Dynamic Musculoskeletal Imaging: Technical Factors

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Highlights:

- Radially under-sampled acquisitions allows one to obtain dynamic musculoskeletal images with isotropic voxel resolution within a reasonable scan time.
- MRI-compatible loading devices are important for inducing repeatable loading of tissues and independently monitoring the movement.
- High resolution models of musculoskeletal tissues can be registered to dynamic images, providing a quantitative assessment of soft tissue (e.g. cartilage) deformation with loading.

Target audience: Clinicians and researchers interested in using dynamic imaging to assess the causes and monitor treatment of musculoskeletal disorders.

Objective: Describe the key technical factors needed to collect and analyze three-dimensional (3D) dynamic images of musculoskeletal tissues.

Need for 3D Dynamic MSK Imaging: Dynamic musculoskeletal (MSK) imaging is valuable for investigating how skeletal, cartilage and muscle tissues behave under functional loading conditions [1]. Previous dynamic MSK imaging technologies acquire only a single image plane or multiple parallel planes, which limits the accuracy with which 3D mechanics can be visualized and quantitatively characterized.

Technical details: VIPR (vastly under-sampled isotropic projection reconstruction) is a k-space acquisition scheme that can achieve isotropic resolution in relatively short scan times without compromising spatial resolution [2]. For dynamic MSK, this is important because VIPR can be used to shorten scan time and thus reduce the number of loading cycles a subject has to perform. In addition, radial sampling and pseudorandom view ordering allows for data sorting to be accomplished retrospectively. This is in contrast to a Cartesian acquisition that would require real-time prospective gating with a position feedback loop. For imaging joints, a cine spoiled gradient-echo sequence can be used in conjunction with VIPR to obtain dynamic anatomical images of interacting skeletal and soft tissue structures. For muscle tissues, phase contrast sequence is used with VIPR to obtain velocity images over the muscle volume.

MRI compatible loading devices serve two distinct purposes: a) Induce functional repeatable cyclic tissue loading within the constraints of a MRI scanner. A knee loading device uses geared inertia disks to induce eccentric quadriceps contractions with knee flexion, which is comparable to that seen in human walking [3]. b) Simultaneously measure the musculoskeletal motion with onboard instrumentation (e.g. a MRI compatible encoder). Motion data is used retrospectively to sort image data into equally spaced time intervals, which are then reconstructed into isotropic volumetric images at each time frame.

In post-processing, high resolution static and dynamic images can be co-registered to assess the interaction of soft tissues (e.g. cartilage) and skeletal structures during movement. High resolution static (e.g. FSE-CUBE) MSK images are first segmented to obtained volumetric models of the bone, cartilage and ligament tissues. Bone position and orientation is then determined using a point-cloud co-registration between the models and dynamic images at each frame. The bone boundaries are clearly visible as low-intensity signals on the 3D images, allowing this registration procedure to robustly converge in a consistent manner (Fig 1). The distance (proximity) between articular surfaces at each frame of motion can then be computed, with negative values indicative of cartilage tissue deformation. For muscle imaging, numerical integration of tissue velocities within volumes of interest (VOI) is used to track tissue motion.

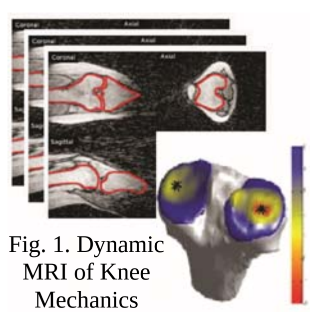

Fig. 1. Dynamic MRI of Knee Mechanics

Conclusion: The development of dynamic, 3D musculoskeletal imaging technologies can provide new insights into *in vivo* tissue mechanics, while providing a quantitative framework to track the causes and treatment of musculoskeletal disorders such as osteoarthritis.

References: 1. Blemker et al., JMRI 25:441-451, 2007, 2. Johnson et al. MRM 60:1329-36, 2008, 3. Kaiser et al. MRM 69:1319-16, 2013.