MR Tagging-based liver elasticity study with the use of full strain tensor analysis for better understanding of mechanical alterations in NAFLD

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Target audience: Scientists and physicians interested in fatty liver (FL) elastography and searching for alternatives for Magnetic Resonance Elastography (MRE).

Purpose: MR Tagging (MRt) is a common method for myocardial strain evaluation and has recently been proved useful for liver stiffness assessment[1]. With the use of heart beating force deforming the adjacent liver instead of external pulsing device used in elastography, MRt can be alternative for MRE in studying liver elasticity. However, the typical MRt-based strain analysis is focused only on principal strains, not taking advantage from full strain tensor properties such as eigenvectors, trace and absolute strain magnitude. These features may potentially change in abnormal tissue conditions, and their evaluation, enriched with parameterization of deformed area range and shape may give better insight to patholigical liver alterations. The purpose of the study was to assess feasibility of the MRt-based cardiac-induced liver deformation analysis with the use of full strain tensor features for detection of the liver elasticity impairment in mouse model of non-alcoholic fatty liver disease (NAFLD).

Methods: Twelve 6-month old C57BL/6J mice were divided into two groups (each of N=6) according to the feeding protocol: Control – standard AIN-93G diet (for 6 months of feeding), NAFLD – 45% kcal high-fat diet + 60% kcal high-fat diet (for 5 + 1 months of feeding, respectively). Animals were examined using 9.4T BioSpec scanner (Bruker, Germany): ECG-gated FLASH-cine sequence preceded with SPAMM tagging (TE 1.5ms, TR 8.5ms, FA 11°, 192×192 data matrix, FOV 30×30mm^2, NA 16, 1.0 mm slice thickness, tagging grid with 0.2 mm tag line, 0.6 mm tag span; LV short-axis heart projection).

HARP algorithm[2] was used for direct computation of each-pixel eulerian two-dimensional strain tensor ε (%) from MRt images. The ε tensor was diagonalized to distinguish principal strains (%): ε_1 (stretching) and ε_2 (compression), the eigenvectors defining spreading directions of ε_1 and ε_2, the trace of ε tensor giving information about fractional volume change $FVC=\varepsilon_1+\varepsilon_2$ (%), and absolute strain magnitude $AbsE=\varepsilon_1\times\varepsilon_2$ (%). To assess the deformation extend within the liver, the maps of ε_1, ε_2, FVC, and AbsE were parameterized using six two-dimensional central image moments[3]: μ_{00}, μ_{11}, μ_{20}, μ_{02}, μ_{30}, μ_{03}, shape eccentricity ECC[3], and seven Hu's invariant image moments[4]: Φ_1-Φ_7 (shape descriptors). All the processing was performed in Matlab (Mathworks, USA).

Results: In NAFLD, the deformed area within all maps was more irregular in comparison to healthy organ (Fig.1). The streamlines of ε_1 and ε_2 directions showed symmetrical strain development about the central point of heart stimulation in healthy liver, while in NAFLD mice the strain penetration seemed to be limited, manifested in confined range of streamlines. In FVC and AbsE maps of FL the major amount of deformation was enclosed in narrow area corresponding to condensation of streamlines in ε_1 and ε_2. The central and invariant moments analysis showed decreased strain area and level within all ε_1, ε_2, FVC and AbsE maps in NAFLD group (Fig.2). The μ_{00} moment was significantly lower in FL with slight decrease of μ_{20} and μ_{02} (not shown here) in comparison to healthy organ. Noticeably larger deformation eccentricity and increased Φ_1-Φ_3 moments were also observed in NAFLD, while the other parameters remained unchanged as compared to Control group.

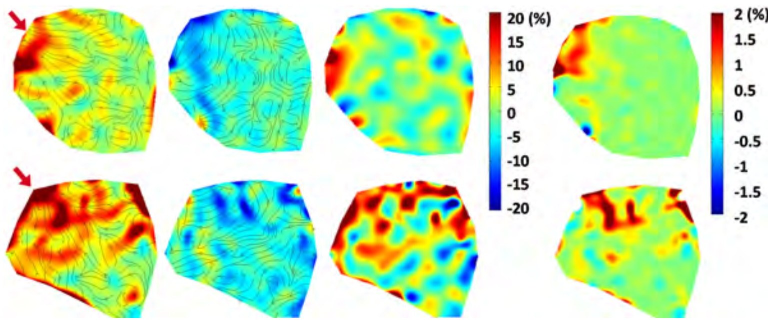
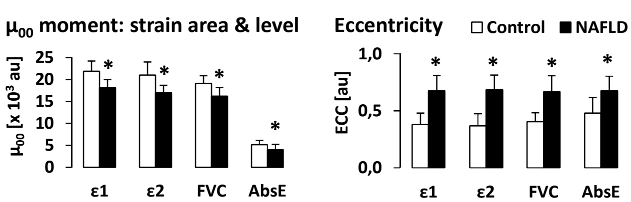


Figure 1. From left to right in columns, the representative maps of: ε_1 strain and ε_2 strain with streamlines of spreading directions, FVC and AbsE for two example subjects: Control (top row) and NAFLD (bottom). Red arrows indicate the pulsating heart position.



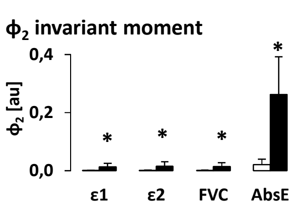


Figure 2. The selected parameters describing deformation area and shape within ε_1, ε_2, FVC and AbsE maps presented in graphs of μ_{00}, ECC and ϕ_2. ***** indicates $p<0.05$ in t-Student test, considered as significant difference between groups.

Discussion: The extended MRt-based deformation analysis benefiting from all strain tensor properties allowed to resolve liver mechanics into absolute strain level, local volumetric changes along with directions of strain spreading within the organ. The proposed visualization showed restricted deformation area in NAFLD, what may suggest increased resistance and viscosity of FL tissue. The observations were compliant with significant differences between groups in quantitative analysis. The lower μ_{00}, μ_{20} and μ_{02} moments in NAFLD indicated smaller area deformed and smaller strain level, while increased eccentricity and Φ_1-Φ_3 moments in FL proved more elliptical shape of deformed area and suggests more one-dimensional stimulation force infiltration into the organ.

Conclusion: MR tagging-based detailed analysis of cardiac-induced liver deformation area range and shape, based on full strain tensor properties, provided a routine suitable for in-vivo measurements of the structural changes within hepatic tissue in NAFLD. The method may be good alternative for classic MRE, which is often insensitive for liver elasticity alterations in early stage of the disease.

References: (1) Mannelli L, Wilson GJ, Dubinsky TJ, et al. Assessment of the liver strain among cirrhotic and normal livers using tagged MRI. JMRI 2012;36:1490-5. (2) Osman N, McVeigh E, Prince J. Imaging heart motion using harmonic phase MRI. IEEE Transactions on Medical Imaging 2000;19:186-202. (3) Teague MR. Image analysis via the general theory of moments. JOSA 1980;70.8:920-930. (4) Hu M-K. Visual pattern recognition by moment invariants. IEEE Transactions on Information Theory 1962;8:179-187.

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