Optimal conditions and sensitivity of brain MRE: from homogeneous to heterogeneous media

Fatiha Andoh

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Magnetic Resonance Elastography (MRE) is an imaging technique for the mechanical characterization of biological tissues. This technique consists in recording by MRI the displacement fields induced by the propagation of an induced shear wave in a target tissue. Mechanical parameters such as the shear wave velocity, shear elasticity or shear viscosity moduli can then be deduced by inverting the differential equations of the acquired displacement fields. Thus, MRE allow to map the mechanical parameters of the medium which are recognized as relevant biomarkers to characterize the pathophysiological state of biological tissues.

However, the promise of absolute quantification of shear viscoelastic moduli by MRE is undermined by the multiple dependence of the results on acquisition parameters and reconstruction methods. Recent works have shown that the factors determining the accuracy and precision of MRE measurement can ultimately be subsumed with two parameters that essentially characterize how well the propagating shear wave is sampled: the spatial sampling factor, $s = \lambda/a$, and the amplitude sampling factor, $Q = q/\Delta q$, where $\lambda$ is the shear wavelength, $a$, the voxel size, $q$, the amplitude of the curl of the displacement field, and $\Delta q$, the associated measurement uncertainty. Optimal conditions on $s$ and $Q$ must be fulfilled to validate MRE outcomes as proven in mechanically homogeneous media.

In this work, optimal conditions were studied in heterogeneous and structured media so that they could be applied to the brain. First, MRE accuracy and precision were investigated with optimal sampling strategies by carrying out multi-frequency experiments on a set of four mechanically-calibrated phantoms that mimic the stages of liver fibrosis and on a heterogeneous breast phantom containing inclusions mimicking tumour lesions stiffer than the surrounding homogeneous parenchyma. Absolute quantification and significant grading could be achieved only when optimal conditions were fulfilled either prospectively by adequate multi-frequency excitation or retrospectively by data multi-resampling.

Then, multi-frequency brain MRE was performed in order to investigate the best conditions to accurately and precisely discriminate cerebral white matter, grey matter, and the cerebellum in a healthy subject. The cerebellum was found to be less elastic and viscous than cerebral white and grey matters, which exhibited similar shear viscoelastic moduli despite their different anatomical structures.

In a last study, physical conditions analogous to microgravity were implemented in the bore of the MRI system to tune brain mechanical properties and challenge MRE sensitivity to inferred changes. Associated tissue stiffening was revealed with optimal MRE by a significant increase of the shear velocity and shear dynamic modulus throughout the brain, especially in the superior peripheral regions. Thereafter, brain MRE, performed in optimal conditions, could be advantageously used to detect mechanical alterations due to similar or inverse pressure changes in pathological processes like haemorrhage, hydrocephalus, or cancer with blood flow redistribution and cerebrospinal fluid accumulation or depletion.

**Keywords:** magnetic resonance elastography, brain, optimal conditions, accuracy, precision, sensitivity, homogeneous, heterogeneous