Application and analysis of multi-echo sequences for Renal MRI using EPG

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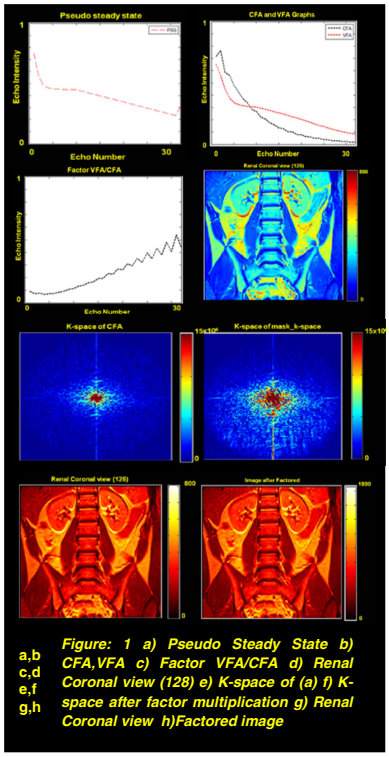

a,b c,d e,f g,h

Figure: 1 a) Pseudo Steady State b) CFA,VFA c) Factor VFA/CFA d) Renal Coronal view (128) e) K-space of (a) f) K-space after factor multiplication g) Renal Coronal view h)Factored image

Target audience: This study would be of relevance to people from MR community who are interested in pulse sequence design applications for renal studies. **Purpose:** The purpose of this study is to show relative improvement in the signal intensities and to reduce the blurring caused due to T2 decay in multi echo MR sequences in an MR Image hence improving the clinical diagnosis. **Theory**: In Carr-Purcell-Meiboom-Gill (CPMG) based multi-echo pulse sequences (e.g. GRASE,TSE) the stimulated echoes play significant role, contributing to increase the amplitude at later echoes when used with low flip angles (FA's) which can be used to optimize the echo signals, to manipulate contrast and to reduce blurring effects due to T2 decay[1]. Variable flip angle (VFA) scheme proves to be effective in maintaining the amplitude at later echoes than constant flip angle (CFA). The magnetization of spins brought close to pseudo- steady state (PSS) [2] to increase the amplitude at later echoes. PSS signal could be designed through equation 1 to 4 with initialization scheme as three control points. Echo Train Length (ETL) of 20 and 32 has been used for phantom simulation and in-vivo data acquisition & simulation respectively. Signal intensities, S_{first}, S_{min} & S_{max} chosen at echo number 1st, 10th and 32nd respectively, rest of the echoes numbered from 2nd to 9th and 11th to 31st calculated as per asymptotic and smooth function approach equation (3) & (4) respectively. Figure 1(a) depicts the PSS signal design as per equation 1 through 4. Look ahead formulation of EPG equation (5) is used to generate VFA's. Figure 1(b) shows the simulated signal intensities for CFA and VFA **Methods:** *In-silico Simulation:* 'Modified Shepp-Logan phantom' with dimension 120x120 was generated and used for the simulation before in-vivo study. Signal intensities were generated for 20 echoes. Two six shot, EPI masks were created and applied on simulated phantom based on VFA and CFA scheme. *In-vivo study*: Six datasets from healthy volunteers were used in this study. Images were acquired using Siemens Magnetom, Avanto 1.5 T scanner as a part of an ERB approved protocol. Turbo Spin Echo (TSE) sequence with respiratory gating used for data acquisition with acquisition parameters chosen as TR/TE=2000/49 ms, FA=130°, ETL of 32 with TF=4 and ESP as 12.1 ms maintaining matrix dimensions as 128x128. Single Renal coronal slice of thickness 5 mm was acquired for each dataset. Figure 1(d) shows renal coronal view of single dataset. The relaxation parameters used in simulation were T1/T2=1265/88 ms obtained from literature for renal cortex [5, 6]. The signal intensities were simulated for CFA and VFA using EPG framework as shown in Figure 1(b). The modulation of acquired echo intensities were performed in k-space. Figure 3 shows the workflow for data acquisition and reconstruction where a factor VFA/CFA as VFA is calculated (shown in figure 1c) and applied on the k-space of CFA image shown in figure 1(e). **Results and Discussion:** As per *In-silico simulation*, the reconstructed VFA image showed significant decrease in the blurring compared to CFA as shown in figure2(c). As per *In-vivo* studies, the reconstructed VFA image showed significant increase in the mean intensities in the Region of Interest (ROI) relevant to the renal anatomy (figure 1h), as relative gain in the k-space (figure 1f) increased by a factor indirectly justifying the hypothesis for VFA over CFA Image. Figure 4 shows the mean and standard deviation calculation for each datasets both for CFA and VFA image in selected ROI relevant to the renal anatomy. We can observe that there is significant increase in the mean intensity for VFA image compared to CFA image indicating the relative increase in SNR. **Conclusion and Future Work:** This study shows significant reduction in blurring and improved signal intensities in the ROI relevant to renal anatomy for VFA's through multi-echo sequence which aid in the accurate quantification of renal perfusion and diagnosis of Chronic Kidney disease. The high SNR also leverage to utilize parallel imaging techniques to accelerate the acquisition of renal MRI data. The use of EPG in CPMG based multi-echo sequence with VFA proves to be effective in increasing SNR, reducing blurring, decreasing acquisition time (requirement to track dynamic changes in physiological process such as Glomerular Filtration Rate(GFR). Use of VFA's also decrease the effective RF power deposition to patient hence reducing the effective SAR overall proving the effectiveness of such sequences in clinical diagnosis can be justified. Future work involves implementation of 3D-GRASE on Philips 1.5 T Multiva for renal perfusion quantification. One of the inherent advantage of using GRASE (as it is combination of TSE and EPI) is the availability of two additional gradient side echoes along with central spin echo making the acquisition faster than their individual counterparts proving its feasibility in clinical studies. [2] **References:** [1]. Weigel et al. JMRI 2014 [2]. Liang et al. PMBS 2014 [3]. Busse et al. MRM 2008 [4]. Alsop MRM 1997. [5] Cutajar et al. MAGMA 2011. [6] Chhor et al.ISMRM 2003.

