MADNESS: Magic Angle Diffusion Employing the Steady State

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INTRODUCTION

The structural anisotropy of the tendon creates static local magnetic fields and decreases the T2 relaxation time. The T2 times are so short that tendons appear black irrespective of the TE. However if the angle between the axis of the tendon and B_0 is the magic angle, 54.7°, then the dipole-dipole interactions are cancelled out and the tendon has a higher signal intensity. Diagnostically the increased signal is often considered an artefact since it can appear similar to focal disease or tendonitis. However, deliberate positioning of the tendon at the magic angle in conjunction with short echo times can be used to collect further information about the structure [1].

METHOD

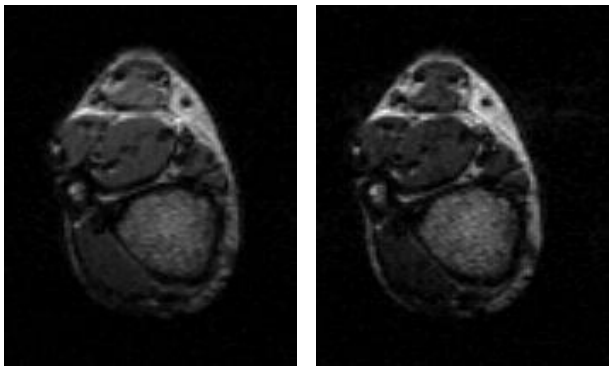
Subjects lay in the lateral decubitus position with their Achilles tendon orientated at 55°. This was achieved using a Magic Angle Insert Unit currently being developed by Lamperth's group at Imperial College. It comprises a platform supporting the structure to be studied which is then moved in the horizontal plane using a software-driven motor. The image plane was angled at 90° to the Achilles tendon.

A diffusion-weighted PSIF sequence was used for image acquisition. The PSIF sequence is a gradient reversed fast imaging by steady state precession sequence and is a short TR method of steady state, coherent, gradient echo imaging. A 1.5T Siemens Vision system was used with a CP-Small-Flex Coil. Sequence parameters were: TR = 31.5 ms, α = 50°, FoV = 250 mm, pixel size = 1.30 x 0.98 x 5.00 mm^3, 8 averages, PE = AP, scan time = 49 s. Diffusion-weighting was on the slice select axis i.e. along the axis of the Achilles tendon. Three b-values were used. These were calculated for this specific sequence including the imaging gradient and cross-term contributions to be 40, 155 and 273 smm^{-2}. Region of interest measurements were taken in the Achilles tendon, muscle and bone marrow.

RESULTS

Transverse, diffusion-weighted PSIF images of the Achilles tendon are shown in figure 1. Signal can be seen in the Achilles tendon confirming that it is at the magic angle. Increasing the diffusion weighting showed a decrease in the signal (fig. 2). The diffusion weighting in the Achilles tendon appears to be slightly less than that in the muscle but more than that in bone marrow.

Quantification of PSIF is problematic. Wu and Buxton [2] looked at the effect of diffusion on steady state magnetization using pulsed field gradients and derived a complex equation describing the attenuation. It is possible to simplify this equation using certain constraints. For constant T_1 and T_2 values it has been derived that $\ln(M^-/M_0) = qD$ [3]. The *q* function includes a b-value dependence and can be modelled by matching phantoms of known T_1, T_2 and ADC. An estimate of the diffusion coefficient in tissue can then be determined. The signal decrease measured in the Achilles tendon is linear when the *ln* of the signal is plotted against the b-value suggesting correlation with this derivation and the possibility of ADC quantification. Preliminary calculations in comparison with known bone marrow ADC values [4] show the Achilles tendon ADC to be of the order of 0.9×10^{-3} mm^2s^{-1}.



A B

Fig 1 Tra DW-PSIF image: A) b = 40 smm^{-2}, B) b = 273 smm^{-2}

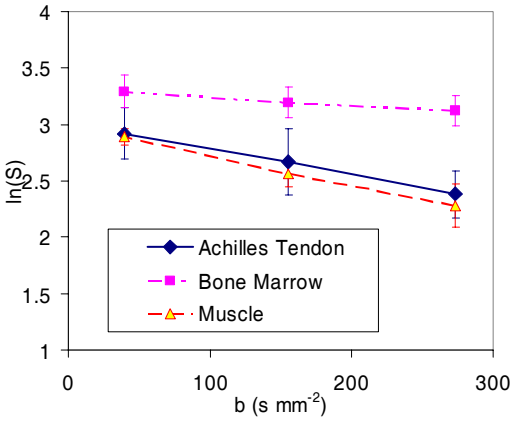


Fig 2 Graph showing diffusion-weighting of tissues

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