3D Ultra-Fast Spin Echo Inner Volume MRI: Neuroimaging Applications

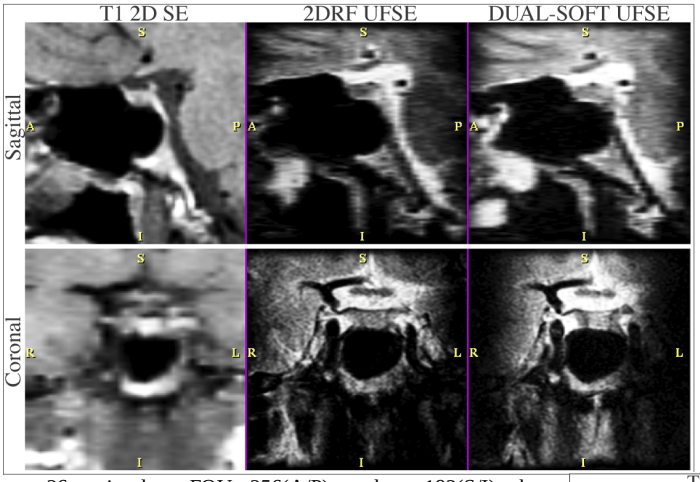
D. Mitsouras[1], R. V. Mulkern[2], A. Edelman[1], G. P. Zientara[3], F. J. Rybicki[3]

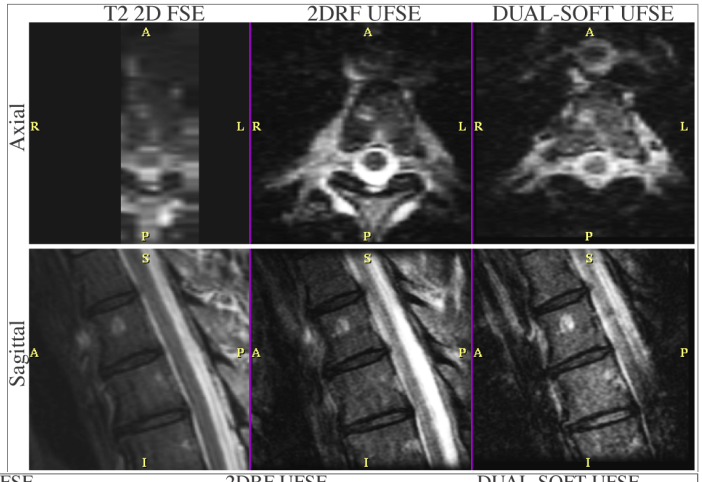
[1]EECS, Lab For Computer Science, Massachusetts Institute of Technology, Cambridge, MA, United States, [2]Radiology, Children's Hospital, Boston, MA, United States, [3]Radiology, Brigham And Women's Hospital, Boston, MA, United States

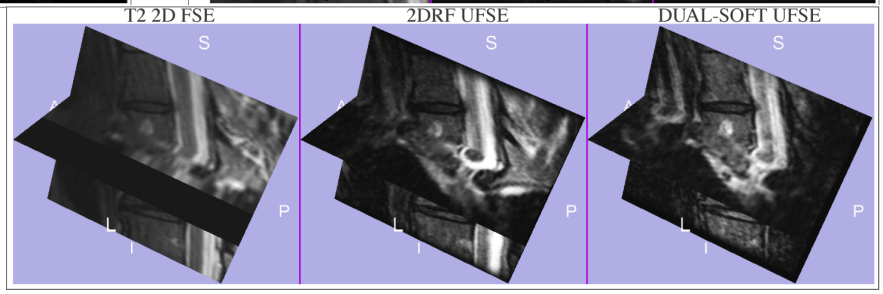
Introduction: In many MRI applications, scan time is expended acquiring data from portions of the field of view outside the diagnostic region of interest in order to satisfy the Nyquist sampling criterion while producing the desired spatial resolution. Often, spatial resolution is sacrificed (most often along the slice-select dimension) in order to limit scan time. Inner volume imaging bandlimits the MR signal to encompass only the ROI, effectively increasing the necessary Nyquist sampling interval ($\Delta\boldsymbol{k}$). Then, target resolution can be obtained in decreased imaging time. Ultra-fast spin echo (UFSE) employs non-selective hard refocusing RF pulses in order to minimize the echo spacing of the readout train so as to reduce T_2-related FSE artifact. However, with UFSE, the bandwidth of the signal is increased proportionally to the size of the entire sample. Although the combination of a UFSE train and inner volume imaging appears intrinsically incompatible, it has been shown, in phantom experiments, that relatively artifact-free 3D FSE MR images at high resolution can be produced by carefully combining the two methods [2]. The technical capability to perform good frequency cutoff spin selection with one or two RF pulses so as to minimize aliasing artifact is currently available. Furthermore, the shorter echo train achieved by non-selective refocusing RF pulses reduces typical FSE imaging artifact, such as blurring associated with relaxation.

