HIGH PRECISION STRAINS MEASURED UNDER APPLIED LOW FREQUENCY LOADING ON A 3.0 T CLINICAL SYSTEM

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Target Audience. The translation and demonstration of displacements under applied loading (dualMRI) on a 3.0T clinical MRI system benefits musculoskeletal and biomechanics researchers, as well as orthopedic clinicians, who use MRI.

Purpose. The mechanical behavior of both tissues and biomaterials is intimately linked to function, especially in orthopedic systems like the intervertebral disc. Previously, we have implemented dualMRI on high-field research MRI systems [1] using phase contrast MRI synchronized with physiologically-relevant, low-frequency cyclic loading in a rabbit intervertebral disc degeneration model [2]. Translation of dualMRI to a clinical scanner would allow for studies of live animals and human subjects, as well as larger tissue systems that cannot fit into a small-bore high-field system. Therefore, the purpose of this study was to translate, evaluate, and demonstrate dualMRI on a 3.0 T system.

Methods. dualMRI was implemented on a 3.0 T clinical MRI system (GE Signa HDx) using a 8-channel knee volume coil and a load-synchronized phase-contrast pulse sequence (Fig. 1). Spatial modulation of magnetization [3] was implemented with the second radiofrequency pulse phase cycled to eliminate artifacts [4]. A phase-encoded image in the deformed configuration was acquired with single shot fast spin echo (SSFSE). Displacements were computed after a phase difference reconstruction [5] and smoothed [6] before Green-Lagrange strains were computed [7]. Displacement and strain precision was evaluated with a cyclically loaded silicone gel phantom (Sylgard 527) across five repeated scan series as the pooled standard deviation of values across 16 points [8]. Phase encoding of 0.33 π/mm, in the undeformed state, was followed by a mixing time of 600 ms before SSFSE (62 ms echo time, 180 × 180 × 3 mm^3 slice, 256 × 256 matrix, 8 averages) in the deformed configuration.

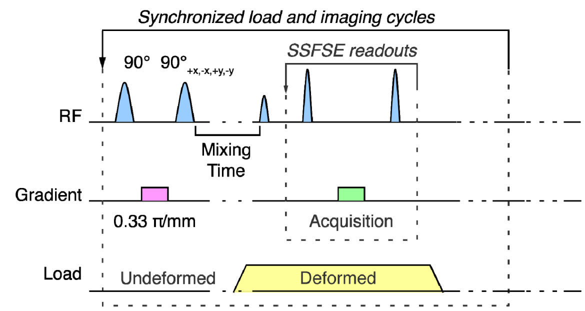

Figure 1: Key dualMRI RF pulse, gradient pulse, and load actions

A cadaveric intervertebral disc segment, inclusive of the 4th and 5th lumbar vertebral bodies, was potted in polymethylmethacrylate and fit into an MRI-compatible loading device. Compression of 450 N was applied for 1.5 s during a 3-s cycle. Preconditioning of 500 loading cycles was applied prior to dualMRI to ensure that the specimen reached a quasi-steady state deformation response [9]. dualMRI parameters were same as for the precision study.

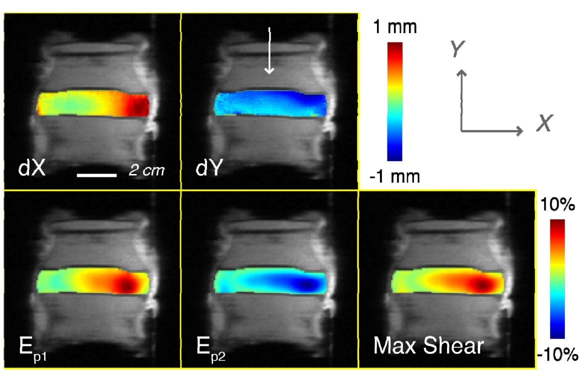

Figure 2: Displacements and principal strains within a disc

Results. In the silicone gel, the average signal-to-noise ratio (SNR) was 4.2, and the precision of raw displacements was 95 µm. After 100 cycles of smoothing, displacement precision improved to 24 µm, and strain precision was 0.3%. dualMRI of the intervertebral disc was implemented with an SNR of 16.4 for high-precision displacements and strains within the disc (Fig. 2).

Discussion. Displacements were computed with precision that was below half the in-plane pixel size, and strain precisions were less than 1%. Intervertebral disc mechanics and range of motion are associated with disc degeneration [10]. Translation of dualMRI to a clinical system allows this relationship, and similar associations between mechanics and function in a number of soft tissues, to be further studied in animal models and human studies.

Conclusion. Translation of dualMRI was accomplished for the first time on a clinical 3.0T system at high displacement and strain precisions and demonstrated in a clinically relevant intervertebral disc segment.

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