In vivo multifrequency MR elastography for the assessment of portal hypertension before and after transjugular intrahepatic portosystemic shunt (TIPS) implantation

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Target audience: Physicians who are interested in the non-invasive assessment of portal hypertension.

Purpose: To investigate the correlation between hepatic venous pressure gradient (HVPG) and in vivo viscoelasticity of the liver and spleen before and after transjugular intrahepatic portosystemic shunt (TIPS) implantation.

Methods: Ten patients (age range 43-70 years, 5 females) with portal hypertension were enrolled in the study. All patients received TIPS placement during which HVPG was measured. In vivo abdominal MR elastography (MRE) was performed twice in each patient: One day prior to the intervention and 48 to 72 hours after the TIPS was implanted. The abdominal MRE setup is the same as described in (1). All experiments were conducted on a 1.5-T MRI scanner equipped with a 12-channel phased array surface coil. The 3D wave field was recorded using a single-shot EPI sequence with motion-encoding gradients (MEG). The frequencies of the external vibration were 25, 30, 40, 50 and 60 Hz. Total acquisition time for 9 consecutive slices of 2.7 × 2.7 × 5 mm^3 resolution, 5 frequencies, 8 wave dynamics and 3 MEG directions was 3 minutes and 40 seconds. Further imaging parameters: FoV 350 × 284 mm, repetition time (TR) 1820 ms, echo time (TE) 54 ms, matrix size 128 × 104. MRE data processing is similar to the methods described in (2): multifrequency dual elasto visco (MDEV) inversion as detailed in (2) was carried out yielding two independent parameter maps, one for the magnitude of the complex shear modulus $|G^*|$ and one for the phase angle of the complex shear modulus φ. Both constants represent lumped viscoelastic parameters which combine both storage and loss properties of the tissue.

Results: Fig 1 shows shear wave images of three curl components at 50 Hz drive frequency, pre- and post-TIPS. The wave length in all three components are noticeably shorter after TIPS placement. The corresponding elastograms demonstrate lower $|G^*|$ values in the post-TIPS experiments. Group mean values of $|G^*|$ and φ are much higher than reported by (1) for healthy volunteers (liver: 6.66 ± 2.41 kPa vs. 1.27 ± 0.17 kPa and 0.824 ± 0.155 vs. 0.407 ± 0.044; spleen: 7.01 ± 1.98 kPa vs. 2.01 ± 0.69 kPa and 0.804 ± 0.171 vs. 0.607 ± 0.152 for $|G^*|$ and φ, respectively) indicating severe fibrosis in our group. Fig 2a and 2b show MRE parameters of the liver and spleen before and after TIPS treatment. $|G^*|$ of the liver has dropped significantly from 8.28 ± 2.14 kPa to 7.02 ± 1.46 kPa (P = 0.014). A similar behavior was observed in the spleen by a decrease from 8.12 ± 1.22 kPa to 6.84 ± 1.60 kPa (P = 0.027). φ has no significant change after the TIPS placement for both liver (pre-TIPS: 0.82 ± 0.15; post-TIPS: 0.82 ± 0.17; P = 1.00) and spleen (pre-TIPS: 0.84 ± 0.19; post-TIPS: 0.77 ± 0.15; P = 0.08). We also observed a linear correlation between the relative changes of spleen stiffness and relative changes of the HVPG (R^2 = 0.659, P = 0.013, **Fig 2**). The relative changes are shown in percentages calculated by dividing the difference of pre- and post-TIPS values by the pre-TIPS values.

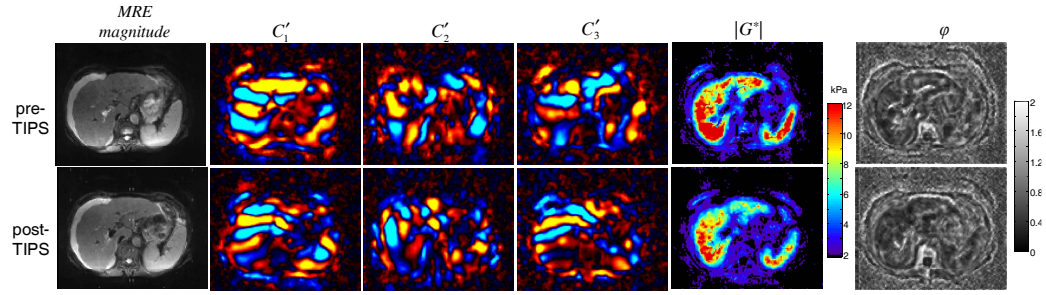

Fig.1: Magnitude of the MRE, three curl components of the wave fields at 50 Hz vibration frequency and reconstructed $|G^*|$ and φ maps in a central slice of a patient before and after TIPS placement.