Methods: The use of non-selective hard pulse refocusers places even greater constraints on the necessary frequency cutoffs of the spatially selective excitations. Two techniques have been previously demonstrated to achieve inner volume selection for use with non-selective refocusers [2]. A 3D hard pulse FSE sequence [1], augmented with each of the two methods of spin selection for inner volume imaging was used in this work. The first method involves spin selection using a 2D-selective RF excitation (2DRF). To take advantage of the short echo spacing of the UFSE, a reversed spiral trajectory (typically 5.5ms) is used to traverse the 2D k-space necessary to excite a disc shape equally throughout the frequency encoded dimension. Rephasing gradients are not required, and the bulk of magnetization is excited at the end of the trajectory, allowing closely spaced (e.g., 3–5ms depending on BW, ROI) hard refocusers. The second method, termed DUAL-SOFT, relies on two 1D orthogonally selective pulses, the $\pi/2$ and the first π pulse, in order to select spins inside a beam along the frequency encoded dimension. Following typical constraints on commercial MRI scanners, the first echo, formed by the selective π pulse, occurs some 12ms after the $\pi/2$ pulse. Following the first echo formation, subsequent echoes are formed by closely spaced (i.e., 3–5ms) non-selective hard π pulses. A single set of additional crushers around the selective π pulse are balanced for the inner volume spins, but unbalanced for the outer volume spins, throughout the echo train, and so serve to avoid spurious echoes from the undesired volume.

Results: A healthy volunteer was imaged using a 1.5T MR scanner (Signa LX EchoSpeed, GE Medical Systems, Milwaukee, WI). *Brain*: Clinical T1 weighted sagittal scan:26cm in-plane FOV, 256(A/P) readout, 192(S/I) phase encodes and 3mm slice thickness, (voxel size 1.016x1.354x3mm). 24 slices were acquired using a single echo spin echo sequence with .5sec TR, 14ms TE, 16KHz BW and 1 NEX; imaging time 208sec, by interleaving the acquisition of slices within a single TR. 2DRF UFSE scan: FOV of 7cm(S/I), 7cm(L/R) and 7.6cm(A/P), using 128(S/I) readout, 100(L/R) phase encodes and 38(A/P) slice encodes (voxel size .547x.7x2mm). Scan parameters were 3sec TR, 100ms Eff.TE, 50 ETL, 32KHz BW, and 2 NEX; imaging time 456sec. Echo spacing was 5ms, in this case limited by the BW. The 2DRF excitation was a 5.6ms long 14-loop spiral that excited a 7cm cylinder with aliasing sidelobes at 22cm radius. DUAL-SOFT scan: identical to 2DRF scan, except 102ms Eff.TE and the first echo at 12ms while all subsequent echoes were spaced at 5ms. *Spine*: Clinical T2 weighted sagittal FSE scan: 40cm in-plane FOV at 512(S/I) readout, 384(A/P) phase encodes and 4mm slice thickness (voxel size .781x1.042x4mm). 7 slices acquired, using a 2D FSE sequence, 16 ETL (appx. 12.8ms echo spacing), 4sec TR, 102ms Eff.TE, 32KHz BW and 4 NEX; imaging time of 392sec by interleaving slices within a single TR. 2DRF UFSE scan: FOV of 8cm(S/I), 8cm(A/P) and 8.4cm(L/R), using 128(S/I) readout, 100(A/P) phase encodes and 38(L/R) slice encodes (voxel size .625x.8x2mm). Parameters were 4sec TR, 100ms Eff.TE, 50 ETL, 32KHz BW, and 4 NEX; total imaging time 672sec. Echo spacing was 5ms, again limited by the BW. The same 2DRF excitation as the brain scan was used. DUAL-SOFT scan: identical to the 2DRF scan, except for 102ms Eff.TE and the first echo was at 12ms while all subsequent echoes were spaced at 5ms.







Conclusions: Both IVUFSE methods achieve high SNR inner volume neuroimaging with tightly spaced echoes, which can provide superior spatial resolution and SNR/unit time compared to the 2D counterparts. For example, the scan time for the spine was increased by a factor of 1.7, however the voxel volume was reduced by a factor of more than 3 ($1mm^3$ vs. $3.26mm^3$). In the brain, voxel volume was decreased by a factor of 5.4 ($.77mm^3$ versus $4.13mm^3$) while scan time was increased by only 2.2. Both IV strategies, 2DRF and DUAL-SOFT, provide similar quality 3D neuroimaging with DUAL-SOFT providing slightly better outer volume suppression. For limited field of view tasks, such as pituitary imaging and MR guided therapies of the spine, IVUFSE may prove a superior method for clinical use.

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References: [1] Mugler JP III et al. Radiology 2000;216: 891-899. [2] Mitsouras D et. al. in Proc. 11th ISMRM, Toronto, Canada, 987 (5/2003).