Accelerated 3D RARE for Positional Weight-Bearing MRI of ACJ Bone Fixation with Metal Implants

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Target audience: MRI developers interested in accelerated MRI by means of optimized variable-density k-space undersampling and constrained reconstruction. Physicians interested in positional MRI under physiological weight-bearing in presence of metal implants.

Purpose: Nowadays clinical routine quite often requires MR imaging in the vicinity of MRI-compatible metal implants[1], either to assess pathologies unrelated to the implant or to directly check the implant effectiveness and the health of the surrounding tissues. Unfortunately, especially at high field strengths, the image quality can be seriously spoiled by artifacts due to the susceptibility effects caused by the implant metal components. In the following an accelerated 3D RARE sequence is presented, aimed at positional MRI under physiological weight-bearing of the shoulder Acromio-Clavicular Joint (ACJ) with bone fixation by means of titanium plates.

Methods: According with clinical requirements, a 3D proton-density weighted RARE with ETL/ESP = 5/15 ms, TR/TE = 180 ms/15 ms, FOV = 200*200*180 mm^3 and matrix = 288 *222*90 was implemented on a 0.25 T MRI system (G-scan, Esaote S.p.A., Genoa, Italy). This scanner is equipped with an open C-shape permanent magnet that can tilt together with the examination bed, allowing MRI under physiological weight-bearing. In order to perform imaging as close as possible to the metal implants, where susceptibility effects produce large off-resonance effects, non-selective, large-bandwidth rectangular RF pulses of the duration of 0.6 ms were used. Given the short ETL, the flip angle for the refocusing pulses was set to 180°. Voxel bandwidth was of 174 Hz/voxel. The best image quality was obtained with a step-wise k-space segmentation along the 3D encoding direction, while keeping the echo assignment unchanged along the 2D encoding direction, as shown in Fig. 1. The full acquisition time of an unaccelerated single scan would be 12'. Morphology and functional assessments require precise quantitative evaluations at different degrees of shoulder abduction[2] leading to an overall examination time exceeding what reasonably doable without motion artifacts, even with collaborative patients. Therefore scan acceleration was used[3]. Two elliptical view variable-density k-space undersampling schemes with an accelerating factor of 2.6 were implemented: Fig. 1b shows a Poisson disc undersampling with rejection of redundant points that are symmetric to the center of the k-space while Fig. 1c shows a centric-circular partial Fourier acquisition. Image reconstruction for both cases was obtained by adding to the compressed sensing reconstruction operator an original L2-norm term (see Fig. 2), such to drive the recovery of the missing points toward the guess of the Projection Onto Convex Sets (POCS) method, whose low-resolution phase estimation comes from the fully sampled k-space central kernel.

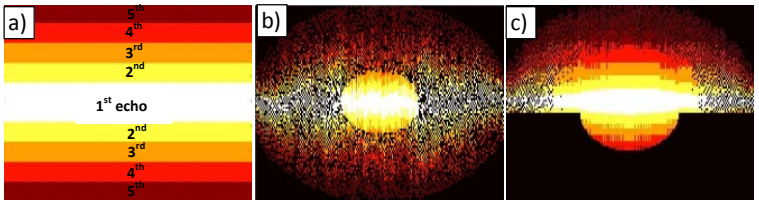

Fig. 1: Color coding to illustrate k-space segmentation, from the 1st echo segment in white, up to last echo one in dark red. 2D and 3D phase-encoding directions are horizontal and vertical respectively. a) Full k-space; b-c) elliptical view with Poisson-disc undersampling either with rejection of centric-symmetric points in b), or with centric-circular partial-Fourier acquisition in c).

In order to allow reliable quantitative evaluations, 3D geometric distortion correction of gradient non-linearity was applied on reconstructed images.

$$\Phi(i) = \| \mathrm{F}_{\mathrm{M}}\, i - y \|_2 + \lambda_{POCS} \| \mathrm{F}_{\overline{\mathrm{M}}}\, i - y_{POCS} \|_2 + \lambda_1 \| \mathrm{W}\, i \|_1 + \lambda_2 \sum_{x,y} | \mathrm{grad}(i(x,y)) |$$

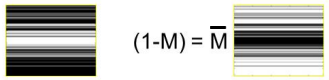

Fig. 2: Compressed sensing operator with the standard data fidelity L2-norm constraint (given, e.g., a typical 1D undersampling mask M). In order to reconstruct partial-Fourier undersampled k-spaces, a novel L2-norm term is coupled by the weight λ_{POCS}, to force the reconstructed data (identified by the mask $\overline{\mathbf{M}}$ = (1-M)) to tend to the POCS estimation y_{POCS}.

Results: A slightly better image quality in terms of effective spatial resolution was obtained by means of the partial Fourier undersampled acquisition of Fig. 1c). Fig.3 shows the corresponding MRI of the ACJ at 120° of abduction of the right shoulder of a patient with bone fixation by means of a titanium plate (see red circles). Single scan acquisition time was of 4'40", corresponding to an overall accelerating factor of 2.6. Note that imaging is virtually devoid of metal-induced artifacts and also tissues very close to the implant are properly imaged.

Discussion: Image quality in terms of SNR, spatial resolution, contrast and metal-induced artifact suppression is suitable for quantitative clinical assessments and it is going to be used in a clinical study to check the ACJ functionality under physiological weight-bearing after bone fixation.

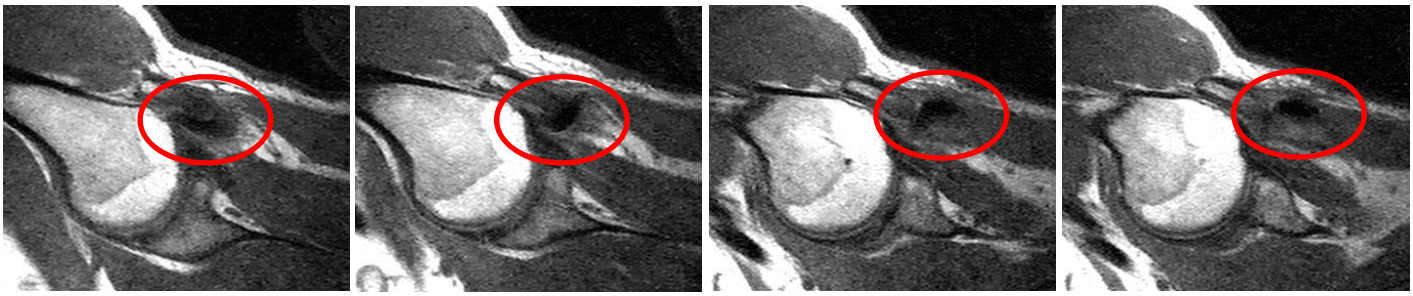

Fig. 3: ACJ 3D RARE MRI at 120° of shoulder abduction of a patient with bone fixation by means of a titanium z-shaped plate (see red circles).

Conclusion: The shown technique is a novel and effective approach to positional MRI under physiological weight-bearing in presence of metal implants. This is a promising application for open-configuration, tilting MRI scanners at low-field. Other clinically relevant applications include *in-vivo* bio-medical testing of implants in presence of muscle activation and physiological weight-bearing in a more natural stance.

References: 1. Hargreaves B.A. *et al.*, AJR 2011, 197:547-555; 2. Izadpanah K. *et al*. AJSM 2012, 40:185-192; 3. Lustig M. *et al*. MRM 2007, 58:1182-1195.