Quantification of 3D Cardiac Motion in Mice Using Multi-Phase DENSE MRI

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MRI provides a valuable tool for noninvasive evaluation of myocardial wall motion. Recently, multi-phase 2D DENSE MRI was developed to quantify cardiac strain in mice at high spatial and temporal resolution [1, 2]. DENSE methods for 3D displacement encoding have also been investigated [3]. Typically, these methods entail multiple acquisitions that are time consuming. In this project, we aimed to achieve quantification of 3D myocardial wall motion in mice using 5 scans. The proposed method was validated by traditional 2D DENSE techniques.

Methods The MRI study was performed on a 9.4T Bruker Biospec (Billerica, MA) horizontal bore magnet with a 3.5 cm quadrature volume coil (Rapid Biomedical GmbH, Germany). 3-month-old male C57BL/6 mice were imaged with both ECG and respiration gating through a small animal gating and monitoring system (SA Instruments, Stony Brook, NY). A total of five acquisitions were used to quantify 3D myocardial motion on one slice of the heart. Table 1 shows the magnitude and polarity of displacement encoding/unencoding gradients for each acquisition. The subtraction of phase images between acquisition 1 and acquisition 2 yielded the x displacement, which can be expressed as $dx = \Delta\varphi_{12}/2\gamma G\Delta t$. Here, γ is the gyromagnetic ratio and Δt is the duration for the encoding gradient. The y displacement and longitudinal displacement were further computed from the subtraction of phase image of acquisition 3 from acquisition 4 and 5, respectively ($dy = \Delta\varphi_{34}/2\gamma G\Delta t$, $dz = \Delta\varphi_{35}/2\alpha\gamma G\Delta t$). In the current study, the displacement encoding gradient (G) was chosen to yield an encoding frequency of 1.1 cycles/mm and α was set at 25%.

Tab. 1: Magnitude and polarity of displacement encoding/unencoding gradients for the five acquisitions.

Acq #	G_x	G_y	G_z
1	G	0	0
2	-G	0	0
3	0	G	αG
4	0	-G	αG
5	0	G	-αG

To validate this 3D method, longitudinal displacement was also measured using 2D DENSE MRI in long-axis image [2]. The proposed method was further compared to complementary DENSE using complementary spatial modulation of magnetization (CSPAMM) [4]. Four acquisitions were acquired for the CSPAMM technique to quantify the longitudinal displacement on short-axis images and the displacement-encoding frequency was set at 2.2 cycles/mm.

Results Both in-plane (x and y) and longitudinal (z) displacements were quantified in mouse hearts using the multi-phase 3D DENSE method. 11 frames were acquired in one cardiac cycle. A representative short-axis map of longitudinal displacement is shown in Fig. 1a. The calculated z-displacement showed strong agreement with that obtained using CSPAMM technique (Fig. 1b). The z-displacement was also obtained from 2D DENSE images of long-axis slices (Fig. 1c). The longitudinal displacement was further validated with both 2D DENSE and CSPAMM in the whole cardiac cycle. To compare these different methods, the displacement was computed from the overlapped regions between the short-axis (3D DENSE & CSPAMM) and long-axis slices (2D DENSE) as indicated in Figs. 1a-c. As shown in Fig. 1d, the longitudinal displacement obtained from the 3D DENSE method showed strong agreement with the results from the other two methods in the whole cardiac cycle.

Since acquisitions entailed displacement-encoding in both y and z directions, the y displacement was also validated using the 2D DENSE method without any encoding gradient applied in the z direction. Strong agreement was observed between the two methods, suggesting that the accuracy of y displacement calculation was not affected by the additional z gradient (data not shown).

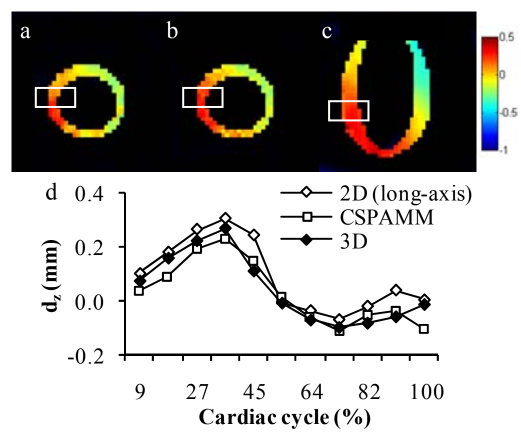

Fig. 1: Representative maps of longitudinal displacement (d_z) acquired with three different methods. **a**: 3D DENSE; **b**: CSPAMM; **c**: 2D DENSE with long-axis at the same cardiac phase (18% of the cardiac cycle). **d**: Comparison of the longitudinal displacements in one cardiac cycle. The displacement was computed from the overlapped region between the short-axis and long-axis images as indicated with the rectangles in subfigures (a)-(c).

Conclusions In the current study, we developed a multi-phase DENSE imaging method for quantification of 3D myocardial motion in mice. Only five acquisitions were required to quantify both in-plane and longitudinal displacements on one slice. The results showed strong agreement with 2D DENSE methods.

References

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