Optimizing MR Signal Contrast of the TMJ Disk

M. Carl[1], H. T. Sanal[2], E. Diaz[2], J. Du[2], O. M. Girard[2], S. Statum[2], R. Znamirowski[2], and C. Chung[2]

[1]GE Healthcare, Applied Science Lab, Milwaukee, WI, United States, [2]Radiology, University of California, San Diego, CA, United States

Background and Objective: The temporomandibular joint (TMJ) is a unique articulation that demonstrates both structural and functional complexity. While the majority of synovial articulations are lined by hyaline cartilage, the TMJ has fibrocartilaginous surfaces. Although diagnostic capabilities have progressed remarkably with MR imaging, significant challenges still remain owing, in part, to the fibrocartilaginous nature of the disc and articular surfaces. These tissues are comprised largely of short T_2 components and conventional MR sequences are limited in their ability to detect signal from them, as well as produce contrast between the fibrocartilaginous disk and surrounding soft tissues. In this study, we used a tissue specific algorithm to optimize contrast based on knowledge of intrinsic MR properties of tissues and equations dictating signal and contrast.

Material and Methods: The left side TMJ was removed en block from the skull and sectioned in the sagittal plane. MR imaging was performed on a 3T MR imaging system (Signa; GE Medical Systems, Milwaukee, WI) with a 3-inch-surface coil placed in contact with the sliced specimens (which was large compared to the ROI). T_1, T_2* and relative proton density (PD) measurements were obtained in the TMJ disc and surrounding soft tissues using UTE MR imaging and are shown in Fig. 1a-c. The relative proton density in Fig.1A was determined by measuring signal intensity values with the following sequence: TR = 5000 ms, TE = 8μs, NEX = 2, 512x511 Matrix, 1 mm slice thickness, 8 cm FOV, 90° flip angle and 50 BW. Total saturation recovery technique was used for T_1 determination (fixed TE 8 μs with TSR values ranging from 14 - 2500 ms) (Fig 2A). Constant TR – variable TE technique was used for T_2* estimation (TE values ranging from 8 μs - 20 ms) (Fig 2B).

Experimentally Determined TMJ Tissue properties: The relative proton density values for the posterior soft tissues, disk, and anterior soft tissues were found to be 0.7, 0.7, and 0.75, respectively. The T_1 values for the posterior soft tissues, disk, and anterior soft tissues were calculated to be 876ms, 901ms, and 812ms, respectively. The T_2* values for the posterior soft tissues, disk, and anterior soft tissues were calculated to be 18ms, 12ms, and 11.5ms, respectively. These values were subsequently used to predict sequence parameters that would optimize contrast between the TMJ disc and anterior/posterior soft tissues in the following manner.

Optimization of Tissue Contrast: The steady state signal of an SPGR pulse train MR sequence is given by [2]:

$$S = M_0 \sin\theta \frac{1-E_1}{1-E_1\cos\theta}\exp\left(-\frac{TE}{T_2}\right) \quad \text{with} \quad E_1 \equiv \exp\left(-\frac{TR}{T_1}\right) \qquad (1)$$

The optimization for tissue contrast is most straightforward in the following cases:

1. If the tissues only vary in T_2 the MR signal contrast is achieved by using a echo time equal to the mean T_2 of the tissues [1]: $TE = \langle T_2 \rangle$
2. If the tissues only vary in proton density, the contrast is maximized my maximizing the signal, which leads to Ernst angle (at the mean T_1) [2]: $\cos\theta = E_1$
3. If the tissues only vary in T_1 one can derive a criterion to maximize T_1 contrast (evaluated at the mean T_1) [3]: $\cos\theta = \left(\frac{2E_1 - 1}{2 - E_1}\right)$

However, in reality all three tissue parameters in Eq.1 vary between tissues. Furthermore, while high proton density or long T_2 values tend to generate a higher signal (positive contrast), a higher T_1 tends to generate less signal (opposite contrast), which results in reduced the tissue contrast. For the more complex case, it is more efficient to solve the problem numerically. The absolute contrast between two tissues I and II, which we will call ΔS, is given by:

$$\Delta S \equiv S^I - S^{II} = \sin\theta\left[M_0{}^I \frac{1-E_1^I}{1-E_1^I\cos\theta}\exp\left(-\frac{TE}{T_2^I}\right) - M_0{}^{II}\frac{1-E_1^{II}}{1-E_1^{II}\cos\theta}\exp\left(-\frac{TE}{T_2^{II}}\right)\right] \qquad (2)$$

