Optimized dynamic contrast-enhanced imaging by view-sharing PROPELLER

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Introduction

The view-sharing PROPELLER (VS-Prop) technique [1, 2] has recently been proposed to achieve better spatiotemporal resolution in dynamic imaging. One design of VS-Prop employs k-space data collection in rotating blades using gradient echo as the readout module to catch the T1-weighted temporal change following contrast injection. As a result, the central k-space was updated much more frequently than the outer k-space filled by temporally succeeding blades. High resolution frames can be reconstructed via a pixel-based optimal blade selection (POBS) algorithm based on least-square-error to effectively minimize artifacts due to under-sampling of the outer k-space [2]. In this study, the accuracy of POBS VS-Prop was evaluated on a flow phantom, followed by demonstration of accelerated first-pass dynamic contrast-enhanced (DCE) cardiovascular imaging on healthy volunteers.

Materials and Methods

VS-Prop reconstruction was performed with the central polygonal k-space of each frame provided by one single blade (target blade) and the peripheral k-space filled by *Nb* consecutive blades (including the target blade). The POBS algorithm searched for the set of neighboring blades exhibiting the closest image contrast with the target blade. Assuming the order of target blade in a series of consecutive blades is *k*, the POBS reconstruction initiates at $k = Nb/2$, and the selection of composed blades was updated iteratively in a least-square-error sense to minimize data inconsistency at outer k-space. Since the dynamic signal response can be spatially varying, the computation was done in a pixel-by-pixel manner.

An acrylic flow phantom was made with a U-shaped tubing loop fixed in agar gel to simulate the vessel. Prepared solution was injected at a constant velocity of 35 cm/sec to mimic a bolus injection of contrast agent. The cross-section view of the flow phantom was successively imaged by fully sampled blades, in matrix size of 256×256 and at an incremental rotation angle of 22.5^0, to record the dynamic signal change of flowing solution as the reference standard. Central 64 k-lines of each blade were cropped to simulate VS-Prop acquisition. A total of forty frames were obtained with TE/TR = 3.3/7.1 ms, flip angle = 15^0, FOV = 256 mm, and thickness = 6 mm. For in vivo studies, DCE MRI was applied on five healthy subjects with a bolus injection of 0.5 dose gadobutrol (Gadovist, Bayer Schering Pharma). Rotating blades in size of 192×28 were obtained at an incremental angle of 20^0 ($Nb = 9$) at TE/TR = 1.3/3.6 ms and FOV = 300 mm. The acquisition duration of single blade is 100 ms, achieving 6.9-fold acceleration in comparison with full sampling. Following a 100-ms delay after R-wave detection, five to seven, subject to heart rate, 6-mm thick slices in short-axis view were acquired from base to apex successively. Notice that here the purpose of VS-Prop technique is not only higher frame rate but also for multi-slice acquisition leading to better spatial coverage. Subjects were asked to hold their breath as long as possible to avoid respiratory motion. Both phantom and human experiments were conducted on a 1.5 T scanner (Signa HDx, GE Healthcare, Milwaukee, WI). The in-vivo study was approved by the local institutional review board, and informed consents were obtained from all subjects in advance.

Results

Figure 1 shows the time curve of an ROI in the tube of the phantom. The dynamic signal response, especially the rapid change from the 11^{th} to 14^{th} frames, was successfully captured by POBS VS-Prop (black solid line) as closely resembling that of full Cartesian sampled blades (red solid line) as compared with VS-Prop without POBS and conventional PROPELLER (black dashed line), the latter showing the most severe smoothing because the central k-space is contributed equally by all composing blades. Cross sectional profiles of the phantom tube (inner diameter 6 mm, at the 13^{th} frame) from POBS VS-Prop also showed the best similarity with fully sampled data (Fig.2). DCE cardiovascular imaging results from POBS VS-Prop (Fig.3, with *k* maps shown at the bottom) of four selective frames (no.8, 13, 18, and 23) showed successful capture of the contrast agent passage with wider slice coverage.

Discussion

Both temporal response (Fig.1) and spatial profile (Fig.2) from the phantom experiments strongly suggested that VS-Prop with POBS achieved excellent agreement with fully sampled data. The largely reduced acquisition window of each frame allows high spatial resolution or wider coverage in dynamic imaging. For the in vivo DCE experiments we presented in this study, the readout duration, chosen as 100 ms, was limited by cardiac pulsation. Although the number of phase encoding can be further reduced for a shorter readout, a consequent larger *Nb* may inevitably enhance the temporal smoothing effect. The preservation of dynamic signal changes in POBS VS-Prop can be understood from an examination of the *k* map, where the target index *k*, an integer between 1 and *Nb*, indicated the combination of composing blades. For example, low *k* values represent that peripheral k-space region was mostly filled by data collected afterward. In Fig.3, the timing of the 8^{th}, 13^{th} and 18^{th} frames roughly corresponds to contrast wash-in of right ventricle, left ventricle, and myocardium (time curves not shown), where low *k* values (dark regions pointed by arrows in *k* maps) can indeed be found to correspond to these areas, indicating that blades with similar contrast (i.e., post-contrast) were collected by POBS for reconstruction. We therefore conclude that POBS VS-Prop has strong potential in DCE MRI applications.

References: [1] Chuang TC et al, ISMRM 2006; abstract no.2954. [2] Chuang TC et al, ISMRM 2008; abstract no.1353.

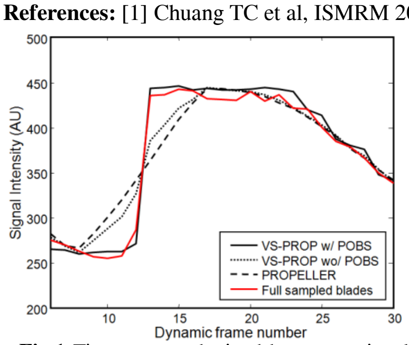

Fig.1 Time curves obtained by conventional PROPELLER (black dashed), VS-Prop without (black dotted) and with POBS (black solid) were compared with that from fully Cartesian sampled blades (red solid line).

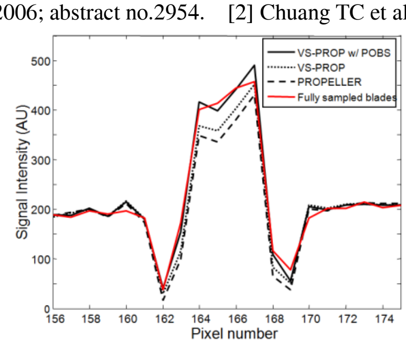

Fig.2 The spatial profiles of the inflow ROI of fully sampled data (red solid), conventional PROPELLER (black dashed), VS-Prop without (black dotted) and with POBS (black solid).

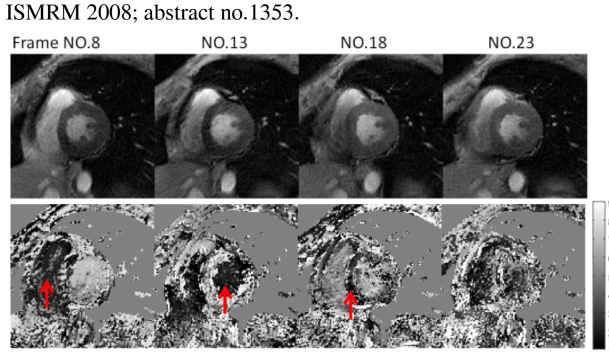

Fig.3 VS-Prop images (upper row) and the corresponding *k* maps (lower row) of selective frames during the first pass of contrast agent.