# In Vivo Determination of Hepatic Stiffness Using Steady-State Free Precession Magnetic Resonance Elastography

*Dieter Klatt, MS,* Patrick Asbach, MD,* Jens Rump, MS,* Sebastian Papazoglou, MS,* Rajan Somasundaram, MD,† Jens Modrow,‡ Jürgen Braun, PhD,§ and Ingolf Sack, PhD**

**Objective:** The objective of this study was to introduce an magnetic resonance elastography (MRE) protocol based on fractional motion encoding and planar wave acquisition for rapid measurements of in vivo human liver stiffness.

**Materials and Methods:** Vibrations of a remote actuator membrane were fed by a rigid rod to the patient's surface beneath the right costal arch resulting in axial shear deflections of the liver. Data acquisition was performed using a balanced steady-state free precession (*b*SSFP) sequence incorporating oscillating gradients for motion sensitization. Tissue vibrations of frequency $f_v = 51$ Hz were tuned by twice the sequence repetition time ($1/f_v = 2TR$). Twenty axial images acquired by time-resolved through-plane wave encoding were used for planar elasticity reconstruction. The MRE data acquisition was achieved within 4 breathholds of 17 seconds each. The method was applied to 12 healthy volunteers and 2 patients with diffuse liver disease (fibrosis grade 3).

**Results:** MRE data acquisition was successful in all volunteers and patients. The elastic moduli were measured with values between $1.99 \pm 0.16$ and $5.77 \pm 0.88$ kPa. Follow-up studies demonstrated the reproducibility of the method and revealed a difference of $0.74 \pm 0.47$ kPa ($P < 0.05$) between the hepatic stiffness of 2 healthy male volunteers.

**Conclusion:** *b*SSFP combined with fractional MRE enables rapid measurement of liver stiffness in vivo. The used actuation principle supports a 2-dimensional analysis of the strain wave field captured by axial wave images. The measured data indicate individual variations of hepatic stiffness in healthy volunteers.

**Key Words:** fractional MR elastography, steady-state free precession, liver, viscoelasticity, shear modulus

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From the Department of *Radiology, Charité-Universitätsmedizin Berlin, Charité Campus Mitte, Berlin, Germany; the †Department of Gastroenterology, Rheumathology and Infectiology; Charité-Universitätsmedizin Berlin, Charité Campus Benjamin Franklin, Berlin, Germany; ‡Modrow Audio Engineering, Berlin, Germany; and the §Institute of Medical Informatics, Charité-Universitätsmedizin Berlin, Charité Campus Benjamin Franklin, Berlin, Germany.

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Reprints: Ingolf Sack, PhD, Department of Radiology; Charité-Universitätsmedizin Berlin, Charité Campus Mitte, Schumannstrasse 20/21, 10117 Berlin, Germany. E-mail: ingolf.sack@charite.de.



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Early detection of onset and progression of liver fibrosis is an important prerequisite for successful treatment of chronic hepatitis in daily clinical practice.[1] At present, percutaneous liver biopsy is the gold standard for assessing the grade and stage of fibrosis.[2] However, this invasive procedure is associated with patient discomfort, especially when repeated biopsies are needed for screening chronic liver disease.[3] Furthermore, reproducibility of the method may be affected by sampling errors and variations in the assessment of the histopathologist.[4,5] Noninvasive cross-sectional imaging modalities such as computed tomography (CT), magnetic resonance imaging (MRI), and ultrasound are unable to determine any of the earliest stages of fibrosis. After further progression of the disease, indirect pathognomonic anatomic changes like an enlarged caudate lobe or the presence of varices can be observed.[6] In addition, different MR contrast media may be useful for detecting fibrosis. A reduced uptake of gadolinium-based hepatospecific MR contrast medium has been observed in a rat model of biliary cirrhosis.[7] Furthermore, a reduction of the uptake of iron oxide-based MR contrast medium into the liver has been described that is related to progression of fibrosis.[8] However, treatment options are limited as a result of the progression of the disease and the fibrosis has most often reached an irreversible stage. These limitations have stimulated the search for new, more sensitive approaches like noninvasive measurements of hepatic stiffness by elastography.

Elastography is based on the detection of tissue strain produced by defined internal or external stresses.[9–15] Ultrasound imaging for in vivo elastography of the liver has been used to monitor shear waves induced by cardiac motions or external transient wave sources.[16–21] In MR elastography (MRE), liver examinations were conducted using continuous-wave excitation on the surface of the body in the low audio-frequency range between 50 and 80 Hz.[22–28] The capability of MRE to selectively capture specific components of the shear wave field in arbitrary image slices potentially increases the accuracy of liver elastography.

Current developments of MRE of human liver are based on spin-echo MRI, EPI, or balanced SSFP sequences combined with different ways of wave generation by electromagnetic coils or pneumatic drivers.[25,27,28] Generally, the setup of drivers in MRE influences initial and boundary conditions of the strain wave field. In most in vivo applications, individual morphologic variations and mechanical shielding of the examined tissue