3-D Local Frequency Estimation Inversion for Abdominal MR Elastography

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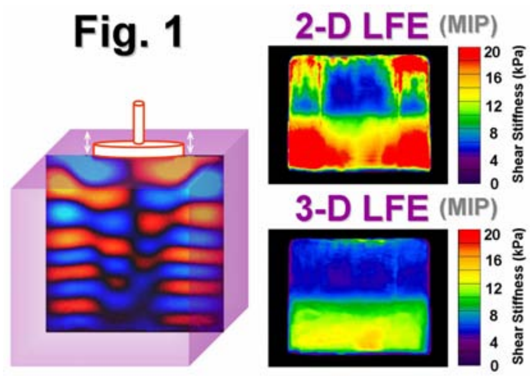
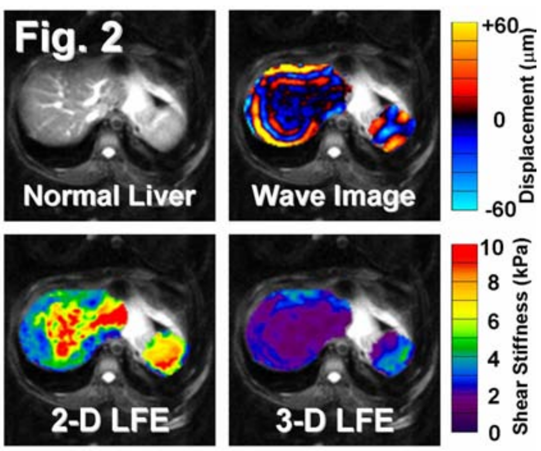
Introduction MR Elastography (1) is a modified phase-contrast MRI technique for quantitatively assessing the mechanical properties of soft tissues by visualizing propagating shear waves in soft tissue. Previous investigations have demonstrated that MRE has promise to quantitatively assess the hepatic fibrosis stage in patients with chronic liver diseases (2, 3). Besides liver tissues, many other abdominal organs are readily accessible by MRE (4). However, shear wave propagation gets very complicated when encountering small objects with complex geometry like the kidneys. A single slice wave image is not adequate for correct stiffness measurements due to the unpredictable non-planar wave propagation. Overestimation is a major problem in such a situation. Therefore, there is a need to acquire 7-D MRE data (3-D spatial, 3-D motion and 1-D temporal) and use a 3-D inversion algorithm, such as the 3-D local frequency estimation (LFE) (5), to obtain reliable shear stiffness estimates. It might provide a useful new quantitative tool for depicting and characterizing abdominal structures, including small and complex organs like pancreas and kidneys.

Materials and Methods All experiments were implemented on a 1.5 T whole-body GE imager (Signa, GE Medical System, Milwaukee, WI, USA). A B-gel phantom with two different stiffness layers (10% and 15% by volume) was used to test the robustness of the 3-D LFE and inversion algorithm. An electromechanical actuator was used to generate longitudinal vibrations at 100 Hz, which produced a complex diffraction-biased shear wave field within the phantom (Fig.1 left). Multi-slice gradient echo MRE sequence was used to image wave fields. Other imaging parameters were: FOV = 14 cm, TR/TE = 1600/19 ms, 40 slices, slice thickness = 3 mm, matrix = 256 × 64, flip angle = 30^{o}, 1 pair of motion encoding gradient (MEG), 3 orthogonal motion sensitizing directions, and 4 phase offsets. Human studies of the abdominal MRE were also conducted to evaluate the 3-D LFE inversion algorithm. Two shot, multi-slice Spin-Echo based EPI MRE was used to collect wave data in 36 axial slices throughout the abdomen with 5-mm thickness. Other imaging parameters were: FOV = 34 cm, TR/TE = 1199/55 ms, Matrix = 96×96, 1 pair of MEG with flow compensation, 3 orthogonal motion sensitizing directions, 4 phase offsets. The total acquisition time is about 5 minutes (20 16-second breatholds). After applying 8 2-D and 20 3-D direction filters respectively, the 2-D and 3-D LFE algorithms were performed to analyze the 7-D wave images from both phantom and human studies.

