Self-Navigated Kinematic Imaging of the Knee

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INTRODUCTION: Self-gating [1,2,3] utilizes raw data to detect underlying tissue motion patterns and reconstruct artifact-free images of dynamic systems. Self-navigation has been applied mostly in cardiac imaging, where both cardiac contraction and breathing create a complex dynamic system. In this work, we propose a new self-gating technique for robust dynamic imaging of joints, and test the acquisition strategy in the flexing knee. We present the preliminary 2D imaging of femorotibial joint in 3T using retrospective reconstruction.

THEORY: The proposed RF-spoiled gradient echo (SPGR) self-navigation imaging sequence is based on a two-echo "flyback" readout [4] with the addition of a navigator projection between the two readouts, similar to that used by Guo et al for cardiac imaging [3]. The k-space trajectory is similar in every TR, a navigator projection is acquired through the center of k-space between two imaging readouts of opposite phase-encode positions (k_y). The projection angle (θ) maintains a constant absolute value throughout the scan regardless of the k_y of the imaging readouts; however its sign follows that of the first imaging readout (Fig. 1) in order to minimize the duration of readout-navigator and navigator-readout transitions in k-space. The "+θ TRs" and "-θ TRs" interleave during scan execution so that two streams of +θ and -θ projections are constantly acquired at a temporal resolution of 2TR. Additionally, TR is minimized by using HOT (Hardware Optimized Trapezoid) gradient waveforms design [5,6]. Since TR depends on the projection angle (θ) it is automatically optimized during prescription. Optionally, θ can be manually chosen (e.g. 45˚ for most robust navigation with orthogonal projections). The two imaging readouts are reconstructed separately and recombined in complex image domain.

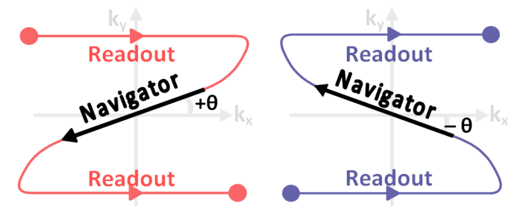

Figure 1. *k*-space trajectories. a) +θ TR where first imaging readout has ky>0. b) Succeeding -θ TR where first imaging readout has ky≤0. The two TRs are alternated in time for high spatiotemporal resolution navigation. The two imaging readouts per TR give the sequence high imaging efficiency.

METHODS: Ungated Acquisitions – two normal volunteer were imaged preliminarily using a standard 8-channel knee coil (InVivo Corp, Gainsville, FL) on a 3T Verio system (Siemens Medical Solutions, Erlangen, Germany). For each volunteer, a sagittal slice was chosen through the right knee and the volunteer was instructed to repeatedly flex and extend the right knee within the confines of the knee coil, which permitted a range of motion of approximately 20 degrees. No periodicity-cueing device was used to guide the regularity of knee motion; the volunteers were allowed to perform the motion at a comfortable pace of their choosing. Scans lasted from 30 to 120sec. Other imaging parameters include: slice thickness 6mm, imaging FOV: 280x280mm, 2D resolution: 1.09mm^2~1.37mm^2, max gradient: 30~40mT/m, max slew rate: 100~125mT/m/ms, flip angle: 10˚ θ: 15˚, and TRs: 9.6~9.8ms. As reference for image quality, images using the exact same sequence were acquired without any knee motion. **Cine Reconstruction** – Briefly, the reconstruction algorithm first retrospectively derived triggers of the knee's cyclic motion from projection data stream (Fig. 2) by automatically choosing a subset of projection pixels and feeding their intensities (in time) to a moving average curve (MAC)-crossing algorithm [7]. Triggers from both streams corroborate each another for robustness. Intervals between triggers are evenly divided into a flexible number of temporal phases (bins). Each TR is *preliminarily* assigned to one such bin based its temporal phase, and each bin is to be reconstructed to one cine frame. However because knee motion is unlikely to have constant angular speed, the TRs preliminarily included in each bin are further selected by removing those with the most dissimilar projections until the desired number of TRs remain in bin (for all phase-encode steps of the cine frame).