$$S_{first} = \sin^2(\alpha_{first}/2) \quad S_{min} = S_{pss}(\alpha_{min}) \quad S_{max} = S_{pss}(\alpha_{max}) \qquad (1)$$

$$S_{pss}(\alpha) = \sin(\alpha/2)^{1/2}\, p_{-1/2}[\sin(\alpha/2)(1+(\sin^2\alpha)/(8\sin^4(\alpha/2)))] \qquad (2)$$

$$S(i+1) = 0.5[S(i) + S_{min}] \qquad (3) \qquad S = S_{min} + \Delta S(n/N)^{3/2} \qquad (4)$$

$$\alpha_{1,2}(n) = 2\arctan(-iE_1E_2Z^- \pm \sqrt{-E_1E_2(Z^-)^2 - (E_2^2F^- - I_n)(E_2^2I_{n-1}I_n)}\,/\,(E_2^2I_{n-1} - I_n)) \qquad (5)$$

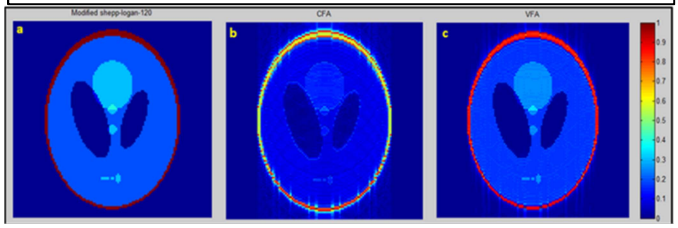

Figure 2.a)'Modified shepp-Logan' b) CFA c) VFA

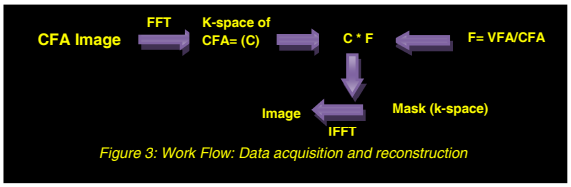

Figure 3: Work Flow: Data acquisition and reconstruction

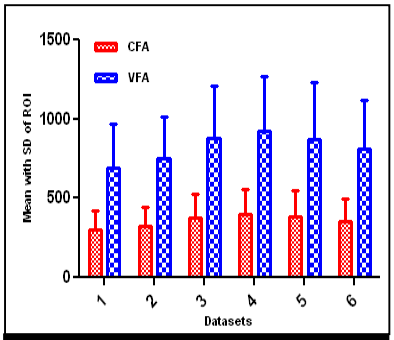

Figure 4: Mean and standard deviation calculation for ROI around renal anatomy