Magnetic resonance elastography

Magnetic resonance elastography (MRE) is a non-invasive medical imaging technique that measures the mechanical properties (stiffness) of soft tissues by introducing shear waves and imaging their propagation using MRI. Pathological tissues are often stiffer than the surrounding normal tissue. For instance, malignant breast tumors are much harder than healthy fibro-glandular tissue. This characteristic has been used by physicians for screening and diagnosis of many diseases, through palpation. MRE calculates the mechanical parameter as elicited by palpation, in a non-invasive and objective way.

Magnetic resonance elastography works by using an additional gradient waveform in the pulse sequence to sensitize the MRI scan to shear waves in the tissue. The shear waves are generated by an electromechanical transducer on the surface of the skin. Both the mechanical excitation and the motion sensitizing gradient are at the same frequency. This encodes the amplitude of the shear wave in the tissue in the phase of the MRI image. An algorithm can be used to extract a quantitative measure of tissue stiffness from the MRI in an elastogram.

Magnetic resonance elastography was first introduced by Muthupillai et al. in 1995 and is being investigated to be used for a multitude of diseases that affect tissue stiffness.

MRE at 30 and 40 Hz provides diagnostic wave images and reliable measurements of pancreatic stiffness in healthy volunteers. MRE at 30-60 Hz is acceptable for PDACs (IQS ≥ 3, ICC and κ ≥ 0.80) [1)].

Magnetic resonance elastography in Neurosurgery

- Understanding the Mechanical Properties of Pituitary Adenomas for Optimized Surgery
- Comparison of different new ultrasonic technologies in resection assessment of neurosurgery
- Repeatability of Magnetic Resonance Elastography-Derived Mechanical Parameters in Intracranial Meningiomas
- Measurement of biomechanical properties of transversely isotropic biological tissue using traveling wave expansion
- Systemic treatment type is not associated with abnormal post-treatment noninvasive liver stiffness measurement in psoriasis
- Boiling Histotripsy in Ex Vivo Human Brain: Proof-of-concept
- Angiographically occult spinal dural arteriovenous fistula diagnosed by exploratory surgery with intraoperative ultrasound: illustrative case
- In vivo characterization of brain tumor biomechanics: magnetic resonance elastography in intracranial B16 melanoma and GL261 glioma mouse models

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Magnetic resonance elastography (MRE) is a novel imaging modality allowing quantification of tissue consistency. Multiple trials have focused on the use of MRE to describe meningioma consistency prior to surgery and on improving diagnostic accuracy of normal pressure hydrocephalus and other dementias. MRE shows promising results, but still lacks direct clinical translational value. Within neurosurgery and neurosciences MRE could contribute and improve decision-making, diagnosis and

treatment. Furthermore, the use of MRE will improve the basic understanding of neuroanatomy, physiology and pathology [2].

Normal pressure hydrocephalus

Magnetic resonance elastography for normal pressure hydrocephalus.

Glioblastoma

Glioblastoma are generally less viscous and softer than healthy brain parenchyma. Unrelated to the morphology-based contrast of standard magnetic resonance imaging, elastography provides an entirely new neuroradiological and contrast related to the biomechanical properties of tumors [3].

Meningioma

Fifteen meningiomas in 14 patients underwent MRE. Tumors with regions of distinctly different stiffness were considered heterogeneous. Intratumoral portions were considered hard if there was a significant area ≥6 kPa. A 5-point scale graded intraoperative consistency. A durometer semiquantitatively measured surgical specimen hardness. Statistics included χ, sensitivity, specificity, positive and negative predicative values, and Spearman rank correlation coefficient.

For MRE and surgery, 9 (60%) and 7 (47%) tumors were homogeneous, 6 (40%) and 8 (53%) tumors were heterogeneous, 6 (40%) and 10 (67%) tumors had hard portions, and 14 (93%) and 12 (80%) tumors had soft portions, respectively. MRE sensitivity, specificity, and positive and negative predictive values were as follows: for heterogeneity, 75%, 100%, 100%, and 87%; for hardness, 60%, 100%, 100%, and 56%; and for softness, 100%, 33%, 86%, and 100%. Overall, 10 tumors (67%) matched well with MRE and intraoperative consistency and correlated between intraoperative observations (P = .02) and durometer readings (P = .03). Tumor size ≤3.5 cm or vascular tumors were more likely to be inconsistent (P < .05).

MRE was excellent at ruling in heterogeneity with hard portions but less effective in ruling out heterogeneity and hard portions, particularly in tumors more vascular or <3.5 cm. MRE is the first technology capable of prospectively evaluating intratumoral stiffness and, with further refinement, will likely prove useful in preoperative planning [4].

Respiratory arrest

Respiratory arrest is a major life-threatening condition leading to cessation of vital functions and hypoxic-anoxic injury of the brain. The progressive structural tissue changes characterizing the dying brain biophysically are unknown. Bertalan et al. used noninvasive magnetic resonance elastography to show that biomechanical tissue properties are highly sensitive to alterations in the brain in the critical period before death. Our findings demonstrate that brain stiffness increases after respiratory arrest even when cardiac function is still preserved. Within 5 minutes of cardiac arrest, cerebral stiffness further increases by up to 30%. This early mechanical signature of the dying brain can be

explained by water accumulation and redistribution from extracellular spaces into cells. These processes, together, increase interstitial and intracellular pressure as revealed by magnetic resonance spectroscopy and diffusion-weighted imaging. Our data suggest that the fast response of cerebral stiffness to respiratory arrest enables the monitoring of life-threatening brain pathology using noninvasive in vivo imaging [5)]

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Song Q, Shi Y, Gao F, Meng Y, Yang R, Liu Y, Zhong S, Hong Y. Feasibility and Reproducibility of Multifrequency Magnetic Resonance Elastography in Healthy and Diseased Pancreases. J Magn Reson Imaging. 2022 Mar 25. doi: 10.1002/jmri.28158. Epub ahead of print. PMID: 35332973.
2)
Aunan-Diop JS, Pedersen CB, Jensen U, Halle B, Harbo F, Poulsen FR. [Magnetic resonance elastography of the brain]. Ugeskr Laeger. 2021 Aug 30;183(35):V02210138. Danish. PMID: 34477092.
3)
Streitberger KJ, Reiss-Zimmermann M, Freimann FB, Bayerl S, Guo J, Arlt F, Wuerfel J, Braun J, Hoffmann KT, Sack I. High-resolution mechanical imaging of glioblastoma by multifrequency magnetic resonance elastography. PLoS One. 2014 Oct 22;9(10):e110588. doi: 10.1371/journal.pone.0110588. eCollection 2014. PubMed PMID: 25338072.
4)
Hughes JD, Fattahi N, Van Gompel J, Arani A, Meyer F, Lanzino G, Link MJ, Ehman R, Huston J. Higher-Resolution Magnetic Resonance Elastography in Meningiomas to Determine Intratumoral Consistency. Neurosurgery. 2015 Oct;77(4):653-9. doi: 10.1227/NEU.0000000000000892. PubMed PMID: 26197204.
5)
Bertalan G, Klein C, Schreyer S, Steiner B, Kreft B, Tzschätzsch H, de Schellenberger AA, Nieminen-Kelhä M, Braun J, Guo J, Sack I. Biomechanical properties of the hypoxic and dying brain quantified by magnetic resonance elastography. Acta Biomater. 2019 Nov 11. pii: S1742-7061(19)30751-2. doi: 10.1016/j.actbio.2019.11.011. [Epub ahead of print] PubMed PMID: 31726251.