Exploring the feasibility of the coherent half-FOV replication passive tracking technique for controllable susceptibility devices in the presence of motion

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Target audience: Interventional radiologists and researchers

Purpose: We previously demonstrated the passive tracking of a controllable device where the susceptibility effect can be mechanically turned ON and OFF.[1] The mechanism of device location exploited the creation of a coherent replication of the susceptibility artifact that is precisely shifted FOV/2 in the phase-encode direction, achieved by toggling the susceptibility effect every TR to create a sequential modulation of k-space. On the other hand, the effects of motion appear mainly as incoherent ghosting in the phase-encode direction because the probability of periodic variation at the temporal frequency on the order of one TR is low. In this study, we explore the other extreme, where the device is toggled only once in between the sequential acquisition of odd and even phase-encodes. The feasibility of locating the controllable susceptibility device and of a catheter balloon using a modified phase-encoding scheme is examined with a discussion of the associated motion artifacts.

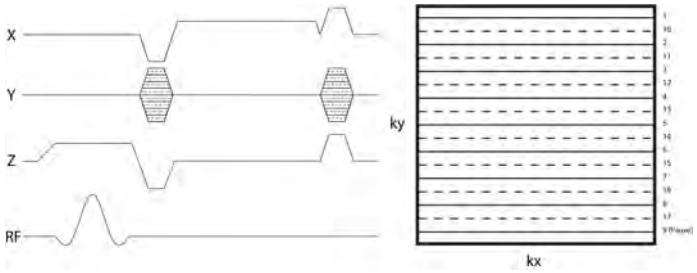

Figure 1: 2D FSPGR sequence (one TR shown, left) with a modified phase-encoding scheme (right) to sequentially sample odd k-space lines in stage 1, pause to allow device toggling, then sample even k-space lines sequentially in stage 2 after the user resumes the sequence.

Methods: Experiments were performed using the body coil on a GE MR750 3.0 T clinical scanner. The pulse sequence is a modified 2D fast spoiled gradient echo (FSPGR) with an acquisition scheme that is separated into two stages (Figure 1). The first stage involves the sequential acquisition of odd lines of k-space after a prescribed number of dummy scans. The sequence pauses and waits for the user to start the second stage. The second stage begins with the same number of dummy scans as the first stage, followed by the sequential acquisition of even lines of k-space. The overall RF chopping phase cycle is preserved. Modulation of k-space is achieved by running the first stage with the device ON and the second stage with the device OFF (using the pause to toggle the device manually). The controllable device consists of two concentric cylinders of titanium and graphite that result in a minimum susceptibility artifact when properly aligned (OFF position); misalignment results in an unbalanced susceptibility effect (ON position).[2] A Bard Dorado PTA dilatation catheter (DR4094) with balloon diameter 9 mm and balloon length 40 mm was used for *in vitro* studies, in a polyacrylamide gel phantom (Figure 2). The balloon was inflated with air during the pause in the imaging sequence. *In vivo* studies were performed in accordance with institutional animal care protocols. A healthy Yorkshire pig (35 kg) was fasted overnight prior to the procedure. The pig was sedated by intramuscular injection with a 23 Ga butterfly needle of ketamine (15 mg/kg) and atropine (0.06 mg/kg). Once sedated, the animal was weighed, intubated, and intravenous (IV) access gained via 22 Ga angiocatheter in the marginal ear vein. The animal received continuous IV fluids and was maintained on a ventilator at 24 breaths/min with 2 L/min of O_2 and isoflurane given to effect. A 6F sheath was placed in the femoral artery and the catheter was advanced toward the common iliac artery using a guidewire under X-ray fluoroscopy.

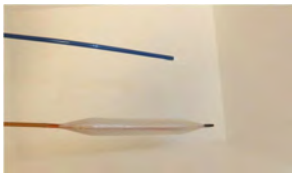

Figure 2: Controllable susceptibility device (top) and balloon catheter (bottom).

