Introduction
The anatomy and function of the musculoskeletal system is strongly determined by the mechanical properties of its component tissues: bone, muscle, tendon, ligament, cartilage, and adipose tissue. Efforts to better understand musculoskeletal biomechanics in health and disease have created an increased need for quantitative estimates of the elastic properties of these tissues. Traditional static and dynamic mechanical testing devices provide reasonable data for specimens of solid materials like bone, but are less satisfactory for semisolid tissues like muscle and adipose tissue. Few options have been available for quantitatively assessing the elastic properties of musculoskeletal tissues in vivo. Static and dynamic estimates of muscle strain can be obtained using spin-tagging and phase contrast MRI, but these do not provide quantitative elasticity data.

Magnetic Resonance Elastography (MRE)
MR Elastography is a quantitative method for imaging mechanical properties [1]. A mechanical driver generates mechanical waves at acoustic frequencies within tissue and a modified phase-contrast MRI sequence is used to image the propagating waves. An oscillating motion-sensitizing gradient is synchronized to the applied vibration, inducing a phase shift in the image that is proportional to the cyclic motion in the corresponding voxels. The acquired wave images are processed using an “inversion” algorithm to create a quantitative image of tissue stiffness, called an “elastogram”. Elastic properties are described quantitatively as moduli. For instance, Young’s modulus of elasticity describes longitudinal deformation (strain) in response to longitudinal force (stress). The shear modulus relates transverse strain to transverse stress. Another physical property of isotropic Hookean solids is Poisson’s ratio, which is the ratio of transverse contraction per unit breadth divided by longitudinal extension per unit length. Most soft tissues have mechanical properties that are intermediate between those of fluids and solids. This leads to the result that there is a consistent relationship between the Young’s and shear moduli of most soft tissues, in that they differ only by a scaling factor of 3. These concepts represent a simplification of the mechanical behavior of soft tissues, which in general are anisotropic, non-Hookean, and viscoelastic.

Skeletal Muscle
MRE is emerging as a unique research tool in biomechanics and exercise physiology, as well as a potential diagnostic method for muscle injuries, myopathies, and neuromuscular conditions [2]. Shear waves are readily generated in skeletal muscle using various mechanical drivers. Positioning and loading devices can be used to apply standardized conditions to muscle systems during imaging. Early studies showed that the stiffness of skeletal muscle varies linearly with applied load, as expected by a “stretched cable” model, allowing MRE to be used to quantitatively assess the distribution of tension in 3D within muscle systems. The technique has been applied successfully to biceps brachii, trapezius, quadriceps, hamstrings, tibialis anterior, gastrocnemius, soleus, flexor digitorum profundus, and other muscles. MRE has been used to validate models of muscle behavior, correlated muscle stiffness with EMG, and evaluated muscle pathology in distal and proximal lower extremity muscles. Wave images of skeletal muscle show obvious evidence of mechanical anisotropy, a so-called “waveguide” effect. Research is focusing on understanding how these patterns of wave propagation can be related to the fiber anatomy of skeletal muscle.

Articular Cartilage
A comprehensive knowledge of the mechanical properties of articular cartilage and its constituents is crucial for understanding its normal function and the pathomechanics of injury and osteoarthritis. Conventional methods for in vitro assessment of the biomechanics of articular cartilage are based on mechanical tests that are limited to bulk measurements taken at the surface of the tissue. MR Elastography offers unique capabilities as a potential tool for basic laboratory research involving cartilage [3]. Preliminary results have demonstrated that the technique can assess the dynamic shear properties of at various depths within articular cartilage specimens with degradation of the collagen and proteoglycan components. Implementation of MRE to evaluate articular cartilage in vivo will be technically challenging, but is potentially feasible.