Single Shot T1-Mapping, using a Radial Look-Locker Sequence and an optimal Profile Order determined by the Golden Cut Rule

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Introduction

The Look-Locker sequence is used for fast T1 determination in brain imaging [1] or applications demanding a high temporal resolution, such as quantitative contrast agent studies [2]. Further acceleration is achieved by using undersampled radial k-space data subsets of one single shot [3-5], and resolving single time points by a linear keyhole approach ("tornado" [6]) for T1 determination. For a discrete profile spacing, this comes with restrictions regarding the profile selection, temporal resolution, and the size and number of keyhole radii used for image reconstruction. The angular spacing has to be optimized depending on these parameters. In this work, a profile order based on the golden cut rule is presented, that does not require any a-priori knowledge about image reconstruction parameters and that permits arbitrary image generation from the entire data set.

Materials and Methods

The radial Look-Locker sequence applies a train of N low flip angle profile acquisitions following an inversion RF-pulse. Usually all profiles P_n are sorted into a small number (LLp<<N) of phases resulting in LLp images with different pre-definded inversion delays Ti, used for the T1 fit. In contrast, the golden cut profile order permits the resolution of a high number of phases at arbitrary time points using arbitrary numbers of profiles: For radial imaging, all profiles contain central k-space samples, decisive for the image contrast. To resolve a certain time point Ti=tn=n*TR, only central k-space data of the two profiles P_{n-1} and P_n , acquired before and after this time point, are exploited in the reconstruction. To all other profiles P_{n-1-r}, acquired earlier, and P_{n+r} , acquired later, a keyhole filter is applied with a radius r, deleting k-space data at k<=r (Fig.1a). In order to guarantee an optimal profile distribution, not only for all numbers of profiles, but also for all keyhole regions, consecutive profiles are spaced by an angular increment of $\theta_{gc} = (\sqrt{5} - 1)/2 * 180° \approx 111.25°$. Thus, each proceeding profile used for image reconstruction divides the largest angular gap of the current set of profiles. Fig.1b shows the profile distribution for different numbers of profiles. Fig. 1c demonstrates the result for the combination of a linearly growing keyhole radius and a golden cut profile spacing.

All images were obtained on a 3T whole body scanner (Philips, Intera). The phantom, which was used for the fit evaluation, includes compartments with T1=300ms to 800ms and was imaged using a FOV=320mm, matrix=128x128, slice thickness=8mm, flip angle=10° and a TR = 5ms. For the T1 fit LLp=300 images with a temporal resolution of ΔTi=5ms were generated from one single shot data set covering 1.5s. For imaging of a volunteer's head a FOV=220mm, slice thickness=5mm, flip angle=10°, matrix=256x256 and a TR=5.2ms were used. LLp=60 images were generated of a temporal resolution of ΔTi=26ms for T1 determination. The images were reconstructed offline, and the entire number of profiles was used for reconstruction of all images. T1 was determined, using the Levenberg-Marquardt algorithm.

Results

Fig. 2 shows the T1 map generated for the phantom experiment. The mean fit error was 3.1%. The technique also provided stable results for the in-vivo application. Fig. 3 shows the T1 map derived from 60 images generated from single shot k-space data.

Discussion/Conclusion

The golden cut profile order overcomes the restrictions of a discrete spacing, regarding the parameter selection for image reconstruction. It guarantees an optimal profile distribution for an arbitrary number of profiles used, and as a result, for all keyhole regions. Thus, it results in a high flexibility in time point resolution and profile selection for image reconstruction. It permits the recovery curve to be sampled with a high temporal resolution, and therefore, it yields stable fit results and high quality T1-maps within 1-2s. This makes the method particularly interesting for applications such as fast quantitative monitoring of drug or contrast agent delivery.

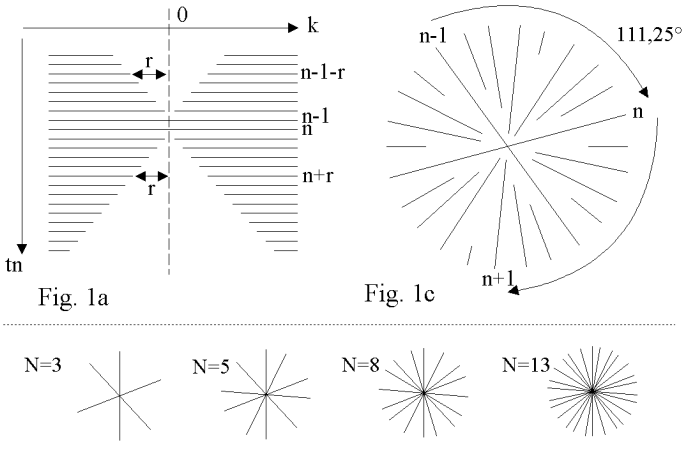

Fig.1. a) Linearly growing keyhole radius for resolution of the time point n*TR. b) Profile distribution for different numbers of profiles c) k-space data preparation for the generation of an image with a contrast according to the time point n*TR.

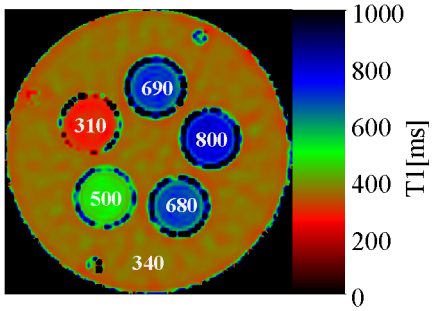

Fig. 2. T1 map derived from 300 images, generated from 300 profiles acquired within 1.5s in one single shot. The true T1 values are indicated in ms for reference.

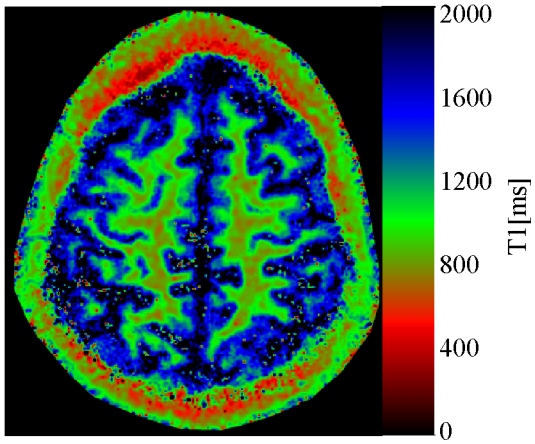

Fig. 3. T1 map derived from 60 images covering the first 1.56s of the single shot inversion recovery acquisition.

References

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