Results and Discussion: Figure 3 shows *in vivo* images acquired to find and track the catheter tip inside the femoral artery of the pig. By switching the device between ON and OFF positions during the pause in the sequence, the region of dephasing around the device appears bright in the phase-encode direction displaced by exactly half of the FOV in the sagittal and coronal views (Figure 3). In addition to the artifact from the device, other artifacts resulting from a combination of motion and flow of the femoral artery are especially apparent in the sagittal image (Figure 3, left). These images were acquired without respiratory gating or breath hold to examine the full effect of respiratory motion on the feasibility of locating the device. Despite the severity of the motion artifacts, the FOV/2 ghost of the device was distinct and the device was located unambiguously *in vivo*. Similar motion and flow artifacts would remain if two images, one acquired with the device ON and the other with the device OFF, were subtracted to visualize the effect of the device in its original location. In large animals, motions that are periodic over short timescales (sub-second) are less common than motion over longer timescales (seconds to minutes). Motion artifacts can be reduced by respiratory gating or using a ventilator breath hold, by minimizing the scan time, and by signal averaging (motional artifacts sum incoherently). After further investigation and modification of the pulse sequence, we were able to increase the bandwidth of the excitation RF pulse to create full body projections (slice thickness larger than 40 cm) and reduce the motion artifacts in the image using low flip angles. With this pulse sequence, we can locate our devices more rapidly and easily. In Figure 4, the FOV/2 ghost of the susceptibility device and balloon in the gel phantom are clearly visible with full projection images. This new method is more efficient compared to toggling the device ON and OFF every TR, reducing the imaging time from several minutes to less than 5 seconds.

Conclusions: A method for passive tracking using our susceptibility device and a clinical balloon catheter was demonstrated *in vitro* and *in vivo* without respiratory gating. The novel tracking method creates a coherent ghost of the susceptibility artifact of the controllable catheter tip and balloon at precisely FOV/2 from the true location in the phase-encode direction. This tracking method is based on a general phase-encoding strategy that can also be implemented on different tools or devices for interventional MR procedures. In the near future, we will demonstrate the projection technique *in vivo* and work on enabling quick snap-to-slice functionality.

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References: [1] W. Dominguez-Viqueira *et al*. (2014) *Proc ISMRM* 22: 3705. [2] W. Dominguez-Viqueira *et al*. (2014) *MRM* 72(1): 269.

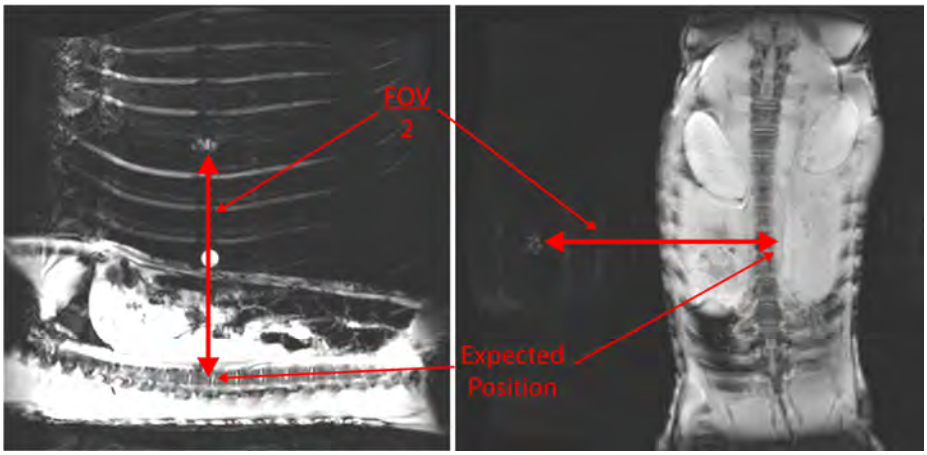

Figure 3: *In vivo* sagittal (left) and coronal (right) slice of pig abdomen showing FOV/2 artifacts of the controllable susceptibility device in the common iliac artery. TR/TE = 100/6.6 ms, FA = 20°, 48 cm FOV, 1 cm slice thickness, 32 dummy scans, acquisition time 28.8 s, total scan time 40 s. Distortion at the edges of the images is the result of gradient warping correction in the default clinical scanner reconstruction.

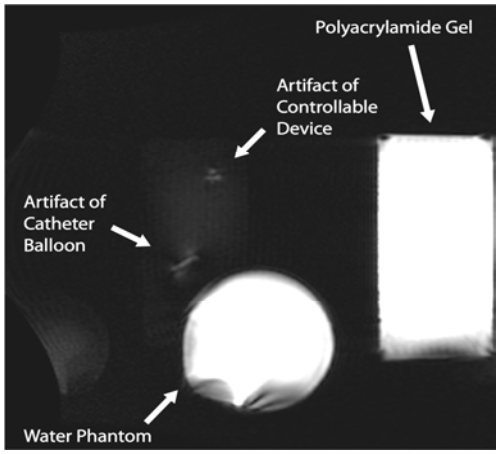

Figure 4: Projection of gel phantom showing the FOV/2 artifacts of the controllable device and catheter balloon. TR/TE = 17/6.8 ms, 48 cm FOV, FA = 1°, 5 mm slice thickness, 0 dummy scans, acquisition time 2 s.