# Cardiac Magnetic Resonance Elastography

## *Initial Results*

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**Objectives:** To develop cardiac magnetic resonance elastography (MRE) for noninvasively measuring left ventricular (LV) pressure-volume (P-V) work.

**Material and Methods:** The anterior chest wall of 8 healthy volunteers was vibrated by 24.3-Hz acoustic waves for stimulating oscillating shear deformation in myocardium and adjacent blood. The induced motion was recorded by an electrocardiogram-gated, vibration-synchronized and segmented gradient-recalled echo MRE sequence acquiring 360 phase-contrast wave images with a temporal resolution of 5.16 milliseconds in the short-axis view during controlled breathing. Relative changes in wave amplitudes served as a measure of LV pressure variation during the cardiac cycle. MRE pressure data were combined with LV volumes obtained from segmentation of 3D cine-steady-state free precession data sets.

**Results:** Shear wave amplitudes decreased from diastole to systole, which reflects the dynamics of myocardial shear modulus variations during the cardiac cycle. Assuming spherical shear stress, a linear relationship between myocardial stiffness and LV pressure was derived. The MRE-measured pressure was plotted as a function of LV volumes. Characteristic P-V cycles displayed an isovolumetric increase in pressure during early systole, whereas less pronounced volume conservation was observed in early diastole. Mean cardiac P-V work in all volunteers was 0.85 ± 0.11 J.

**Conclusion:** In vivo cardiac MRE is a noninvasive method for measuring pressure-related heart function determined by shear modulus variations in the LV wall. This is the first noninvasive mechanical test of cardiac work in the human heart and is potentially useful for assessing pathologies associated with increased myocardial stiffness such as diastolic dysfunction.

**Key Words:** MR elastography, cardiac function, shear modulus, pressure, volume

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The pressure-volume (P-V) relationship is a highly reliable parameter for assessing myocardial contractility in the intact circulation. This relationship is almost insensitive to changes in preload and afterload, which is why it is widely used in animal studies and occasionally clinically.[1,2] Determination of the P-V relationship requires the simultaneous acquisition of ventricular volume and pressure data. While ventricular volume can be noninvasively assessed by modern imaging modalities, the gold standard for determining ventricular pressure continues to be measurements performed using high fidelity micromanometers or conductance catheters during cardiac catheterization.[3,4] The demanding technique and a relatively high probability of undesirable events during the invasive procedure limits its daily use, and consequently there is a lack of pertinent information for the diagnosis of heart diseases that are neither associated with a clear morphologic typology nor develop a characteristic motion, strain or perfusion pattern that can be visualized with echocardiography or magnetic resonance imaging (MRI).[5–7] Particularly the definition of diastolic dysfunction remains demanding since myocardial relaxation is most pronounced during left ventricular (LV)-inflow and ventricular pressure evolution. Different parameters have been proposed for noninvasively identifying diastolic dysfunction using echocardiography.[8,9] Widely used parameters are the mitral valve inflow pattern, isovolumetric relaxation (IVR) time and other parameters derived from tissue Doppler imaging. Despite the indisputable benefit of echocardiographic indices in modern cardiology, ventricular pressure or pressure-related quantities cannot be measured without applying forces to the heart. Furthermore, the hemodynamic counterforce or the response of the tissue to external or intrinsic mechanical stimulation has to be measured.[4]

## MR Elastography

Elastography combines mechanical tissue stimulation with the measurement of the resulting deformation using soft-tissue imaging modalities such as MRI or ultrasound for measuring shear waves.[10,11] The stimulated shear deformation measured by elastography is related to the shear-elastic and shear-viscous behavior of biologic tissues that varies by several orders of magnitude throughout the human body.[12] Recently, MR elastography (MRE) has shown rapid progress in the assessment of the viscoelastic behavior of human organs that are not palpable from the body surface.[13–16] In