K-SpaceTrajectory Measurement with Signal Shifting

M. Beaumont[1,2], C. Segebarth[1,2], L. Lamalle[2,3], E. L. Barbier[1,2]

[1]Inserm, U 594, Grenoble, F-38043, France, [2]Univ Grenoble 1, Grenoble, F-38043, France, [3]Inserm, IFR 1, Grenoble, F-38043, France

Introduction: Different approaches for measuring k-space trajectory have been described in the literature. Self-encoding gradient techniques [1] are time consuming due to the high number of phase encoding steps needed (number of steps ~ matrix size). The approach with off-center slice selections [2] is faster (four steps) but has apparently not been used to measuring high k-space values (i.e. beyond 300 m^{-1}, typically), when phase dispersion may lead to signal destruction (Fig. 1), and to errors in the estimate of the trajectories at the k-space periphery. To reduce signal dephasing, the slice thickness may be decreased [3], at the expense of signal loss, however. To overcome this difficulty without significantly increasing the acquisition time, we propose an approach whereby a dephasing gradient is applied, prior to the gradient to be calibrated, to shift in time the signal maximum.

Material and methods: The k-space trajectory measurement technique with off-center slice selections [2] uses an off-center slice selection gradient along the same axis as the gradient to be calibrated. On the other encoding axis, gradients are switched off. For each encoding axis, two slice locations are used.
With the method proposed here, we perform a few measurements whereby a dephasing gradient is applied between slice selection and encoding gradient to be calibrated (Fig. 2). Typically, three dephasing gradient amplitudes are used (*G*, *zero* and *-G*). The gradient duration and its amplitude *G* are chosen depending on the gradient waveform to be calibrated. Complex signals from the different measurements from the same slice are added. We then determine the k-space trajectory from the phase difference between signals from the two slices.
Acquisitions were performed on a 2.35 T scanner with a cylindrical phantom filled with water. The gradients slew rate and maximal amplitude were 12.8 G/cm/ms and 9.6 G/cm. Two slices at locations of -10 mm and 10 mm were excited, along each axis of interest, with a slice thickness of 1 mm. The amplitude *G* and the duration of the dephasing gradient were 0.6 G/cm and 1360 µs (gradient area = 540 m^{-1}). Gradient waveforms were implemented to generate a variable density spiral trajectory [4] reaching 1360 m^{-1} in k-space, with 26 interleaves.

Results: Fig. 1 shows the signal amplitude (Fig. 1a) and the corresponding estimate of the trajectory in the k_x direction (Fig. 1b) with the original approach [2]. Fig. 3a shows an example of a spiral trajectory estimated with the conventional off-center slices method. When dephasing gradients are used, the resulting trajectory (Fig. 3b) is much more precisely estimated, even at the k-space periphery. When dephasing gradients are switched off and the signal is averaged three times, instead, the estimate of the trajectory is not significantly improved compared to the one shown on Fig. 3a. Exciting four different off-center slices, instead of two with the conventional off-center slices method, does not significantly improve the estimate of the trajectory at the k-space periphery either. One also observed, as anticipated, that the signal amplitude cancels out when the phase accumulated across the slice is multiple of π.

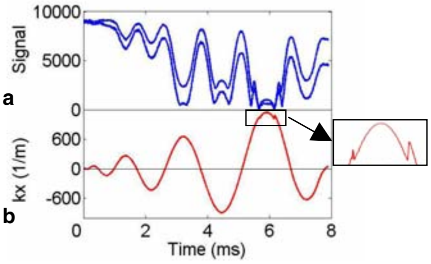

Figure 1: (a) Signal envelopes from two off-center slices orthogonal to the direction of the encoding gradient to be calibrated. (b) The resulting trajectory becomes poorly estimated as soon as any of the two signals gets close to zero.

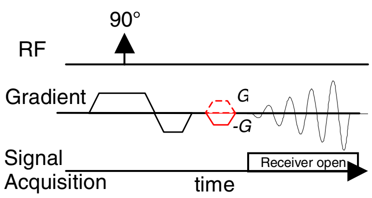

Figure 2: Pulse sequence used to measure the trajectory. Note the presence of a dephasing gradient before the spatial encoding gradient waveform to be calibrated.

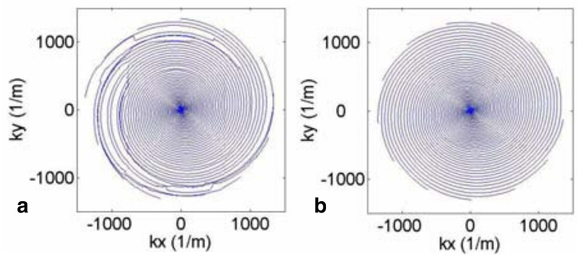

Figure 3: Trajectories obtained with off-center slice selection based techniques: (a) without using a dephasing gradient (original approach, 4*TR / interleaf), (b) using three values of a dephasing gradient (new approach, 12*TR / interleaf). Only one over two interleaves is represented for the sake of clarity.

Discussion: When k-space trajectories reach high values (over 500 m^{-1} with our systems), the signal to noise ratio level at the end of the acquisition is unacceptable to produce noiseless trajectory. By introducing dephasing gradients, signal can be recovered in the k-space periphery. With this technique, the accuracy of the k-space trajectory measurement then becomes comparable to that obtained with the self-encoding gradient technique [1] (results not shown), while the overall acquisition time is divided by the factor *matrix size/3*. We are currently exploring how to determine the optimal dephasing gradient amplitude according to the k-space trajectory of interest, knowing that signal minima occur when the accumulated phase across the selected slice is equal to a multiple of π.

References:

1. Alley, M., et al., *Gradient characterization using a Fourier-transform technique.* Magn Reson Med, 1998. **39**: p. 581-587.
2. Zhang, Y., et al., *A novel k-space trajectory measurement technique.* Magn Reson Med, 1998. **39**(6): p. 999-1004.
3. Dyun, J., et al., *Simple correction Method for k-space trajectory deviations in MRI.* J Magn Reson, 1998. **132**: p. 150-153.
4. Kim, D.H., et al., *Simple analytic variable density spiral design.* Magn Reson Med, 2003. **50**(1): p. 214-9.