However, since MR image noise also plays a crucial role in the perceived image contrast, we are ultimately interested in maximizing the contrast-to-noise ratio (CNR):

$CNR \equiv \frac{\Delta S}{Noise} \sim \sqrt{NEX}$ The number of averages (NEX) decreases linearly with an increase in the repetition time TR: $NEX \sim \frac{1}{TR} \rightarrow CNR \sim \frac{\Delta S}{\sqrt{TR}}$

Hence in order to optimize the CNR, the parameter that was optimized in the numerical simulations was the expression in Eq.2 divided by √TR.

Experimental TMJ Contrast: The above algorithm was used to optimize the contrast of the disc to surrounding soft tissues. Since the proton density and T_1 values were comparable, we would expect the optimum range of parameters to follow into the group 2. The optimum parameters were found to be: flip angle α = 16°, TR = 30 ms and TE = 8.38 ms, yielding the image shown in Fig.3. Within that image, the bow tie appearance of the disk is nicely displayed with its distinct borders and low signal intensity. CNR between disc and the posterior soft tissues and CNR between disc and the anterior soft tissues were calculated as 32 and 26 respectively.

Conclusion: Contrast can be optimized between tissues in a systematic fashion with knowledge of their intrinsic MR properties and consideration of Bloch's equations. This approach to image optimization could be instrumental in improving diagnostic capabilities in the clinical setting. While this method is valid for the tissues studied here, it has been shown that the classical signal behavior (Eq.1) is not applicable for tissues with very short T_2s [4]. The above simple algorithm however can readily be adapted for more complex signal equations.

References: [1]: E. M. Haacke, *Magnetic Resonance Imaging* (1999) [2]: M. A. Bernstein, *Handbook of MRI Pulse Sequences* (2004)
[3]: N. J. Pelc, MRM, 29:695-699 (1993) [4]: D. J. Tyler, JMRI 25:279 (2007)

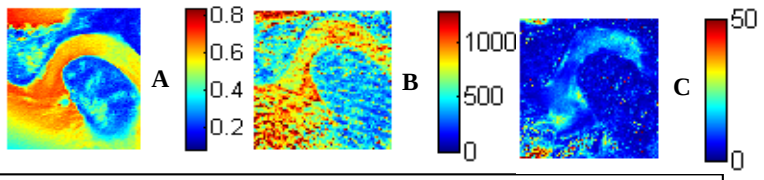

Fig 1: Color maps showing TMJ components of **A)** Relative Proton Density, **B)** T_1, **C)** T_2

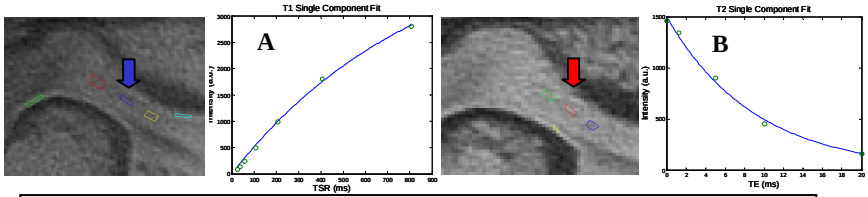

Fig 2: A) T_1 fitting for the TMJ disc using saturation recovery, **B)** T_2 fitting for the TMJ disc.

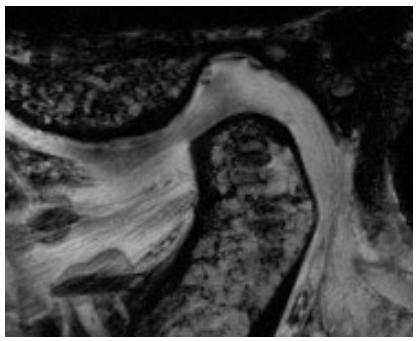

Fig 3: 2D SPGR sequence with optimized TR of 30 ms, TE of 8.4 ms and flip angle of 16° using 120 NEX. The disc is nicely outlined so that the contrast is successfully optimized with facile delineation between disc and soft tissues.