Correction of Physiologically Induced Global Off-Resonance Effects in Dynamic Echo-Planar and Spiral Functional Imaging

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To decrease noise from respiration induced phase and frequency fluctuations, a simple correction of the "**D**ynamic **O**ff-**R**esonance in **K**-space" (DORK) was developed. The correction uses phase information from the center of *k*-space and a navigator echo, and is illustrated with dynamic scans of single-shot and segmented EPI and, for the first time, spiral imaging of the human brain at 7T. The DORK correction significantly reduced artifacts: pixel shift for EPI, blurring for spiral, and ghosting. While spiral imaging was found to exhibit less noise than EPI before correction, the residual noise after the DORK correction was comparable.

Introduction In functional magnetic resonance imaging, a rapid method such as echo-planar (EPI) or spiral is used to collect a dynamic series of images. These techniques are sensitive to changes in resonance frequency, which can arise from respiration and are more significant at high magnetic fields. Corrections have been made using navigator echo phase for magnetic field drift [1-3]. However, to date no corrections have been reported for respiration-induced dynamic off-resonance effects.

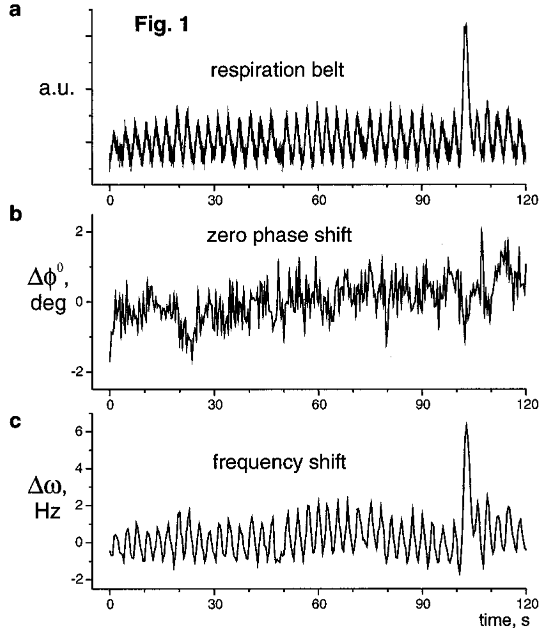
Methods The DORK correction uses phase information from a navigator echo as well as the imaging echo at the center of *k*-space to estimate zero phase and frequency shift (Fig 1b, 1c) and subsequently to correct the data in the k-space. For multisegment imaging, each segment was treated independently.

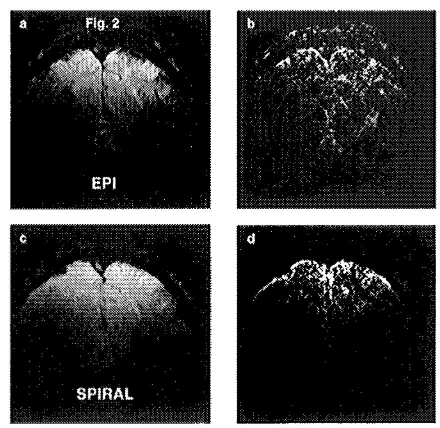
Single-shot and 4-segment EPI and spiral imaging was performed on a 7T/ 90 cm system using a 7-cm quadrature surface coil pair for T/R (FOV 12.8 cm, TE 20 ms, axial plane).

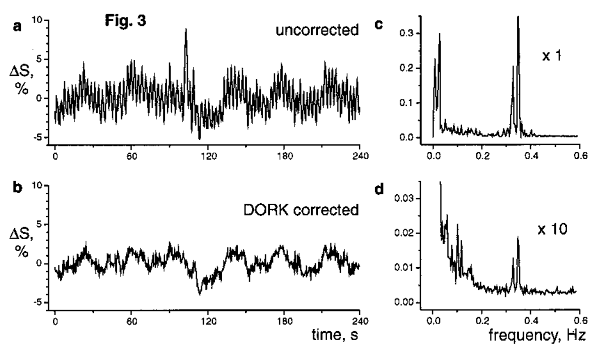
Results It was expected that the effects of off-resonance would be most prominent near the edges of image features. To demonstrate this, difference images were made of the EPI and spiral time series before and after the DORK correction (Fig 2b, 2d). The difference images revealed that the correction is largest for image regions, where intensity changes are discernible, as near edges, fissures, and vessels. In the EPI case, image ghosts were also strongly influenced (Fig 2b). Based on these observations, a normalized edge-based weighting function was used in total error calculation to emphasize edge structures.

The global off-resonance correlated highly with the respiration (CC = 0.84, Fig 1a, 1c), which was shown recently [4]. DORK varied between volunteers from $\sigma_{\Delta\omega} = 0.71$ to 1.7 Hz. When one subject was asked to breathe deeply, $\sigma_{\Delta\omega}$ increased threefold from 0.8 to 3.2 Hz. The DORK correction reduced the noise in the time series significantly, predominately respiratory noise at ~0.33 Hz (Fig 3). Averaged over 13 studies, σ_{resp} of 2.1% (1.1%) was reduced to $\sigma_{resp}^{corr} = 0.97\%$ (0.87%) for EPI (spiral) time series.

In summary, the significance of the DORK correction lies in its efficiency and simplicity and its usefulness for various types of dynamic imaging studies. Functional imaging and other difference and phase imaging techniques, e.g., arterial spin labeling for blood flow measurements can benefit greatly from its use. The DORK correction significantly reduces the temporal fluctuation in a imaging series by reducing dynamic off-resonance induced imaging artifacts such as distortion and ghosting in single short EPI, blurring in spiral, and ghosting and segmentation artifacts in multi-segmented imaging. Application of the DORK correction is not limited to respiration-induced fluctuations, as it can be used for correction of any other source of global frequency change in a dynamic imaging series, such as magnetic field drift. This may be very important for scanners exhibiting significant field drifts due to factors such as heating of the shims or the gradient coils from extended periods of rapid imaging common in fMRI.







References 1. Wowk B, MRM 1997, 1029. 2. Liu HL, JMRI 2001, 308. 3. Durand E, MRM 2001, 198. 4. van de Moortele PF, MRM 2002, in press.

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