# Ultrashort-$T_2$ and Magic-Angle Contrast: A Comparison

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## Introduction

Certain types of highly ordered tissues, such as tendons, ligaments, or peripheral nerves, show a variation in $T_2$ relaxation time depending on the orientation with respect to the external field $B_0$ [1]. The effect is caused by residual dipolar coupling that vanishes at an angle of 54.7°, called the magic angle [2]. Measuring an anatomy at different angles towards the external field allows identification and selective visualization of tissue components that are subject to dipolar effects. Furthermore, information about the microscopic fiber orientation can be obtained. While the arising contrast can be termed "magic angle contrast", ultrashort TE (UTE) imaging enables the visualization of a general short-$T_2$* contrast caused by dipolar and other decay mechanisms [3]. In this work, both contrasts are acquired to characterize short-$T_2$ components in tendons and bones of the hand, using 3D isotropic data measured at UTE and a later echo time at various orientations.

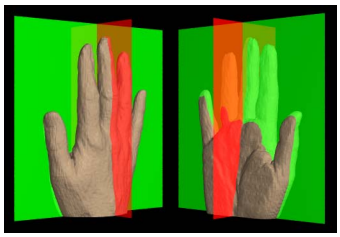

*Figure 1: Surface-rendered 3D data. Planes indicate the slice positions for Fig. 2 (red) and Fig. 3 (green).*

## Methods

A 3D radial dual echo sequence is used to acquire isotropic images at ultrashort $TE_1$ and a later in-phase echo time $TE_2$ [4,5]. For the observation of magic angle effects, the right hand of volunteers was scanned at 5 different angles with respect to the external field. To control orientation, the hand rested on a plate that was locked at discrete inclinations. MR scans were performed on a clinical 1.5 T whole body scanner (Achieva 1.5T, Philips Medical Systems) using a transmit/receive birdcage coil. All scans were performed with the following parameters: isotropic FOV 200 mm, matrix size $128^3$, flip angle 10°, $TE_1/TE_2/TR$ = 0.08/4.6/7.4 ms, radial profiles per echo 24576, and total scan duration 3 min 2 s. To generate short-$T_2$* contrast, subtraction images were created between the image volumes acquired at $TE_1$ and $TE_2$. To generate "magic angle contrast", the anatomy measured at different orientations was registered to one orientation, allowing the calculation of subtraction images. For registration, a library based on the multi-resolution approach described in [6] was used.

## Results and Discussion

Figure 2 shows sagittal slices (as indicated in Fig. 1) through the middle finger of the hand acquired at different orientations at TE = 4.6 ms. While the finger flexor tendon, running from the wrist to the finger tip, is black in the orientation parallel to $B_0$ (arrows), segments oriented close the magic angle of 54.7° exhibit high intensity (indicated by bars). This effect is caused by the orientation-dependent variation of $T_2$ over a range from roughly 2 to 20 ms [1], with $T_2$ being longest at the magic angle. Thus, depending on $T_2$ at the actual orientation, different levels of signal decay occur at TE = 4.6 ms. Registration (Fig. 2, right) allows the calculation of subtraction images between different orientations, so that tissues exhibiting the magic angle effect can be visualized selectively, as displayed in the 1st row in Fig. 3. This technique greatly benefits from the isotropic resolution of the data acquired by the 3D radial technique. Close to the magic angle, the signal variation leads to positive contrast in the tendons (arrows). Correspondingly, tendons have high signal in the echo image close to the magic angle (Fig. 2, 2nd row, last image). Interestingly, the average signal level over a region of interest in the middle tendon shows a slight signal decrease at low angles before the increase close to the magic angle (Fig. 4). In images acquired at ultrashort TE = 0.08 ms (being much shorter than $T_2$), no signal decay occurs (Fig.2, 3rd row; Fig. 4). Hence, short-$T_2$* components decayed between the acquisition of the 1st and the 2nd echo can be extracted (4th row). The tendon signal here is maximal for alignment parallel to $B_0$ and vanishes at the magic angle, thus showing an inverse behavior compared with the magic angle contrast (1st row). In addition, short-$T_2$* contrast highlights parts of the bones, which do not exhibit magic angle contrast.

