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Assessment of Iterative Regularized Parallel Imaging Reconstruction for Quantitative Magnetic Resonance Imaging

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Kurzfassung

Mit nicht linearer paralleler Bildrekonstruktion unter Verwendung iterativ regularisierter Gauss Newton Methoden (IRGN) konnten besonders hohe Beschleunigungsfaktoren bei der MR Bildgebung erzielt werden. Bei dieser Technik werden die Daten mit Arrayspulen aufgenommen und sowohl die Spulensensitivitäten als auch das Bild aus den unterabgetasteten Daten berechnet. Für die Bildrekonstruktion ist es notwendig verschiedene Normalisierungsschritte für jedes Bild und jede Empfangsspule durchzuführen. Im Rahmen diese Arbeit wurde untersucht ob es durch den komplexen Rekonstruktionsvorgang zu Einschränkungen bei der Anwendung des Verfahrens für die quantitative Bestimmung von NMR-Parametern (T2) kommt. Dafür wurden Messungen mit voller Kodierung mit dem etablierten Parallelimagingverfahren „Grappa“ und mit der IRGN Rekonstruktion verglichen. Es zeigte sich, das beide Parallelimagingverfahren für quantitative Auswertungen grundsätzlich geeignet sind. Für die verwendete kartesische Bildkodierung konnten gewisse Vorteile der IRGN Rekonstruktion in Bereichen mit geringem SNR im Vergleich zur verwendeten „Grappa“ Implementierung gefunden werden. Für eine radiale k-Raum Abtastung sind weitere Untersuchungen notwendig.

Abstract

Nonlinear parallel imaging reconstruction using an iterative regularized Gauss Newton method (IRGN) has shown its potential in several applications. This technique acquires data using array coils were the coil sensitivites and the image are both computed from the under sampled data. Several normalization steps for each image and each receiver coil are necessary prior image reconstruction. In the current work it was examined if the complex reconstruction process limits the applicability of this method for quantitative determination of NMR parameters (T2). Hence measurements with full encoding using the established parallel imaging method „Grappa“ were compared with the IRGN reconstruction. It was shown that both parallel imaging techniques are in principle applicable for quantitative determination. In the case of the applied cartesian image encoding certain advantages of the IRGN reconstruction in comparison to the applied „Grappa“ implementation were found in areas with low SNR. Further examinations are necessary for radial k-space sampling.

1 Introduction

The concept of conventional parallel MRI is based on the fact that the spatial receiver sensitivities are utilized for image generation, since the contribution of a signal source varies with its relative position to the receiver coil. The combination of Fourier phases encoding steps and the spatial information provided by the coil sensitivity distribution of the receiver coil arrays allows the reconstruction of MR-images from basically under sampled data. Hence spatial encoding can be performed more efficiently.

Nowadays parallel imaging techniques are widely used in different applications of MRI [1]. The various implementations can be generally divided into two groups. Depending whether the coil sensitivities can be directly determined during the process of image reconstruction from the undersampled data or an additional scan is necessary for their computation.

The recent developed iterative regularized Gauss Newton method (IRGN) [2] for parallel imaging determines both the coil sensitivities and the image from undersampled multi-coil data. The numerical implementation of this sophisticated method is computationally demanding but it allows for specific applications very high accelerating factors [3,4].

In this study it was investigated if this type of reconstruction is applicable for quantitative imaging despite the complex reconstruction including image individual normalization. For that purpose high resolution multi-echo imaging with different acceleration factors was used for the quantification of the transverse relaxation time (T2).

2 Methods

Three multi Spin-Echo (SE) datasets from phantoms and a healthy volunteer were acquired on a clinical 3T scanner with different acceleration factors (fully sampled, AF=2 and AF=4). One phantom consisted of 6 water samples with varying Gd-DTPA (Magnevist®) concentration ranging between 0.95 and 6.7 mM. A second experiment using a homogeneous water phantom filled with 6.8mM Gd-DOTA (Dotarem®) was carried out to examine the reconstruction performance in low SNR regime. Scanning parameters were TR=1800 ms, 10 echos, 150 mm FOV, 256x256 matrix, 10 slices, echo spacing=20/9.2 ms, slice thickness=5/2 mm for the phantom/in vivo respectively. In

vivo measurements were performed with a 8Ch tx/rx knee coil while the water samples and the homogenous phantom were imaged with a 32Ch tx/rx and 12 Ch rx head coil respectively. In order to estimate the coil sensitivities 24 parallel imaging reference lines were used in the Cartesian k-space. Subsequent rawdata were exported from the scanner, and offline reconstructed using the IRGN method.
The T2 maps were computed using monoexponential linear least squares curve fitting on a pixel-by-pixel basis. The initial spin-echo was excluded from the fitting procedure to minimize artifacts in the T2 calculation due to non-ideal slice profile or B1-inhomogeneities [5]. Echo signals below the noise level at longer echo times were discarded. For the water samples, ROIs were manually placed over each probe in the T2 maps of the central slice. In the homogenous phantom four ROIs were placed at the border and one centre. In the in-vivo case the ROIs were manually placed in a homogeneous region of the specific tissue.

