

Intensity speckle MR elastography

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Introduction: Magnetic resonance elastography (MRE) allows the measurement of the mechanical properties of living tissue by combining shear waves and motion sensitive MRI [1]. In classical MRE, shear wave images are evaluated using an appropriate wave inversion technique for calculating an estimate of the spatial distribution of the shear modulus within the region of interest [2].

Problem: Wave inversion is mathematically ill-posed and thus error prone due to unknown boundary conditions and discrete and noisy data. For this reason, recent developments aimed to deduce structure related information from MRE wave images without the need of wave inversion [3, 4].

Objective: In this paper we present an analysis of shear wave scattering by means of a statistical analysis of the shear wave intensity. From this analysis a single dimensionless fit parameter is available. This parameter provides a measure for the length scale on which shear wave scattering occurs. Hence, this parameter is sensitive to the mechanical structure of tissue on a mesoscopic level which is otherwise inaccessible by non-invasive medical imaging modalities. The novel method is demonstrated by phantom experiments and *in vivo* MRE of the human brain.

Theory: In heterogeneous media such as the human brain, shear waves are frequently scattered by elastic discontinuities. Elastic wave scattering appears as characteristic variations of wave intensity called *speckle patterns*. Speckle patterns in MRE result from constructive interference of multiply scattered shear waves. Such patterns can be characterized by the distribution $P(I)$ of the intensity, normalized to its mean value [5]. Multiple scattering can yield an exponential intensity distribution indicating that the local intensities are statistically independent and normally distributed random values. Then wave energy, i.e. wave intensity is diffusively propagated. When scattering is even more pronounced, the distribution at large intensities can change towards a stretched exponential:

$$P(I) \propto \exp(-2\sqrt{g}I) \cdot \quad (1)$$

The fit parameter, g , is related to the mean distance between elastic discontinuities and the local change in elasticity. It can be viewed as being a combined measure for the degree of heterogeneity and thus provides a measure that is closely related to the structural properties of the tissue. A small value for g suggests a high degree of heterogeneity.

Methods: MRE experiments were performed in a 1.5 T scanner (Sonata, Siemens, Erlangen, Germany) using a multifrequency MRE setup as introduced in [6]. Experiments were conducted on a gel phantom with 100 parallel glass cylinders ($R=1.5$ mm) as scatterers at frequencies of 25, 50, 75 and 100 Hz. In a second series of experiments the brain of a healthy male volunteer aged 37 years was investigated using vibration frequencies of 25, 37.5, 50 and 62.5 Hz. A transverse slice was selected as image plane for both experiments. Shear wave excitation and motion encoding in the phantom experiment were chosen parallel to the cylinders corresponding to a set-up of scalar waves. To account for the more complicated geometry of brain structure motion encoding was there subsequently applied along the direction of slice-selection, phase-encoding and read-out for determining the total shear wave intensity within the image plane. The time series of wave images was temporally Fourier transformed and the images at the aforementioned frequencies were taken for further processing. A region of interest (ROI) was manually chosen that included the parenchyma without sulci and ventricles. Intensity speckles inside the ROI were normalized to the mean intensity inside the ROI and then binned. The resulting histograms were fitted to (1) using a nonlinear least-squares regression algorithm.

Results:

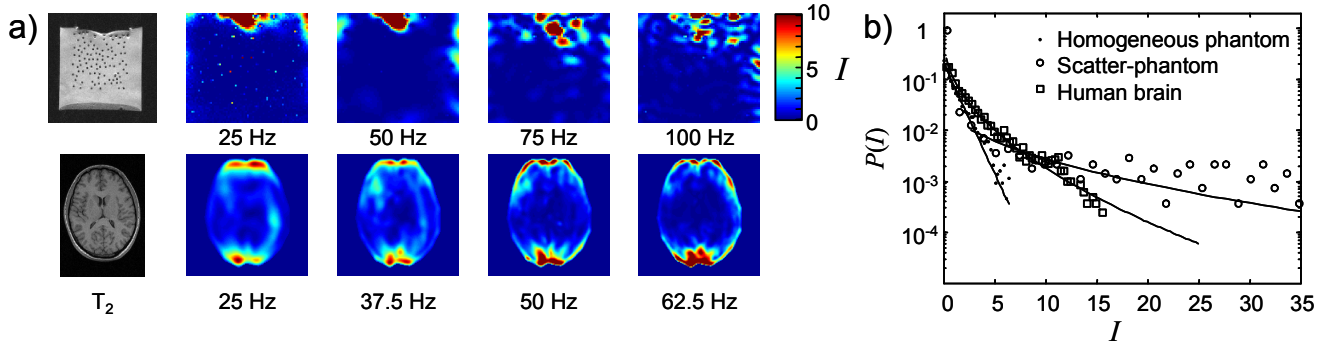


Figure: a) shows the magnitude images of the transverse slices and the normalized shear wave intensity inside the ROI for the gel phantom and the brain. Intensity peaks are clearly visible in regions where the majority of shear wave energy was coupled into the phantom and the brain, respectively. The speckles do not display a residual texture due to wave fronts. Instead a speckled distribution of intensity is observed, suggesting that shear wave scattering at heterogeneities has dissolved any wave fronts. The distribution of shear wave intensity at 50 Hz is shown in figure b) for the gel phantom and the brain. For comparison the distribution for a homogeneous gel phantom without scatterers was also included. Solid lines represent the fits to eq. (1). The fit parameter was determined with $g=0.1, 0.2, 0.2, 0.3$ and $g=1, 1.1, 0.8, 0.6$ for the scattering phantom and the brain, respectively. In case without scatterers the fit corresponded to $g \rightarrow \infty$.

Discussion and Conclusion: The results demonstrate the feasibility of the proposed statistical analysis of intensity speckles in MRE. The experimental intensity distribution of gel phantoms and human brain is well reproduced by the stretched exponential function. The heterogeneity parameter g was significantly lower in the phantom with glass cylinders than in brain. This is due to the very large stiffness variations inside the glass-gel phantom. In contrast, the phantom without scatterers shows a pure exponential intensity distribution which is due to noise. The intensity distribution observed in brain strongly suggests that scattering occurs in MRE of the human brain which can be used to derive material parameters. Further experiments are required for investigating the potential of speckle intensity MRE as a novel neuroradiological marker for diffuse pathological changes of brain tissue.

References:

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