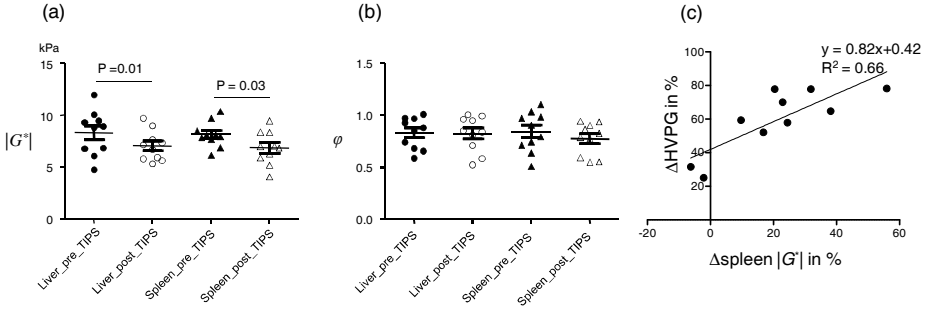

Fig.2: Mean values and standard error of $|G^*|$ (a) and φ (b) in the liver and spleen for all patients. (c) Linear regression analysis between the relative change of the spleen shear stiffness and the relative changes of HVPG after TIPS placement.

Discussion: We observed a significant softening of both liver and spleen after TIPS placement as indicated by a reduced $|G^*|$. This observation is consistent with previous studies (3-5). In the present study we investigated for the first time the viscoelastic response of the liver and spleen to TIPS within a short period of at maximum 4 days. Since portal decompression is a dynamic process, our study design aimed on the instantaneous viscoelastic feedback to changes of HVPG. φ is closely related to the attenuation behavior of the tissue. Since mechanical attenuation is linked to the topology of the underlying viscoelastic network, our experiments indicate that the network geometry in the liver and spleen remains unaffected by TIPS-induced decompression. Our study showed for the first time that the viscoelasticity change in spleen is linearly correlated with the alteration of HVPG due to TIPS. Recently it was reported that the spleen loss modulus linearly correlates with the HVPG (4) which is consistent to our results. Given that $|G^*|$ is a combination of both storage modulus and loss modulus, the hypothesis is raised that an alteration of splenic hemodynamics is responsible for the observed changes in stiffness.

Conclusion: The magnitude shear moduli $|G^*|$ of liver and spleen were both sensitive to the portal decompression following TIPS. The relative change of $|G^*|$-values in the spleen prior and after TIPS was linearly correlated with the invasively measured HVPG and can potentially serve as an imaging marker for the noninvasive assessment of portal pressure in follow-up investigations after TIPS.

Literature: [1] Guo J, et al. Patient-Activated Three-Dimensional Multifrequency Magnetic Resonance Elastography for High-Resolution Mechanical Imaging of the Liver and Spleen. Rofo. 2013;doi.org/10.1055/s-0033-1350510. [2]Braun J, et al. High-resolution mechanical imaging of the human brain by three-dimensional multifrequency magnetic resonance elastography at 7T. Neuroimage. 2014;90:308-14.[3]Ronot M, et al. Assessment of portal hypertension and high-risk oesophageal varices with liver and spleen three-dimensional multifrequency MR elastography in liver cirrhosis. European Radiology. 2014;24(6):1394-402.[4]Talwalkar JA, et al. Feasibility of In Vivo MR Elastographic Splenic Stiffness Measurements in the Assessment of Portal Hypertension. American Journal of Roentgenology. 2009;193(1):122-7.[5] Robic MA, Procopet B, Metivier S, et al. Liver stiffness accurately predicts portal hypertension related complications in patients with chronic liver disease: a prospective study. Journal of Hepatology. 2011;55(5):1017-24.