Multiple Echo Multi Shot (MEMS) Diffusion Sequence

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Introduction: Multiple echo (ME) images to obtain T_2 measurements and diffusion imaging have been usually considered as two independent experiments. Both methods require the acquisition of a series of images to describe the transversal relaxation time and the diffusion coefficient of the structure of interest. It has been proposed to obtain all these images within one scan, resulting in a reduction of imaging time. This was achieved by acquiring multiple echo images, each one with different diffusion weighting factors (DWF) using a single shot EPI sequence (MESS) [1, 2]. However, the problem with this approach is the associated long echo read-out, consequently the minimum achievable echo time (TE) tend to be long, allowing the computation of T_2 maps only to tissues with relatively long T_2s. To address this issue we propose to extend this method to acquire ME images using a multi shot (MEMS) approach with different DWF, which allow us to reach shorter TEs.

Methods: A single shot dual echo EPI sequence with diffusion gradients and echo navigators, only for the first echo, was modified so that to include diffusion gradients in any of the two echoes. In order to reduce the TEs, the sequence was combined with a muti- shot approach. The sequence was build up on a Philips Intera 1.5T and the resulting sequence is shown in figure 1.

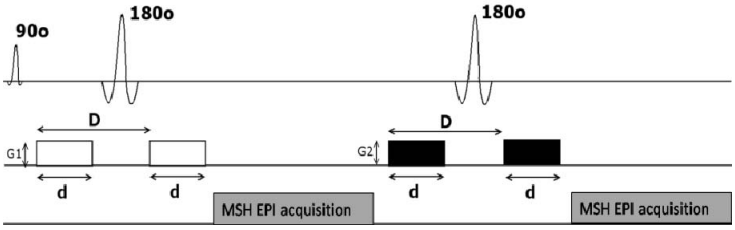

Figure 1. MEMS Sequence diagram

Experiments (summarized in table 1) were performed in three different phantoms (1 bottle of copper sulfated water and 2 bottles with different concentration of NiCl2 and agarose). Diffusion coefficient and T_2 reference values were acquired using conventional sequences (Scan 1 and 2). The next two scans were acquired with a MESS and MEMS diffusion sequence. Diffusion weightings (DW) were applied in three orthogonal directions. All scan were acquired with a matrix of 128x128, a FOV 230x230 mm^2 and TR = 1000ms with no repetition.

Table 1. Sequence descriptions

Scan Nº	Description	Echo 1	Echo 2
1	DW single shot EPI, matrix 96 x96.	b=[150 300 600] s/mm^2 TE_1 = 78 ms	NA
2	Dual Spin Echo, matrix 128 x128.	TE_1 = 30 ms	TE_2 = 150 ms
3	MESS, , matrix 80 x 80.	b=[150 300] s/mm^2 TE_1 = 63 ms	b=[300 600] s/mm^2 TE_2 = 177 ms
4	MEMS, , matrix 96 x 96.	b=[150 300] s/mm^2 TE_1 = 15 ms	b=[300 600] s/mm^2 TE_2 = 110 ms

Additionally, *in vivo* acquisitions were obtained from a calf of a healthy volunteer (male, 29 years old). In this case the MEMS sequence was acquired with TE_1/TE_2 = 13/52ms and b values of 150 and 300 s/mm^2 for both echoes. The dual spin echo sequence was acquired with (TE_1/TE_2 = 13/50 ms).

In the MESS and MEMS scans, mean diffusivity (MD), T_2 values were calculated using $S_{ij}=S_0 e^{-bi.ADCi} e^{-TEj/T2}$, where b_i and ADC are the different b values and the apparent diffusion coefficient in each image respectively; TE_j, the different echo times and S_{ij} the measured signal.

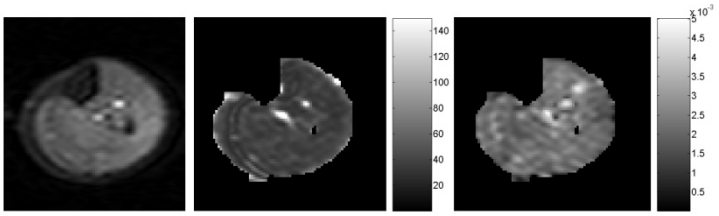

Figure 2 - Left: T2-weighted image. Center: T2 map (ms). Right: MD map calculated from the MEMS acquisition (mm^2/s)

Results: Results of the MD (x10^{-3} mm^2/s) and T_2 (ms) for different experiments are given in table 2, average and standard deviations are measured within the ROI. It is noticeable an underestimation of the T_2 values in phantom experiments and an excellent correlation of the MD values of the MEMS sequence with the gold standard scan. Muscle MD and T_2 values are in good agreement with literature [3, 4]. Images of the in-vivo experiments are shown in Figure 2.

Table 2. T2 (ms) and MD values (mm^2/s) measured in each experiment.

Scan	Phantom 1		Phantom 2		Phantom 3		In-Vivo	
Gold Standard	302±7	2.30±0.06	240 +- 9	2.27 +- 0.04	281 +- 6	2.22 +- 0.03	28.3 +- 0.8	1.50 +- 0.11
MESS	201 +- 6	2.28 +- 0.04	174 +- 6	2.29 +- 0.06	381 +- 10	2.24 +- 0.02	NA	NA
MEMS	165 +- 3	2.37±0.04	150 +- 2	2.28 +- 0.02	243 +- 14	2.27 +- 0.03	25.9 +- 1.4	1.52+- 0.18

Conclusion and discussion: The proposed MEMS sequence provides valuable information of T_2 decay and mean diffusivity from a single scan. Results of the MD are well correlated with a gold standard scan. The multi-shot approach allows us to drastically reduce the echo time (75% for the 1st echo and 48% for the 2nd echo), so that the technique can be applied in tissues with short T_2, such as muscle. Result of the MEMS sequence showed a good agreement for the T_2 and MD measurements in in-vivo data.

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References [1] Li, Sotak, JMR, 92:411 (1991). [2] Nana, Zhao, Hu, MRM, 60:1512 (2008). [3] Yanagisama, Shimao, Maruyama et al., MRI, 27:69 (2009). [4] Nygren, JMRI, 23:177 (2006).