Group-encoded Ungated Inversion Nulling for Non-contrast Enhancement in the Steady State (GUINNESS): a balanced SSFP-Dixon technique for breath-held non-contrast MRA

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Purpose: While contrast-enhanced MR Angiography (CEMRA) is widely used for evaluation of vascular pathology, recent nephrogenic systemic fibrosis (NSF) concerns following administration of Gadolinium based contrast agents have spurred interest in non-contrast MRA methods. Balanced steady state free precession (b-SSFP) imaging [1-3] has shown great promise due to its high SNR and short scan times and has been successful in coronary and renal artery imaging. Robust fat suppression remains challenging at high field strengths due to B_0 and B_1 inhomogeneities. Conventional fat saturation compromises the SSFP steady state, causing ghosting artifacts. We propose GUINNESS (**G**roup-encoded **U**ngated **I**nversion **N**ulling for **N**on-contrast **E**nhancement in the **S**teady **S**tate) a balanced SSFP-Dixon 3D technique with a novel group-encoded k-space segmentation scheme for **breath-held** non-contrast MRA.

Methods: Pulse sequence: A group-encoded view ordering scheme was developed to a) minimize eddy currents- views within a segment are grouped together to avoid large gradient jumps b) retain sequential and centric view ordering properties for contrast manipulation and immunity to breath-hold loss c) enable use of non-separable sampling patterns such as 2D self-calibrated parallel imaging [4] as well as k-space corner removal. The new flexible view ordering helped restrict scan times to breath-holding limits. A color-coded group-encoding scheme is shown in Figure 1. To minimize the scan time further, we optimized the number of views (VPS) acquired per inversion (IR) pulse. Bloch simulations of b-SSFP with a 55º flip angle allowed us to use a long acquisition train (800 views) per IR pulse with minimal reduction in blood-tissue contrast. A 3D dual-echo bipolar readout balanced SSFP pulse sequence with a robust two-point Dixon reconstruction algorithm [5] was used for fat-water separation, eliminating the need for conventional fat suppression pulses. A slab-selective hyperbolic secant π pulse offset in the inferior direction relative to the acquisition slab was used to simultaneously effect venous and background suppression. The inversion time was chosen to optimally trade-off background/venous blood suppression and in-flowing arterial blood signal and was set to 1300ms at 3T. VPS was varied from 300-1000 to determine the optimal value. This enabled us to acquire the 3D volume in a single breath-hold, eliminating the need for respiratory triggering which could be unreliable or prolong scan times, especially in sick and elderly patients. Additionally, free-breathing scans were acquired to assess the motion robustness of the group-encoded k-space segmentation scheme.

Experiments- Imaging parameters for GUINNESS were as follows: 55° flip, ± 167 kHz bandwidth, TR/TE_1/TE_2 4.1/1.3/2.4 ms, 192x256 matrix, 35-37 cm FOV, 1.4-2 mm thick, 32-40 slices, 800 k-space points per segment, TI=1300ms. A self-calibrating hybrid space parallel imaging scheme with an acceleration factor of 2.5 was used in the phase encoding direction. This resulted in an overall breath-holding time of 18-20s. Seventeen subjects (6 patients, 11 normal) were imaged on a 3T GE MR750 system (GE Healthcare, Waukesha, WI) using an 8-channel torso array coil under an IRB-approved protocol.

Results: Figure 2A-C compares GUINNESS acquisitions with VPS of 300, 800 and 1200 acquired on a healthy subject with BH times of 25s, 20s and 18s respectively. Note the excellent arterial-background contrast and good in-flow effect achieved in a short BH time in (B) (VPS=800). Longer VPS leads to increased venous and background signal (arrows in C). Figure 3 compares MIPs from an 18s GUINNESS acquisition on a patient with fibro-muscular dysplasia (FMD) with a conventional CEMRA MIP. Note the narrowing of the right renal artery depicted on both techniques as well as the beaded appearance of the left renal arteries. Figure 4 compares MIPs from a free-breathing GUINNESS scan (A) and a 20s breath-hold scan (B) demonstrating the inherent robustness to breath-hold loss of the technique.

Discussion: The proposed GUINNESS technique yields excellent fat suppression, high SNR and contrast and excellent visualization of the renal vasculature, especially at 3T where conventional fat saturation techniques are suboptimal. By using a centric group-encoding scheme, we could acquire a large number of views for each IR pulse, reducing BH times. We also eliminated the need for respiratory and ECG gating making it more robust. The centricity further imparts a degree of robustness to the sequence which could be useful in patients who cannot hold their breath reliably.

References: [1] Katoh et al. Kidney Int 66:1272–1278 (2004) [2] Takei et al. Proc ISMRM, p3420 (2008) [3] Saranathan et al. Proc. ISMRM, p3900 (2009) [4] Beatty et al. Proc ISMRM, p1749 (2007) [5] Ma et al. MRM. 52:415-419 (2004)

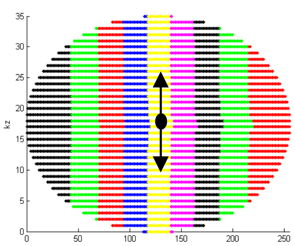

Fig. 1. Group-encoding scheme

Fig. 2. GUINNESS images with VPS - 300 (A), 800 (B) and 1200 (C). Note the increasing renal vein, IVC and background signal with increasing VPS. VPS = 800 (B) is an optimal tradeoff between BH time, in-flow signal and image contrast

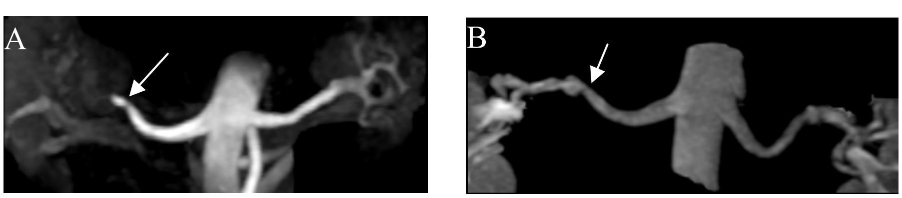

Fig. 3. MIP of GUINNESS scan (A) with a VPS of 800 on a patient with FMD depicting the beaded appearance of the renal arteries. Note that the right renal artery stenosis correlates with the contrast-enhanced MRA (B)

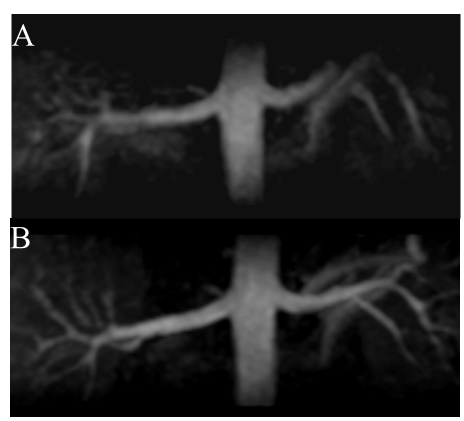

Fig. 4. MIPs from a fully free-breathing scan (A) compared to a breath-hold (B) demonstrating the motion robustness of the proposed group-encoded scheme