Flow Quantification in Real-time with Golden Angle Acquisition and k-t BLAST Reconstruction

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Introduction

Magnetic Resonance Imaging has been shown to be a valuable tool for the non-invasive assessment of the blood flow velocity. In phase contrast imaging, the phase of the NMR signal depends on the constant-velocity motion of the nuclei in the presence of flow encoding field gradients [1]. However, the need for multiple acquisitions and inherently long scan times limits the use of the standard PC technique. To overcome these limitations, the PC acquisition has recently been combined with *k-t* BLAST and *k-t* SENSE [2] reconstruction methods for cine flow quantification in a single breath-hold without compromising spatial or temporal resolution [3]. The separate acquisition of the training data requires a strictly periodic motion pattern or ECG triggering. In contrast, we demonstrate a novel approach to provide *real-time* flow quantification by use of optimal radial scanning and k-t BLAST reconstruction. The Golden Angle acquisition [4] permits the arbitrary and retrospective selection of time frames of arbitrary size, in order to address the *variable* kinetics occurring during scanning.

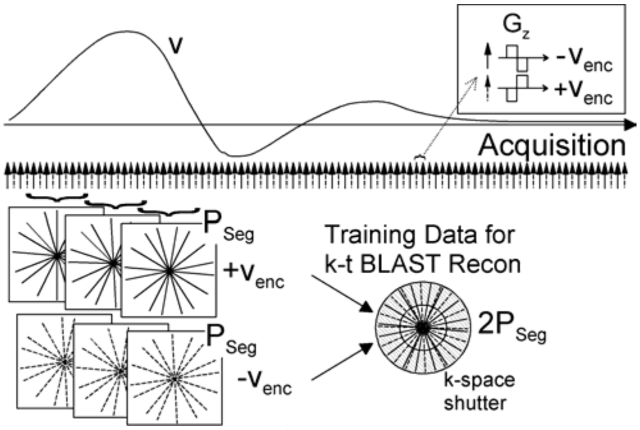

Fig. 1. Method: interleaved PC acquisition with symmetric flow encoding gradients, optimal radial scanning and k-t BLAST reconstruction (see text).

Methods

All imaging was conducted on 1.5T clinical scanners (Philips Achieva, The Netherlands) on healthy volunteers. Through-plane quantification was performed in a slice perpendicular to the femoral artery. The interleaved encoding of flow in opposite directions yields two encoding segments ($+v_{enc}$ and $-v_{enc}$, see Fig. 1), in each of which succeeding views are spaced by the Golden Angle (ϕ_{GR}=111.25° [4]) for an optimal distribution of an arbitrary selection of views in k-space. Frames can thus be depicted retrospectively with arbitrary temporal resolution at arbitrary time points. The usage of radial scanning obviates extra scan time for the acquisition of the training images required in the *k-t* BLAST reconstruction, as the fully sampled center of the radial k-space can be extracted by k-space shuttering before reconstruction to learn the spatiotemporal correlations of the MR signal during scanning [5]. To improve the quality of the training images, especially for very sparsely sampled k-spaces, the $+v_{enc}$ and $-v_{enc}$ acquisitions are rotated against each other by $0.5\phi_{GR}$, and the training image is derived from the fully sampled center of the combination of both datasets (see Fig. 1). Scan parameters: FOV=10cm, slice=2cm, matrix=96x96, TR/TE=4.7/2.6ms, flip angle=15°.

Results

From the continuous acquisition over a period of 5.2s, frames were extracted with different temporal resolutions ΔT=0.14ms and 0.27ms (15 and 28 views per frame, and 30 and 56 views for the training images, respectively). The resulting dynamic pattern of the blood flow velocity is depicted in Fig. 2 (left). One of the cardiac cycles is furthermore compared with a conventional Cartesian cardiac gated experiment (Fig. 2, right). The latter was performed for the same spatial resolution and geometry but required 53s to obtain quantitative velocity information over 9 heart phases. Fig. 3 shows the magnitude images obtained by *k-t* BLAST reconstruction from selections of 15 and 28 views. Despite the high undersampling factors, the image quality was adequate. The image reconstructed from 28 views appears slightly sharper, however, when using a better temporal resolution (15 views), highly dynamic events like the peak velocity can be determined more reliably (see Fig. 2).

Discussion and Conclusion

We have presented a novel approach to real-time flow quantification based on optimal radial scanning and k-t BLAST reconstruction. The flow quantification was in very good agreement with standard cardiac-gated multi-shot experiments. The acquisition scheme permits the retrospective optimization of the temporal resolution of a time frame to the varying kinetics occurring during scanning and the k-t BLAST reconstruction counteracts the effects of undersampling. The improvement of the training images, achieved by combining the interleaved encoding segments, resulted in favorable image quality even for very high undersampling factors. Furthermore, the concurrence of the dynamic frames and the training images prevents misregistration [5], regardless the variability of the flow or motion pattern. In contrast to standard PC approaches and recent Cartesian *k-t* BLAST flow measurements, the dynamic quantification enables a reliable detection of irregularities and any deviation from a strictly periodic flow or motion pattern.

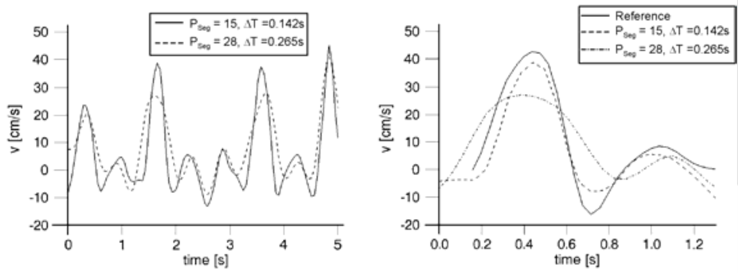

Fig. 2. Left - mean blood flow velocity in the femoral artery depicted in two different temporal resolutions (0.14 and 0.27s). Right - comparison of one of the cardiac cycles with a Cartesian cardiac-gated experiment (1min).

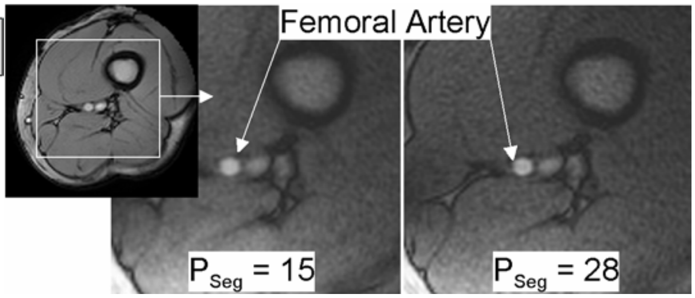

Fig. 3. Two reconstructed time frames from radial datasets of only 15 and 28 views (temp. res. 0.14s and 0.27s).

References:

[1] Bryant DJ, et al J. Comp. Assist. Tomogr. 8, 588-593, 1984

[2] Tsao J, et al, MRM 50, 1031-1042, 2003

[3] Baltes C, et al, MRM 54, 1430-1428, 2005

[4] Winkelmann S, et al, IEEE TMI, 2006, in press

[5] Hansen MS, et al, MRM 55, 85-91, 2006