Iterative signal decay correction for fast T_1 measurements

T. Nielsen[1], T. Schaeffter[1]

[1]Philips Research, Hamburg, HH, Germany

Introduction

The fast acquisition of T1 maps is demanded in quantitative brain imaging [1] or in contrast agent studies [2], where a Look-Locker sequence is applied [3]: Following an inversion rf-pulse, a train of rf-pulses is applied to obtain a number of gradient echoes. Since a number of gradient echoes are used to obtain k-space lines for an image at a given inversion time, the signal decay during this acquisition results in image artifacts and thus to wrong T1 values. An iterative mapping method is proposed that uses the estimated T1-values to correct the signal decay during image acquisition. The technique was tested on simulated and phantom data obtained on a clinical 3T MR-scanner.

Methods

A Look-Locker type sequence was used for T1-mapping: After the inversion pulse n_{PH} images are acquired at different inversion delays. For this, the gradient echoes were grouped into n_{PH} phases, and for each image, a number of n_{TFE} k-space lines were acquired during one readout train, resulting in a total number of n_{TFE}*n_{PH} readout pulses following one inversion pulse. Two problems are associated with this approach: 1.) The decay is altered by the readout pulses giving an apparent decay time T_1*. 2.) The different k-space lines are not acquired at the same inversion delay, which leads to image artifacts if the time difference is significant compared with T_1* (large n_{TFE}). It causes a broadening of the local PSF in the phase encoding direction. The first problem can be solved by applying an appropriate correction. The second problem can be solved by taking the signal decay during image acquisition into account, which is similar to a method proposed to correct for the T_2* decay in single-shot acquisitions [4]. We use an iterative correction scheme comprising two steps:

1.) Estimate the T_1* values.

We fit the model function $A^{(i)}(x,y) - B^{(i)}(x,y)*\exp(-t/T_1*^{(i)}(x,y))$ to the signal $S^{(i)}(x,y)$ of each pixel. Here, i denotes the iteration step, and t is the mean time of each of the n_{PH} phases.

2.) Use $T_1*^{(i)}$ and $A^{(i)}$ from the fit to correct the signal:

We solve $E(T_1*^{(i)})(S^{(i+1)}-A^{(i)}) = F(S^{(i)}-A^{(i)})$ for $S^{(i+1)}$. Here, F denotes the usual Cartesian Fourier-encoding, and E represents Cartesian Fourier-encoding including the T_1* decay during the acquisition of one phase. E depends on the profile ordering used (e.g. linear or low-high).

Steps 1 and 2 can be iterated resulting in improved estimates of T_1*, A, and B. The iteration is stopped after a few cycles to obtain final values of T_1*, A, and B. These are used to calculate $T_1 = T_1* (B-A)/A$ [5].

We used simulated datasets and phantom scans acquired on a 3T Philips Intera to evaluate the correction method.

Results and Discussion

Figure 1 shows typical artifacts due to T_1 decay on a phantom scan (flip angle 10°, TR=8 ms, n_{TFE}=32, n_{PH}=8). The upper image shows the first phase, which is most affected by the T_1 decay, because here the signal changes are fastest. The lower image shows the last phase for a comparison, which is not affected by the T_1 decay because the system is already in the steady state. The T_1 decay causes a smear in the phase encoding direction, lowering the spatial resolution, and a wrong absolute magnitude near the edges. Since the magnitude of the first phase is most important for the fitting of B, a wrong value of B is determined without the correction. This also affects the calculation of T_1. Figure 2 shows two profiles through a T_1 phantom with and without the correction method applied: without the correction, T_1 values are more than 10% off, especially for the low T_1 values. The true T_1 values of 300 and 700 ms can be recovered by the correction method.

Conclusion

The iterative correction method presented here can be used to improve fast T_1 measurements in a self consistent way. It is especially useful, where the acquisition time for one phase is comparable with the T_1* times. Spatial resolution in the phase encoding direction as well as absolute values of the T_1 map are improved.

References

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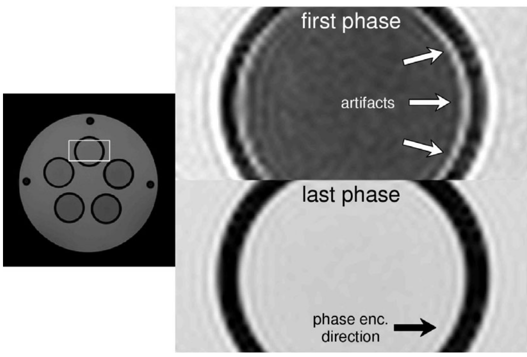

Figure 1:
Left: Overview of the phantom with a rectangle indicating the zoomed area.
Right: Uncorrected images of phantom scan. Artifacts near edges are visible in the first phase image.

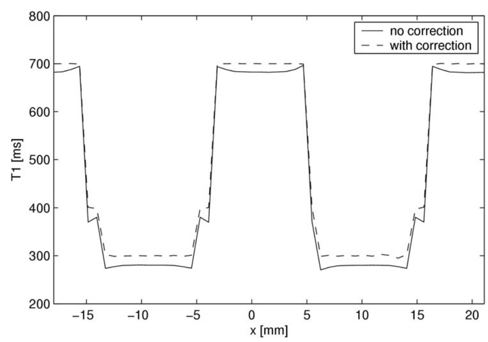

Figure 2:
Profiles through T1 map with and without iterative correction.