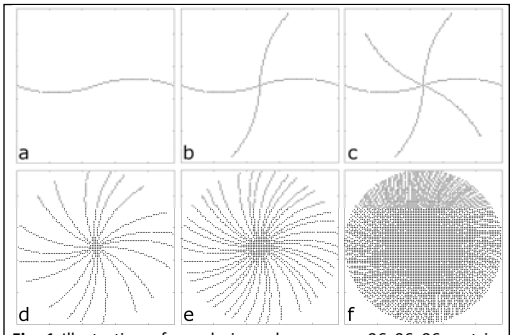


**Fig. 1** Illustration of reordering scheme on a 96x96x96 matrix. Every TR, a series of Cartesian readouts, spirally arranged on the phase encoding plane is acquired (a). A golden angle rotation of the spiral is performed between each TR (b,c). Pseudo-uniform sampling of the phase-encoding plane is obtained with any subset of TRs (d-f. TA=20 sec. 40 sec. 2 min).

## Results

The MoCoRAGE acquisitions were successfully performed in all volunteers and the instant of the motion could always be reliably identified by the FID navigator (Fig. 2A). Rigid registration parameters derived from the partial k-space reconstructions were always consistent to those obtained from the 4min-to-4min case, even when using the 10 sec sub-volume. The average registration error from 5 volunteer scans with 2 motion patterns each was 0.32±0.17 mm, 0.55±0.35 mm, 0.71±0.50 mm, 0.79±0.49 mm and 1.00±0.47 mm registering the two full datasets (green and cyan) using the motion parameters obtained with the 2 min, 1 min, 30 sec, 20 sec, and 10 sec sub-volumes. Qualitative comparison among the motion corrected images (Fig. 2C) showed only minor differences between the corrected datasets.

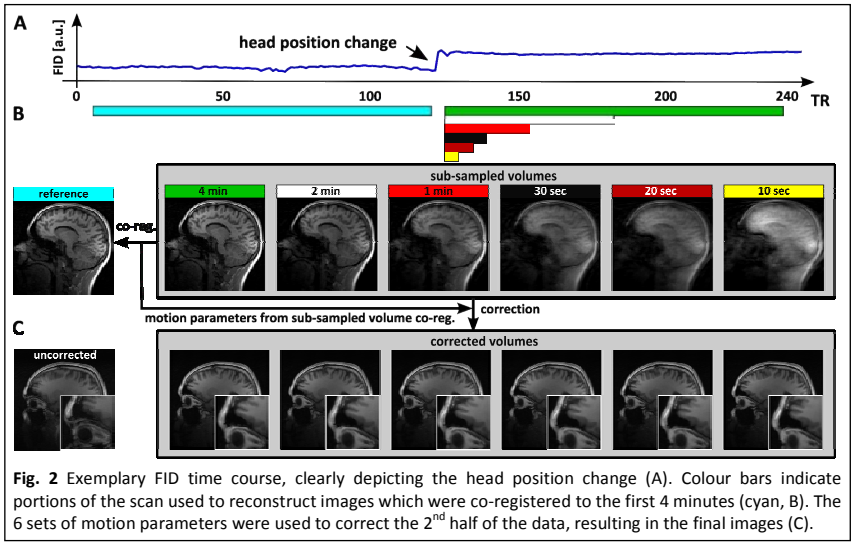


**Fig. 2** Exemplary FID time course, clearly depicting the head position change (A). Colour bars indicate portions of the scan used to reconstruct images which were co-registered to the first 4 minutes (cyan, B). The 6 sets of motion parameters were used to correct the 2nd half of the data, resulting in the final images (C).

## Discussion and Conclusions

We demonstrated and tested the feasibility of the described MoCoRAGE approach. The initial results are encouraging, but more detailed analyses need to be performed to identify the limitations of the current framework in terms of accuracy of the intrinsic motion detection/correction and the acceptance in clinical routine compared to the standard MP-RAGE. Due to the hybrid arrangement of the sampling scheme, the oversampling of k-space and the pseudo-random distribution of the samples over time, this technique will be a good candidate for compressed sensing iterative reconstructions.

*NOTE: The first two authors contributed equally to this work.*

## References:

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