Optimized Three Dimensional Sodium Imaging of the Human Heart on a Clinical 3T Scanner

Neville D Gai[1], Carlos Rochitte[2], Marcelo Nacif[3], and David A Bluemke[1]

[1]Radiology & Imaging Sciences, National Institutes of Health, Bethesda, MD, United States, [2]Heart Institute - InCor - University of São Paulo Medical School, São Paulo, SP, Brazil, [3]Radiology Department of Faculdade de Medicina, Universidade Federal Fluminense, Niterói, RJ, Brazil

Introduction: The feasibility of performing 3D sodium imaging of the heart on a clinical 3T scanner is explored here. Using a stack of spirals pulse sequence along with sequence optimization allows for imaging of the entire human heart in a clinically reasonable scan time. Sequence optimization is performed by considering factors such as spoiling, nutation angles, repetition time, echo time, T1/T2 relaxation, off-resonance, data acquisition window, motion and segmented k-space acquisition suitable for cardiac imaging. Simulations based on Bloch equations as well as the exact trajectory used for data acquisition provide a clearer picture of the parameter combinations that work best for sodium imaging of the heart. Phantom studies were done to validate the choice of parameters and for corroboration with simulations. Images obtained from human volunteers show that the heart can be imaged with a nominal resolution of $5 \times 5 \times 10$ mm^3 in about 8 minutes.

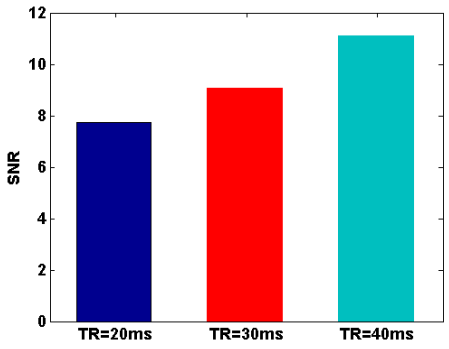

Figure 1: SNR measured in sodium phantom keeping cardiac window constant while varying TR of sequence from 20ms to 40ms.

Materials and Methods: Spiral imaging [1,2] provides time efficient k-space coverage and has several advantages especially for sodium imaging. Chief among them are the possibility of reduced echo time (since the trajectory begins a $\mathbf{k} = 0$) and reduced motion artifacts. In addition, the absence of off-resonant species such as signal from fat and the much reduced B_0 field inhomogeneity artifact (by virtue of gyromagnetic ratio being ~¼ of ^{1}H) provide an ideal combination of circumstances for sodium imaging. Reduced off-resonance artifact allows for longer data acquisition windows. A segmented version of spiral imaging is suitable for triggered acquisition. Two versions of gradient recalled echo — FISP or SSFP-FID and spoiled gradient echo [3] were considered for spiral imaging. Keeping the total cardiac window constant, the sequence was optimized for SNR through Bloch simulations for TR and flip angle. Exact acquisition trajectory was used to get the PSF under conditions of relaxation, off-resonance and motion. The final optimized solution was based on offsetting considerations of SNR, relaxation and non-ideal imaging conditions.

MRI experiments: Phantom (*Ph*) with 80mM Na+ concentration and five volunteers (*Vol*) were imaged on a broadband 3T Philips Achieva (software release 3.2.1) scanner using an integrated ^{23}Na/^{1}H transmit-receive surface coil (Rapid Biomedical GmbH). Scan parameters were: FOV=30cm, TR/TE=40/0.75ms, spiral arms=18, echo train length=9, cardiac gating, res.= 4×4×8mm^3 (Ph) and 5×5×10mm^3 (*Vol*); NSA=16(*Ph*), 22(*Vol*), scan time: 5:22 (*Ph*) and 6-8min (*Vol* based on heart rate). As a surface coil was used without parallel imaging, SNR was measured in pre-processed reconstructed images using ROIs drawn in the object and background. Since noise was typically high, a conservative measure (Henkelman [4]) for SNR was employed.

Results: Simulations showed that the SNR/time increases with increasing TR. Figure 1 shows the SNR measured in the sodium phantom for three different scan prescriptions where the TR was varied from 20ms to 40ms (each using the corresponding optimum flip angle) while the cardiac acquisition window was kept constant at 360ms for each. Figure 2 shows the PSF (only center FOV/4 shown) for sequence parameters described in Methods section with relaxation and off-resonance related to typical values in the left ventricle [5]. Figure 3 shows six contiguous slices obtained along the short axis in a volunteer. The reformatted long axis image clearly delineates the septum and the lateral wall of the left ventricle. SNR measured in the septum was 12.7±3.4 across the five volunteers.

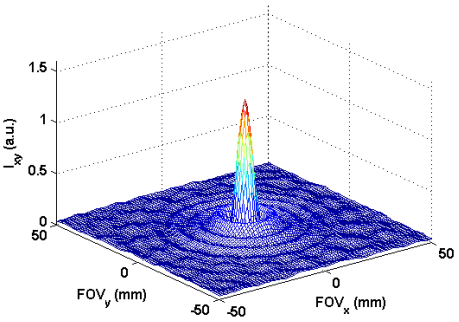

Figure 2: Field inhomogeneity results in a change in the PSF whereby the peak value falls from 1.72 (a.u.) to 1.28 (a.u.) for the optimized sequence.

Discussion: In-vivo sodium MRI on clinical scanners requires extended scan times to realize sufficient SNR. In particular, sodium imaging of the heart dictates efficient use of scanning time primarily to counter artifacts from patient motion (cardiac and respiratory motion, patient movement and patient-coil displacement). Clinical scanning of unsedated patients is even more challenging with a surface coil as patient discomfort (due to prone position) and heart rate variation can result in lengthier scans or scans that result in poor image quality. Hence traversing the k-space in a fast, efficient manner is important. B1 inhomogeneity from the surface coil as well as limits on the maximum B1 delivered by the sodium coil result in rapid signal fall off away from the coil and increased echo time, respectively. Encoding along z for the 3D acquisition also accounts for a slight increase in echo time. As a result about 25% of the total sodium signal is lost. Currently, it's not clear whether using continuous non-triggered acquisition is beneficial. Our observations over a limited data set were inconclusive. In some subjects, image SNR with continuous scanning led to improved definition of the distal parts of myocardium. However, in other volunteers, non-triggered images exhibited greatly increased blurring and partial volume effects, negating any beneficial effects of improved SNR. Finally, scanning time could be increased further to improve SNR as the effective time spent acquiring a single slice is still quite low (~40 s/slice). However, the probability of motion artifacts due to patient movement increases.

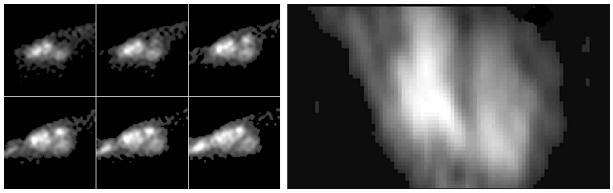

Figure 3: Six (of 18) slices obtained along the short axis using the optimized 3D spiral sequence. Reformatted image on right. Resolution was 5×5×10mm^3.

References: [1] C. Ahn et al. IEEE TMI 1986; 5:2-7. [2] C. Meyer et al. MRM 1992; 28:202-213. [3] P. van der Meulen et al. MRM 1988 ; 6 :355-368. [4] R. Henkelman. Med. Phys. 1985 ; 12 :232-233. [5] K. Sung et al. MAGMA, 2010;23 :85-91.