RESULTS: Fig. 2 shows a portion of raw navigator projections acquired with the proposed self-gating sequence (TR=9.8ms, θ=45˚). The shown scan (1min, 12800TRs, ~40 knee motion cycles) was reconstructed to 20 cine frames (Fig 3) . Each frame (1.09mm^2, 256x256) had 1 line in all phase-encode steps and the total scan efficiency was 83%. Cine reconstruction was successful for all scans acquired on the two volunteers.

DISCUSSION: The proposed acquisition strategy acquires navigator signals with very high temporal resolution (2TRs), at two projection angles, and in an interleaved fashion. Both projections are used in motion extraction, and the results are combined for robustness. There is little chance that a projection angle cannot capture the motion in question. Though the range of motion in these experiments was limited, specialized coils could be used to achieve a more clinically relevant range of motion (30-60˚) in the knee [8,9] or to visualize the motion of other joints such as the shoulder. Such self-gated kinematic imaging can also be used in musculoskeletal motion tracking as an alternative to phase-contrast imaging [10] and real-time imaging [11,12]. Hence, we present the first use of self-navigation targeted at joint kinematic imaging.

REFERENCES: [1]: Larson MRM 51 (2004); [2] Larson MRM 53 (2005); [3] Guo Proc ISMRM 4152 (2010); [4] Herzka MRM 47 (2002); [5] Atalar MRM 32 (1994); [6] Derbyshire MRM (2011); [7] Lu Med Phys 33(10) (2006); [8] Blackburne J Bone & Joint Surgery 53: 241-242 (1977); [9] Insall Radiology 101:101-104 (1971); [10] Behnam J Biomech (2010); [11] Draper JMRI 28 (2008); [12] Blemker JMRI 25 (2007).

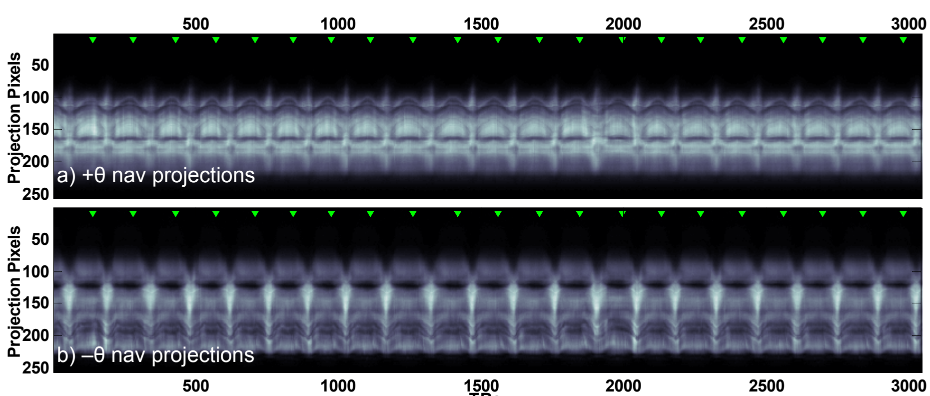

Figure 2. a),b) Navigator projection of knee acquired during the first 30sec of an SPGR scan showing approximately 20 cycles of the flexion-extension motion. Gating triggers were automatically derived (green markers) and used in retrospective cine reconstruction.

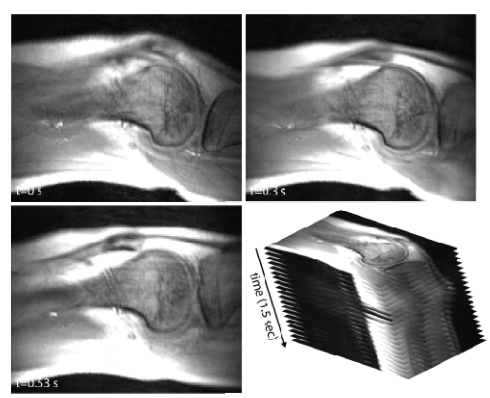

Figure 3. Three individual cine frames from the scan shown in Fig 2 showing the knee joint in motion. The cine was retrospectively reconstructed to 20 frames.