Image de-blurring of PROPELLER EPI using a k-space weighting scheme

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Introduction

The multi-shot PROPELLER-EPI technique has been shown to be an effective method for high-resolution diffusion tensor imaging (1). Since each rotating blade of k-space data is acquired by single-shot spin-echo EPI, susceptibility-induced off-resonance effects could lead to geometric distortions along the phase-encoding direction (2). A combination of these rotating data blades thus results in blurring in the final PROPELLER-EPI images. One method to reduce the blurring effect is to use triangular windowing, which weighs the k-space data according to the timing distance from the center of the spin-echo in a monotonically decreasing manner. (2) Since the off-resonance effects increase as the departing time from the spin-echo increases, the weighting operation reduces the contributions of data that are less reliable. In this work, we further compare the effects on blurring and signal-to-noise ratio (SNR) using exponential windowing functions at different decaying time constants.

Materials and Methods

Imaging experiments were performed on a 3T system (Philips Achieva, Best, Netherlands). In the phantom experiment, each blade of the PROPELLER-EPI imaging was acquired using single-shot spin-echo EPI (TR/TE = 1000/50 ms, 2-fold SENSE) at an echo train length of 32. A total of 14 blades covered the entire circular k-space at 26-degree increment, aiming at the matrix size of 256x256 for the final images. As for in-vivo experiment, 24 blades spaced at 15-degree increment were collected using the following parameters: TR/TE = 1000/80 ms, 39*256 blade size, 3-fold SENSE acceleration. Following acquisition, the k-space data were digitally transferred to a personal computer for processing using software developed under the Matlab® platform (Mathworks, Naticks, MA). Reconstruction of the PROPELLER-EPI images followed the procedure of spatial registration, phase correction, k-space windowing, re-gridding, density compensation, and Fourier transformation after k-space data combination. The windows consisted of a function monotonically decreasing from the central k-space line where the spin-echo formed (i.e., zero phase encoding) to the outer k-space along the phase-encoding direction for each blade. Such operations were performed only for data points that were acquired by multiple blades (1). In this work, the decreasing functions were exponential decaying functions at various time constants (Fig.1). Note that since the off-resonance effects increase as the departing time from the spin-echo increases, we anticipate that a smaller time constant for the k-space window should place less weighting on data far from the spin-echo, thereby help reducing blurring effects. In the case of PROPELLER fast spin-echo which do not suffer from off-resonance (3), windowing helps reducing point-spread-function blurring from T2 decaying (not shown).

Results

Figure 2 shows the images of a resolution phantom reconstructed using the same set of k-space data acquired using the PROPELLER-EPI technique. The only difference was in the time constants used in the exponential windowing functions. Note that the conspicuity of the small holes becomes progressively improved as the time constant reduced, demonstrating effective reduction of the blurring effects. However, the de-emphasis of data from outer k-space also decreased the effective number of signal averaging. As a result, SNR reduced as the time constant decreased, showing obvious trade-off with spatial resolution. Images acquired from human brain (Fig.3) shows the same trend as evidenced from the frontal lobe.

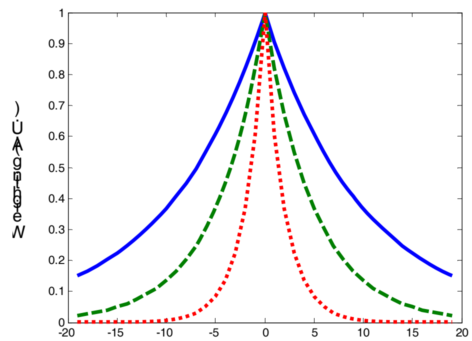

Fig.1 The blue solid, green dash, and red dot lines respectively show the exponential decaying windows at time constants of 10, 5, and 2 echo spacings. The x-axis indicates the index of echoes away from spin-echo (the central k-space line).

Discussion

Results from this work show that the k-space windowing have dramatic effects that are visually perceivable on PROPELLER-EPI images. By choosing an appropriate window function with time constant that is sufficiently small, data that are prone to off-resonance errors could be de-emphasized, resulting in reduced blurring and thus high spatial resolution. Since the EPI off-resonance effects become increasingly prominent as echo train length and echo spacing increase, the use of windowing in PROPELLER-EPI is particularly important in high in-plane resolution imaging. Nevertheless, the prerequisite to maintain adequate SNR is also crucial.

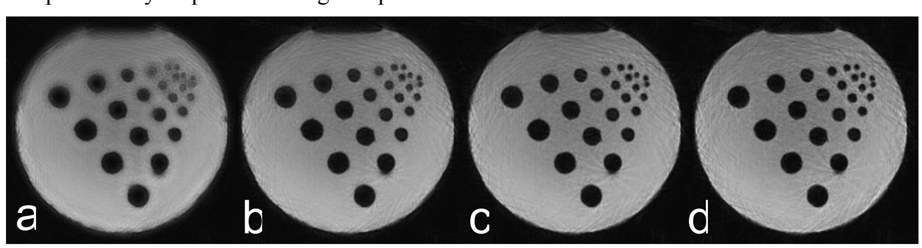

Fig.2a showed the PROPELLER image of phantom reconstructed without exponential windowing, i.e., an unlimited large time constant. **b, c,** and **d** were reconstructed with exponential windowing at time constant of 10, 5, and 2 echo spacings.

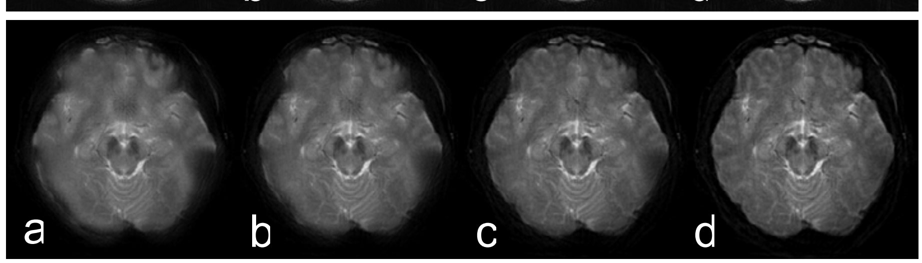

Fig.3a showed the PROPELLER image of human brain reconstructed without windowing; **b, c,** and **d** were reconstructed with exponential windowing at time constant of 10, 5, and 2 echo spacings.

References

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