3 Results

The resulting reconstructed images of the in vivo measurement and the first phantom data acquired without acceleration using sum of squares (SOS) and with AF=2, 4 using IRGN are shown in figure 1. The reconstructions show that the image quality of all accelerated scans is visually comparable to the fully sampled data. No residual aliasing artifacts or local noise amplification were observed up to AF=4.

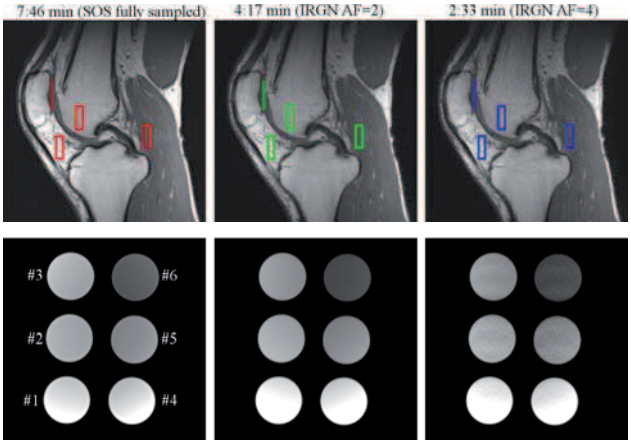

Figure 1 Representative images of different reconstruction techniques for different acceleration factors.

In the phantom case, using an echo spacing of 20 ms, the increase of the noise level in low signal regimes due to the inherent noise characteristic of the SOS reconstruction [6,7] pretended signal in dark areas of the reconstructed image. In contrary the additional noise level introduced in low signal areas usig IRGN was less dominant. A consequence of the weighting operation of the reconstructed images at each echo time with their SOS of the current coil sensitivites [2]. This different signal characteristic was most prominent for sample #6. The mean signal time courses originating from a circular ROI place in sample #6 for both reconstructions are depicted in figure 2.

Additionally the mean signal from a rectangular ROI placed in the background is given.

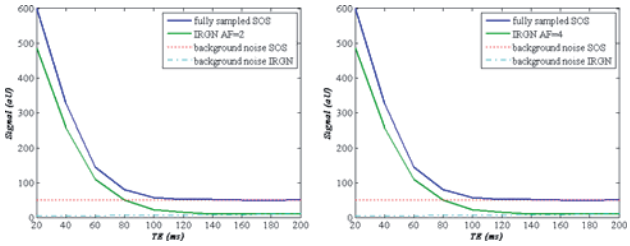

Figure 2 Comparison of the signal time course of sample #6 and background for the SOS and IRGN reconstruction.

The resulting T2 maps of the different tissues for the different acceleration factors are shown in figure 3.

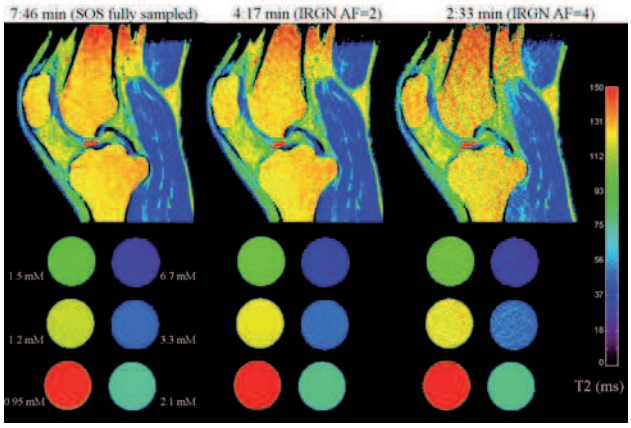

Figure 3 Corresponding T2 maps for different acceleration factors, concentrations are given in mM.

At an acceleration factor of 4 the general noise enhancement introduces noisier T2 maps compared to the fully sampled data, still the relaxation times are in agreement with literature values [8,9].
The resulting T2 maps of the phantom are shown in figure 3, mean T2 values of the different tissues and the phantoms are shown in figure 4. Error bars represent the standard deviation (SD).

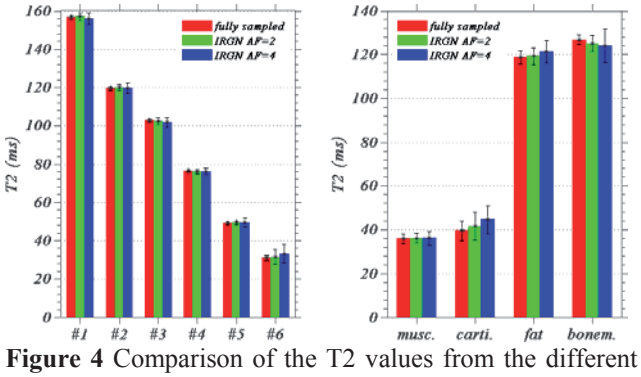

Figure 4 Comparison of the T2 values from the different reconstruction methods.

