Magic Angle Enhanced Imaging in High-Field MRI Using an Automated MR-Conditional Positioner

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Magic Angle Effect in High-field, Small-bore MRI Scanners: The clinical and functional importance of using the pronounced dipolar coupling Magic Angle (MA) effect has been shown extensively in tendon and cartilage MRI studies [1]. Positioning a target tissue with dense structures at an orientation of approximately 55^o (MA) can increase T2/T2* values, resulting in an increase in image signal intensity. In high-field preclinical MRI studies, the improved resolution and sensitivity resulting from the MA effect can assist in the evaluation of fibrous and cartilaginous functional microstructures [2]. However, the confined environment of a small bore in a typical high-field animal scanner imposes severe spatial constraints, causing practical difficulties when orienting tissue samples precisely at a specific angle. We hypothesized that an automated positioner, using a custom-designed pneumatic motor and optical encoder, could (1) permit accurate placement of tissues relative to B_0, and (2) facilitate MA enhanced imaging in a 9.4T small-bore (12cm) scanner while maintaining excellent MRI compatibility.

Experimental Setup for Automated Positioner (Fig 1): The positioner (a) consisted of a pneumatic motor connected to a platform to move a tissue sample at a controlled angle relative to B_0. The motor housing (b) directs air flow in a clockwise/anticlockwise direction to turn a rotor which drives an axle connected to a 400:1 ratio planetary gearbox. Compressed air of ~40PSI is supplied by two lines, each controlled by a DC solenoid valve (ITT Alcon, SC) located outside the scanner room (c). The positioner was encoded using optical fibers (b), and an encoding disk on the back of the rotor. Given the small size (12cm) of the MRI bore, and the limitations of MRI-conditional materials, the positioner was assembled from plastic LEGOs. This modularity of the LEGO building blocks allowed quick development of the platforms, iterating through design processes rapidly. The air valves were pulse-width modulated by a USB 6009 DAQ card (National Instruments, TX) which also received positional data from optical decoding circuitry. The positioner was controlled using a proportional–integral–derivative controller tuned by the Ziegler–Nichols method and programmed in LabView® 8.2, which also provided a control interface. An emergency stop button was available to stop the device and release air pressure if necessary.

(a) Positioner with two sample holder platforms (b) Motor & encoder (c) Positioner setup schematic in MRI

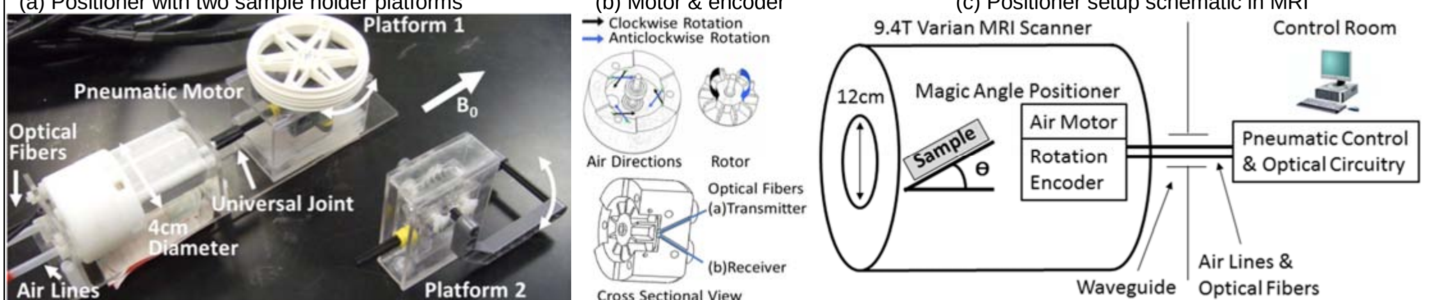

Fig 1. MA positioner: (a) Assembly. Interchangeable platforms 1 & 2 rotate samples along Y & X axes of the scanner respectively with a resolution of ±0.1 degrees. (b) Principles of the pneumatic motor and optical encoder. (c) Positioner setup at 9.4T Varian scanner.

Ex-vivo Tendon Collagen Study and Results: The positioner was set up in a 9.4T Varian horizontal MRI scanner (Fig 1c). Tests were performed with ex-vivo sheep Achilles tendon samples suspended in agarose gel to observe the increase in tendon collagen signal intensity as the positioner varied the tendon orientation (Fig2). A custom-made surface coil was placed on top of the tendon sampler holder. Images were obtained at an increasing angle relative to B_0 with a 2D high-resolution gradient-echo multi-slice sequence (TR=3000ms; TE=5 ms, FOV=14x7mm; MTX=512x256, Spatial Resolution=30x30μm^2, Slice thickness=0.5mmx12 slices). Fig 2b shows an increase of 218% in tendon signals at the MA of 55^o compared to 0^o. Tendon signal intensity was normalized to the surrounding gel. No apparent change in gel signal intensity was observed at different angles to B_0.

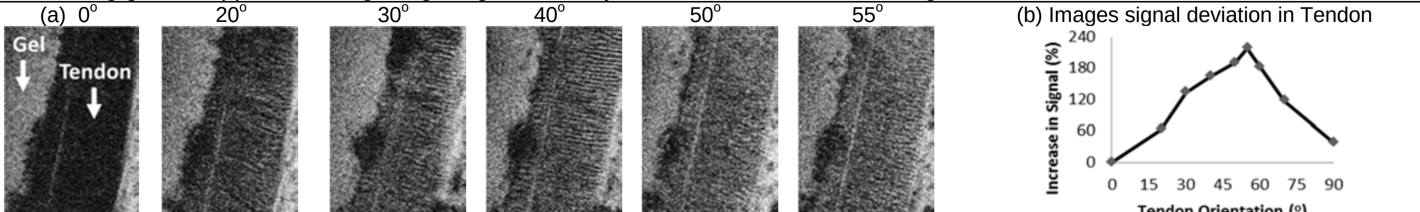

Fig 2. MA effect in tendon collagen fibers at 9.4T MRI at 30x30 μm^2: (a) 0- 55 degree relative to B_0. (b) Increase in tendon signal intensity

Conclusion: MA effect largely increases MR signals from tendon tissues, and is a simple technique to enhance the signal intensity for microstructural evaluation of tendinous and fibrous tissues in high-field and high-resolution MRI. High-field MRI-conditional automated positioner was demonstrated using custom-designed pneumatic motor-optical encoder unit and standard building blocks, facilitating simple and economic setup for MA related studies. This setup can also be applied to orientation-sensitive MR techniques such as quantitative susceptibility mapping and susceptibility tensor imaging [3], and may possess potentials for in vivo animal studies.

Ref.: [1] Rea et.al, Concepts in Mag. Res. Part B, 2010, 37B(4), 220-225. [2] Mountain et.al, Magn Reson Med, 2011, 66(2), 520-527. [3] Liu et.al, Magn Reson Med., 2010, 63(6):1471-1417. **Acknowledgement:** LEGO, Inc.