MR Elastography: Overview , Driver Technology, and Applications for Abdominal Imaging

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Introduction

Many diseases markedly affect the mechanical properties of tissues and this accounts for the efficacy of palpation, a centuries-old technique of clinical medicine. MR Elastography (MRE) is an emerging diagnostic imaging technique for quantitatively assessing the mechanical properties of tissue [1,2]. It is a three-step process, involving: (i) generating mechanical waves within the tissues of interest, (ii) imaging the micron-level displacements caused by propagating waves using a special MR imaging technique with oscillating motion-sensitizing gradients, and (iii) processing the wave images using an "inversion" algorithm to generate quantitative maps of mechanical properties. Suitable dynamic stress for MRE can be generated by surface drivers, inertial effects, acoustic radiation pressure, or endogenous physiologic mechanisms. MRE acquisition sequences are capable of visualizing waves causing less than 100 nanometers in displacement amplitude. Inversion algorithms based on continuum mechanics are used to process the acquired data to generate maps of mechanical properties such as depict stiffness, viscosity, attenuation, and anisotropy.

MRE has been applied to assess a variety of tissues, ranging in stiffness from lung to cartilage. Human studies have demonstrated that it is feasible to quantitatively image the mechanical properties of skeletal muscles, gray and white matter in the brain, thyroid, kidney, liver, and skin. Studies have shown changes in tissue mechanical properties in patients with breast, brain, and thyroid tumors, and diseases of muscle. Evidence is also emerging that the mechanical environment in tissue (that can be measured with MRE) has a profound effect on the function of many cells through a process called *mechanotransduction*.

Clinical Application: MRE of the Liver

Chronic liver disease is serious worldwide problem, and hepatic fibrosis is the most important consequence. If not detected and treated, fibrosis eventually leads to cirrhosis which is irreversible and associated with high mortality. Currently, needle biopsy is the accepted method for detecting and quantifying hepatic fibrosis. This procedure is invasive, expensive, and is affected by sampling error.

Clinical studies by multiple investigators have recently established that MRE is an accurate method for diagnosing hepatic fibrosis [3-7]. In this application, the liver is illuminated with shear waves, typically in the range of 40-90 Hz. MRE-derived hepatic stiffness increases systematically with fibrosis stage. In our most recent published study, encompassing 50 patients with biopsy-proven liver disease and 35 normal volunteers, ROC analysis showed that, with a shear stiffness cut-off value of 2.93 kPa, the predicted sensitivity and specificity for detecting liver fibrosis is 98% and 99%, respectively. ROC analysis also provided evidence that MR elastography can discriminate between patients with moderate and severe fibrosis (grades 2–4) and those with mild fibrosis (sensitivity, 86%; specificity, 85%). Importantly, hepatic stiffness is not systematically influenced by the presence of steatosis.

Emerging experience in over 300 liver MRE exams performed for clinical purposes at Mayo Clinic suggests that MRE also has promise for characterizing focal liver lesions. Benign liver masses, including cavernous hemangiomas, hepatic adenomas, and focal nodular hyperplasia have typical stiffness values in the 3 kPa range, slightly stiffer than normal liver parenchyma. Malignant focal masses of the liver, including hepatocellular carcinomas, metastases, and cholangiocarcinomas are much stiffer than normal liver tissue. In a series of 48 liver masses (36 malignant and 12 benign), a threshold of 5 kPa correctly differentiated 100% of malignant from benign masses using MRE.

MRE of the other Abdominal Structures

Preliminary results indicate that it is feasible to apply MRE to visualize the mechanical properties of other abdominal and pelvic structures including the spleen, gastric wall, adrenal glands, pancreas, bowel, kidneys, and bladder wall. In studies of patients with chronic liver disease we have observed a very strong correlation between the measured stiffness of the spleen and the biopsy-proven grade of hepatic fibrosis. We speculate that this may reflect the presence of portal venous hypertension, with the spleen becoming stiffer with increasing pulp pressure and raising the potential of estimating portal pressure with MRE.

Conclusion

Results obtained by multiple investigators have provided strong evidence that MRE has excellent diagnostic accuracy for assessing hepatic fibrosis. MRE is safer, more comfortable, and less expensive than liver biopsy and may be more accurate. Other abdominal applications are likely to emerge.

References

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