The comparison of the mean values show that the relaxation times computed from the accelerated IRGN scans lie in the interval mean ± SD of the fully sampled SOS data.

Resulting T2 maps of the homogeneous phantom obtained from the IRGN at different acceleration factors are shown in figure 5. Additionally for comparison reason a T2 map obtained from GRAPPA with AF=4 is depicted as well.

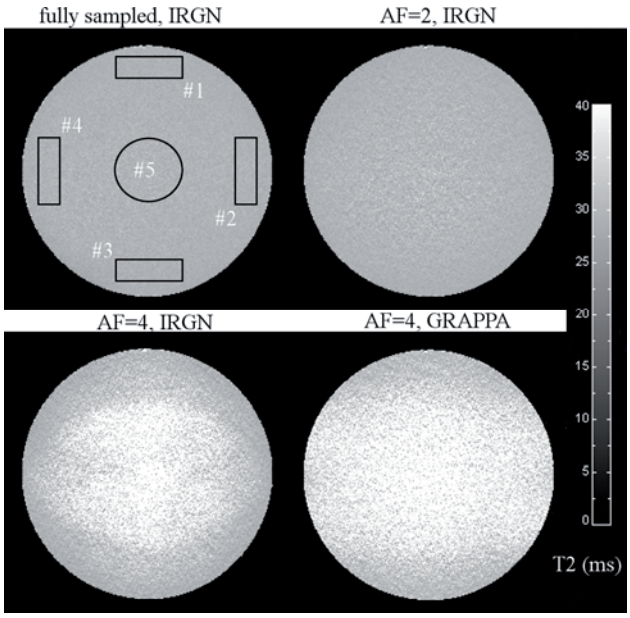

Figure 5 Comparison of the spatial varying T2 values in homogeneous phantom at different AF and reconstruction methods, phase encoding: L-> R.

Up to an accelearation factor of 2 the resulting T2 values in the entire phantom can be considered as reliable T2 estimates. In the challenging area at the phantom´s center (table 1, ROI 5), where the sensitivities of the different coils overlapped, hence less independent coil information was available, both algorithms yielded corrupted T2 estimates when using four fold under sampling.

IRGN	ROI 1	ROI 2	ROI 3	ROI 4	ROI 5
fully sampled	29.32 ± 1.01	29.46 ± 1.16	29.25 ± 1.18	29.53 ± 1.31	29.70 ± 1.58
AF = 2	29.69 ± 1.59	29.69 ± 1.55	29.66 ± 1.60	29.82 ± 1.78	30.59 ± 2.47
AF = 4	32.85 ± 4.67	32.93 ± 4.53	32.51 ± 4.47	33.85 ± 5.51	54.42 ± 23.81

GRAPPA	ROI 1	ROI 2	ROI 3	ROI 4	ROI 5
fully sampled	30.33 ± 1.08	30.31 ± 1.17	30.44 ± 1.27	30.41 ± 1.29	31.30 ± 1.68
AF = 2	30.10 ± 1.49	30.24 ± 1.49	30.17 ± 1.53	30.32 ± 1.69	31.08 ± 2.25
AF = 4	34.08 ± 5.16	40.09 ± 7.47	35.06 ± 5.93	40.27 ± 7.61	52.78 ± 18.87

Table 1 Comparison of the T2 values from homogenous phantom for the different reconstructions, T2 given in ms.

With AF=4 the IRGN technique showed in the outer regions superior reconstruction results than GRAPPA. This was confirmed by evaluating the resulting T2 values in the corresponding ROI. Results are given in table 1, demonstrating higher mean values and increased standard deviations of T2 obtained by using GRAPPA.

4 Discussion

In this study we successfully demonstrated that nonlinear parallel imaging IRGN is applicable to quantitative MRI. Compared to conventional parallel imaging techniques, which apply SOS for combining the individual reconstructed coil images, IRGN does not produce a noise related signal bias. This might be a specific advantage for diffusion weighted imaging using high b-factors.

The experiment with the homogenous phantom revealed the common limits of parallel reconstruction techniques including IRGN, where with increasing acceleration factors the SNR drops and the uncertainty of the determined T2 increases. At high acceleration IRGN showed at the border regions of a homogeneous the phantom a better performance as GRAPPA.

Besides the computational requirements of IRGN its attenuated noise level increase makes it a valuable alternative to conventional parallel imaging, especially in low SNR regime. Future work will be targeted on modelling a formalism of the noise characteristic of IRGN equivalent to the g-factor. For radial k-space sampling it is expected that the performance of the IRGN reconstruction is even better but it must be investigated additionally.

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