A fast acquisition method for 3D displacement and strain imaging

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Introduction

Elasticity imaging offers a means for quantitating tissue hardness. It has been shown that although this hardness may relate to disease state [1], a three-dimensional (3D) elasticity reconstruction is necessary to provide an elasticity map that is both geometrically and quantitatively accurate [2]. In order to perform a 3D reconstruction, one must measure the full 3D displacement vector, ***u(r)***. Although a fast, two-dimensional (2D) displacement vector acquisition based on stimulated echoes (STEs) has been developed (meta-DENSE) [3], its T_2^* sensitivity makes it difficult to apply directly to volumetric imaging. Exceedingly long acquisitions (over 3 hours) were therefore required to measure a complete ***u(r)*** using STEs. Here we present a modification to meta-DENSE which removes its T_2^* sensitivity, allowing it to be applied to 3D imaging. Using this modification we have acquired a 128x128x16 map of ***u(r)*** in just 16 minutes while increasing the average displacement error per voxel from approximately 14 μm to 19 μm.

Theory

The meta-DENSE sequence consists of a STE spin preparation followed by a train of π pulses. It produces a 2D displacement image wherein voxel's phase, ϕ, is given as $\boldsymbol{\Phi_d} \bullet \boldsymbol{u} + S_1$, where $\boldsymbol{\Phi_d}$ is the displacement sensitivity [rad/mm], $\boldsymbol{u}$ is the displacement vector [mm], and S_1 is the phase due to the T_2^* sensitivity of the sequence [rad]. S_1 is proportional to τ_1, the separation between the first two π/2 pulses. If there are large inhomogenieties or susceptibility differences across a voxel, then intravoxel dephasing due to S_1 may destroy the signal from that voxel. Using the coherence pathway phase-graph technique [4], it is apparent that a signal free from S_1 contamination may be obtained simply by displacing the read-out window so that it is centered about a time τ_1 sec before $T_E/2$, where T_E is the spacing between π pulses. Due to its T_2^* insensitivity, this displaced-echo meta-DENSE (demeta-DENSE) sequence may be applied to volumetric as well as thick-slice imaging.

Methods

A silicone gel phantom, measuring 80x80x160 mm^3 and containing a single, hard conical inclusion was imaged using the demeta-DENSE sequence. The phantom was subjected to a mild pre-load, and a 128x128x16 image was taken over a 110x75x20 mm^3 field-of-view in *x*, *y*, and *z*, respectively. The repetition time was 1 sec, the mixing time 150 ms, T_E was 14.5 ms, and τ_1 was 2.6 ms. All read-out windows were therefore centered around a time 4.65 ms after each π pulse. The displacement sensitivity was 1.70 π/mm in the read-out (*x*) direction, and 2.04 π/mm in both the first phase-encode (*y*) and second phase-encode (*z*) directions. A series of 8 images was taken at each echo-train length (ETL) from 2 to 16 echoes. A series from a similarly sensitive STE sequence was taken as a control. The standard deviation of the phase maps, appropriately masked, was taken across all 8 realizations for each ETL and displacement component. This was then spatially averaged to yield a displacement error estimate for each ETL and encoding direction.

Results

Figure 1 shows representative magnitude (a and b) and phase images (c and d) from the *x*-encoded displacement data from the control (a and c) and ETL=16 (b and d) experiments. Although there is clearly more blur and noise in the ETL=16 image, the average displacement error is only ~35% greater than in the control (19 vs 14 μm).

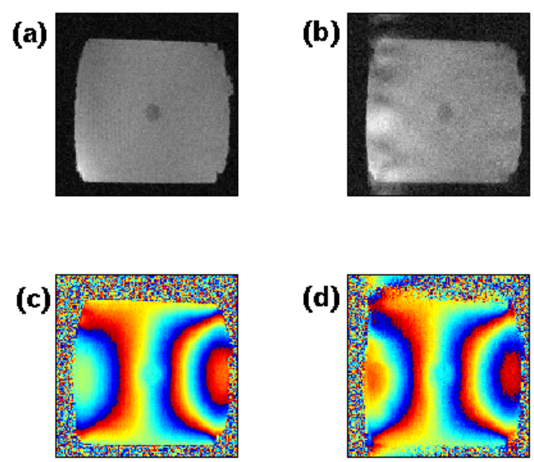

Figure 1

Discussion and Conclusions

3D demeta-DENSE clearly offers great temporal advantages over standard 3D STE acquisitions, bringing the time to acquire a 128x128x8 3D displacement-encoded image to a clinically feasible 16 minutes with an ETL of 8. However, because of the displacement encoding gradients located between every π pulse, demeta-DENSE exhibits more susceptibility to motion artifact than STEs. Additionally, demeta-DENSE requires larger inter-echo spacing (by τ_1) than meta-DENSE, enhancing blur due to T_2 decay when compared to meta-DENSE. Finally, it is likely that this T_2 blur will dominate the displacement estimation errors when compared to inherent phase instability errors. This will be the subject of continued investigation.

References

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