Reduction in Flow Artifacts by using Interleaved Data Acquisition in Segmented Balanced Steady-state Free Precession Cardiac MR Imaging

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INTRODUCTION

Cine cardiac MR imaging is used to assess cardiac wall motion and function and to evaluate a wide variety of cardiac diseases. The advantages of cine MR imaging using balanced steady-state free precession (SSFP) imaging include the high contrast between the blood pool and myocardium and high reproducibility for the evaluation of wall motion and left ventricular ejection fraction (LVEF). Nonetheless, dark flow artifacts may occur using this imaging technique, and these obscure the myocardial border. These imaging artifacts are thought to be related to several effects: off-resonance effects, out-of-slice effects, and in-flow effects of the blood flow. Successful reduction of this type of artifact has been achieved by reshimming the gradients or by readjusting the center frequency. However, reshimming presents challenges in regards to respiratory and cardiac motion, with susceptibility variations between the lung and heart, and with high velocity blood flow.

The purpose of this study is to determine the usefulness of another technique for the reduction in the flow artifacts in the left ventricular (LV) cavity: the use of odd-even interleaved data acquisition.

METHODS

MR Imaging: Cardiac MR examinations were performed using a four-element phased-array cardiac coil and a 1.5 T imager. Breath-hold cine segmented balanced SSFP imaging was performed using the following parameters: TR, 4.2-4.8 msec; TE, 1.7 msec; flip angle, 60 degrees; cardiac phase, 16-20 after view sharing; RBW, 125 kHz; imaging matrix, 256 x 128; FOV, 32 x 32 cm^2; and slice thickness, 8-10 mm with a 0-2 mm gap. The segments were obtained sequentially, and two data acquisition schemes were used in each segment: a sequential data acquisition and an odd-even interleaved data acquisition scheme that acquired the odd k-space number first (e.g. 1,3, ---, 15), and then acquired the even k-space number (e.g. 2,4, ---, 16).

Imaging Analysis: Eleven short-axis view planes at the mid-ventricular level and nine long-axis view planes through the LV apex were acquired from the 15 patients with various cardiac diseases (e.g. hypertrophic cardiomyopathy, dilated cardiomyopathy). Two independent observers separately scored the dark flow artifacts in the LV cavity, the ghost outside the heart in the phase-encoding direction, and the visualization of the myocardial border in the cine MR images acquired using the sequential and odd-even interleaved phase order methods as follows: 2 = the artifact or ghost was barely visualized or the myocardial border was well visualized; 1 = the artifact or ghost was moderately visualized or the myocardial border was partially visualized; 0 = the artifact or ghost was prominent or the myocardial border was barely visualized. The differences in the scores of the two data acquisition accorded to the flow artifact, the ghost outside the heart, and the visualization of myocardial border were then statistically analyzed. The statistical differences were also evaluated when the acquired MR images were divided into two groups based on the imaging planes and on the LVEF (higher [n = 9] or lower than 60% [n = 11]).

RESULTS

The scores of the flow artifacts in the LV cavity and the visualization of the myocardial border were significantly higher in the segmented balanced SSFP images using the odd-even interleaved phase order than those in the images acquired using the sequential phase order ($P < 0.01$). Conversely, the scores of the ghost outside the heart were significantly lower in the segmented balanced SSFP images acquired using the odd-even interleaved phase order ($P < 0.01$). The segmented balanced SSFP images acquired using the odd-even interleaved phase order in each segment removed the flow artifacts to the edge of the field of view, and allowed for a better visualization of the myocardial border. These statistical differences were obtained irrespective of the imaging views and LVEF values ($P < 0.05$), except the dark flow artifacts in cases with higher LVEF values ($P = 0.13$) or in the long axis view ($P = 0.39$).

DISCUSSION

The odd-even interleaved data acquisition in each segment reduced the flow artifacts in the LV cavity in the cine cardiac MR images using segmented balanced SSFP imaging sequence. The improvement in the image quality in these images using this data acquisition was independent of the imaging planes and the LVEF values. Compared with the reshimming of the gradient or the readjustment of the center frequency, there are technical advantages of the use of this k-space data acquisition, such as easy control, less operator-dependence, less sensitivity to magnetic inhomogeneity.

In conclusion, odd-even interleaved k-space data acquisition should be applied to cine segmented balanced SSFP cardiac MR imaging to reduce dark flow artifacts in the LV cavity, and to improve the visualization of the myocardial border.

References: Markl, M , et al. MRM 2003; 50: 892-903