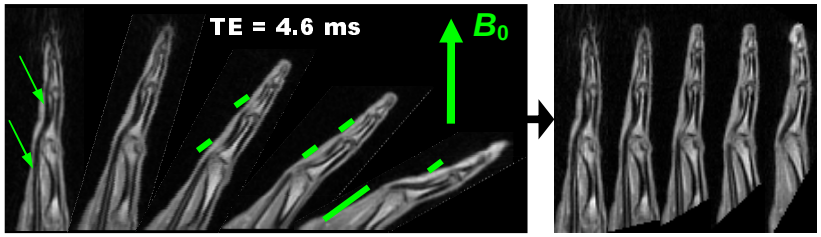


*Figure 2: Sagittal slices of 3D echo data at different angles with $B_0$ (left). Green bars indicate segments of the flexor tendons oriented at the magic angle 54.7°. At this orientation, prolonged $T_2$ leads to higher signal intensity. For later difference image calculation, all scans have been registered to the same orientation (right).*

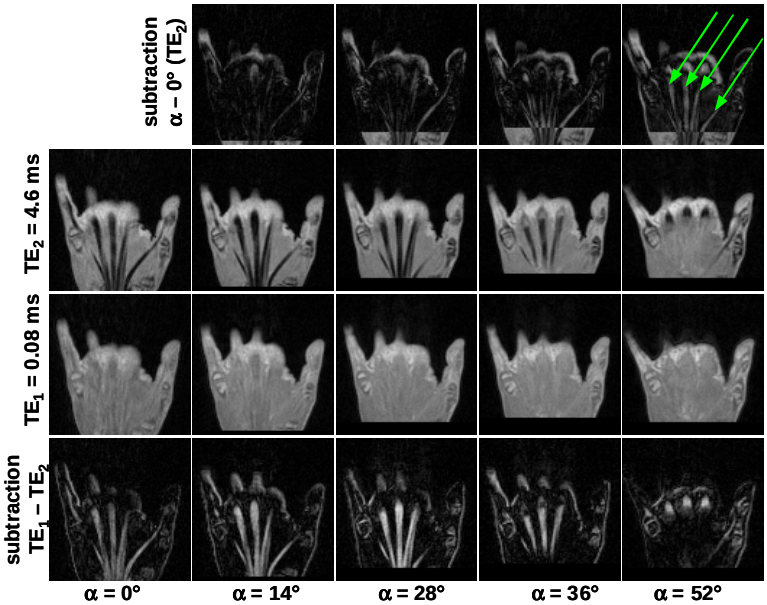


*Figure 3: Comparison of contrasts in a coronal slice extracted from registered 3D data. 1st row: subtraction of echo images with $\alpha > 0$ from image with $\alpha = 0°$. Arrows indicate magic angle contrast in the flexor tendons. 2nd row: gradient echo images at different orientations with the external field. 3rd row: UTE images. 4th row: subtraction images between UTE and gradient echo images highlighting short-$T_2$ components only.*

## Conclusion

The acquisition of UTE images with tissues aligned at different angles with the external field allows clarification whether short transverse relaxation times $T_2$ are caused by dipolar interaction or not. In case of dipolar relaxation time shortening, the orientation dependence of the observed signal can be used to determine microscopic fiber orientation. With a large number of scanned orientations, fiber tracking may become feasible. Therefore, it can be helpful to make use of differently oriented main fields (cylindric versus open magnet configuration). Furthermore, to speed up acquisition, dynamic scanning of anatomy being reoriented in the field may be desirable.

## References

[1] Bydder M *et al.*, JMRI 25:290-300 (2007). [2] Fullerton GD *et al.*, JMRI 25:345-361 (2007). [3] Gatehouse PD *et al.*, Clin. Radiol. 58, 1-19 (2003). [4] Glover GH *et al.*, JMRI 2, 47-52 (1992). [5] Rahmer J *et al.*, MRM 55, 1075-1082 (2006). [6] P. Thévenaz *et al.*, IEEE Trans Image Proc. 7,27-41 (1998).

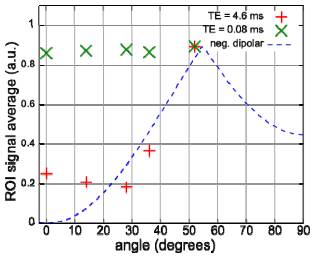


*Figure 4: Signal levels extracted from the middle tendon in Fig. 3. At ultrashort TE, signal level is independent of orientation (green), while at TE = 4.6 ms, a strong dependency occurs (red). As a guide to the eye, the inverse dipolar interaction is plotted.*