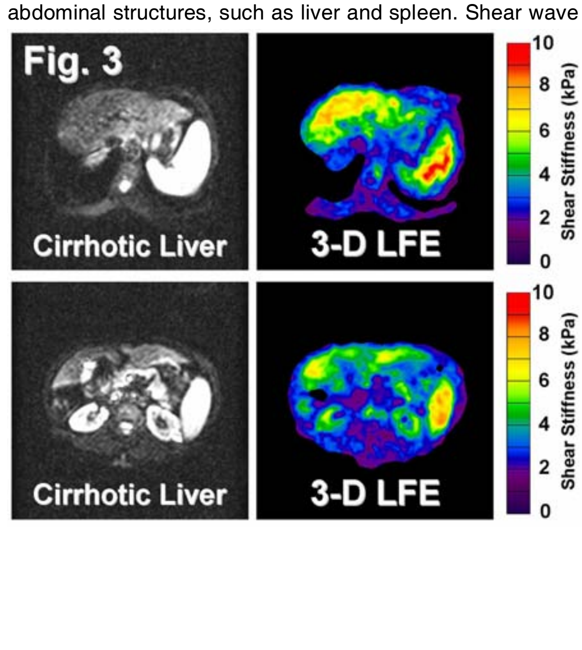




Results The resulting 3-D elastograms of the phantom study are shown on the right of Fig.1. They are MIP (maximum intensity projection) images from a side view to demonstrate the accuracy of the overall stiffness measurements throughout the entire phantom. The 3-D LFE inversion results in more uniform stiffness estimates in each layer of the phantom, while 2-D LFE is prone to overestimating the stiffness at the edges due to the complexity of the wave field.

Figure 2 demonstrates both 2-D and 3-D LFE results on a normal volunteer. The 2-D LFE result (left bottom) has many high-stiffness artifacts and significantly overestimates the stiffness of the liver. This may due to the small imaging matrix, or the low SNR, or through-plane wave propagation effects. The 3-D LFE result (right bottom) has the expected homogeneity for a healthy liver, and the mean estimates of the liver and spleen tissue are closer to previously established values (liver: 2 kPa, spleen: 3 kPa) (2, 6). In liver patient studies, reproducible shear stiffness estimates were obtained using the 3-D LFE algorithm. Figure 3 illustrates two examples. Many abdominal structures, including liver, spleen and kidneys, can be seen in the magnitude images and corresponding elastograms. The kidneys appear well defined as stiff outer cortex and soft inner medulla.

Discussion Among the many inversion algorithms available to researchers in MRE (5), LFE has proven to be a very fast and robust technique. While sometimes lower in resolution than other techniques, in practice it is still adequate for analyzing the larger, more homogenous abdominal structures, such as liver and spleen. Shear wave propagation is very complicated within the abdominal organs, and 2-D LFE processes only one slice of the three-dimensional data, which leads to overestimation if the wave is not propagating exactly along that imaging plane. The 3-D LFE algorithm can obtain reliable stiffness by accounting for these through-plane effects.



Conclusion Experience with MR Elastography (MRE) of abdominal organs has demonstrated that shear wave propagation is typically very complex. Simple planar wave imaging with 2D inversion can generate erroneous results, especially at the edges, or encountering with low SNR/resolution, or not accounting for through-plane wave propagation effects. Three dimensional wave acquisition and 3D inversion is the obvious solution, but can be time consuming. We developed an echo-planar based method for 3D wave imaging in the abdomen and compared 2D and 3D inversions in various regions. The results demonstrate that the 2D approach may provide valid results in specific locations within the liver, but elsewhere, a 3D approach is needed.

Reference

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