

Optimal tag distance for myocardial MR motion analysis of healthy and diseased mice

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Introduction

Tagged cinematographic (cine) MRI using SPATial Modulation of Magnetization (SPAMM) enables assessment of tissue displacement *in vivo*¹. This technique is often used to study local myocardial function in mouse models of cardiac pathology, resulting in important insights in disease processes. Tissue displacement can be quantified from tagged images using optical flow analysis^{2,3}. However, a poorly chosen tag distance may result in inaccurate estimations of displacement. Only a few studies address the question, which tag distance results in the most accurate estimation of displacement⁴. Therefore, the aim of this study was to determine the optimal SPAMM tag distance to accurately calculate tissue displacement in the healthy and hypertrophied mouse left ventricle (LV), using optical flow analysis.

Methods

Simulations: A reconstruction quality criterion ϵ (see *Data analysis*) was introduced to determine the accuracy of the estimated tissue displacement. Synthetic images were used to determine the relationship between ϵ and the difference between the actual displacement and the flow-based estimated displacement. Three flow fields were defined and scaled with a time-varying factor (Fig. 1). Image series of 15 time frames were created with tags applied in horizontal and vertical direction, and with a 180° phase shift for complementary SPAMM (CSPAMM) reconstruction⁵. This was done by creating sinusoidal intensity patterns with Gaussian noise added in k-space, which were deformed according to the artificial flow fields. Images were created with tag distances ranging from 0.5 to 1.5 mm in steps of 0.05 mm. **Experiments:** C57BL/6 mice (♂, age 12 weeks, n=4) underwent transverse aortic constriction (TAC) to induce LV hypertrophy and impaired LV contractility⁶. Healthy mice (n=3) served as controls. At the age of 16 weeks MRI measurements were performed at 9.4T. Cine MR images were obtained using an ECG triggered and respiratory gated FLASH sequence in 2 long-axis and a midventricular short-axis plane. Imaging parameters were: TR = 7 ms, TE = 1.8 ms, NSA = 6, $\alpha = 15^\circ$, FOV = 3x3 cm², matrix = 192x192, slice thickness = 1 mm, number of cardiac frames = 15. Short axis tagged images were obtained by preceding the FLASH sequence with a SPAMM preparation module. Tags were applied in horizontal and vertical direction, and with a 180° phase shift for CSPAMM reconstruction. Tag distances were 0.5, 0.75, 1.0, 1.25 and 1.5 mm. **Data analysis:** Cine MR images were segmented using CAAS MRV FARM (Pie Medical Imaging, The Netherlands) to obtain LV ejection fraction. Local tissue displacement in synthetic and experimental tagged images was quantified using optical flow analysis³. Briefly, the phase of the CSPAMM tagged pattern was extracted by spectral filtering of the 1st harmonic peak. Discontinuities from 2 π phase jumps were removed by taking the sine of the resulting phase images. Local tissue velocities were then obtained by solving a multi-scale version of the optical flow constraint equation with 3 scales in the temporal and spatial direction. The mean absolute error (MAE) of the obtained displacements was calculated pixelwise between the actual frame n+1 and the reconstructed frame n+1, based on the calculated flow from the previous frame n. Finally, ϵ (expressed in arbitrary units [A/U]) was calculated per tag distance for the synthetic and experimental data in both mouse groups by taking the average MAE over all animals, time frames and myocardial pixels. To test for statistical significance a one-sided Student *t*-test or an ANOVA for repeated measures followed by a Bonferroni post-hoc test (SPSS 16.0) was used, with p-values less than 0.05 considered statistically significant.

Results

The reconstructed flow fields from the simulations contained some vectors with an erroneous length and/or orientation. The number of erroneous vectors in the flow fields with 0.75 to 1.5 mm wide tags were comparable, but substantially lower as compared to those obtained from 0.5 mm wide tags. Importantly, simulations showed a linear correlation between ϵ and the actual flow error in the synthetic images for all tested flow fields ($r > 0.97$, $p < 0.001$, Fig. 2). Ejection fraction in the TAC mice significantly decreased to 42.1±9.5% four weeks post surgery, as compared to control mice 65.4±6.1% ($p < 0.01$) indicative for impaired LV function. No significant differences were found between ϵ in the healthy and hypertrophied hearts ($p = 0.88$). A decrease of ϵ was observed with increased tag distance from 0.5 to 1.0 mm in both experimental groups ($p < 0.001$, Fig. 3). No significant change of ϵ was observed when increasing the tag distance further from 1.0 to 1.5 mm.

Discussion and conclusion

In this study a quality criterion ϵ was used to determine the accuracy of the estimated tissue displacement fields from SPAMM tagged images in the mouse heart. Simulations showed an excellent, linear correlation between ϵ and the actual flow error. Therefore, it was concluded that ϵ provides a good measure to evaluate *in vivo* accuracy of the estimated tissue displacements from SPAMM tagged images. Experiments showed that tags with a distance smaller than 1 mm (frequently used for mouse cardiac tagging) led to a decreased accuracy of estimated tissue displacements. This is indicated by a decrease of ϵ for increasing tag distance from 0.5 to 1.0 mm, which was followed by a flat phase. No significant differences were found between healthy and hypertrophied mouse hearts. Taken together, we conclude that the most accurate estimations for *in vivo* murine myocardial displacements are obtained with tag distances between 1.0 and 1.5 mm, both in healthy and hypertrophied hearts.

Acknowledgement

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References

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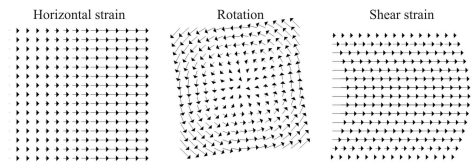


Fig. 1. Flow fields used to create synthetic images.

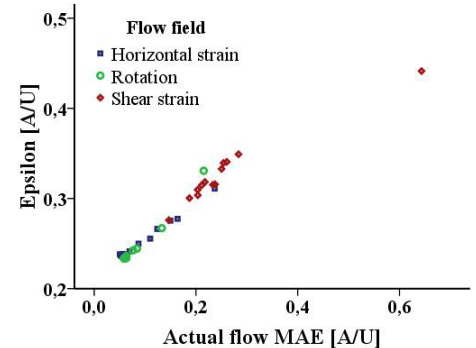


Fig. 2. Simulations demonstrated a linear relationship between the quality criterion ϵ and the actual flow error.

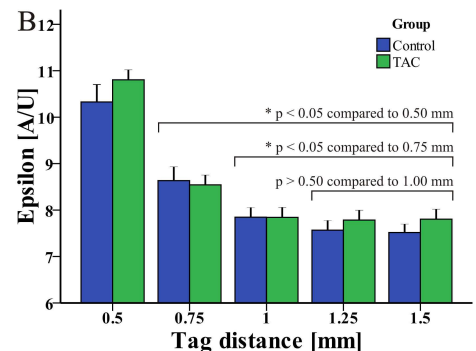
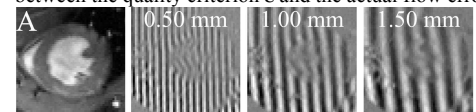


Fig. 3. (A) Examples of end diastolic cine and CSPAMM images obtained in the mouse LV. (B) Experimental results showed a decrease of ϵ for increasing tag distance, indicative for improved accuracy of estimated displacement fields. Values indicated are means±SD.