# T2 Maps and Diffusion-Weighted Imaging of Knee Cartilage with a DESS Sequence at 3T

**E. Staroswiecki[1,2], K. L. Granlund[1,2], M. T. Alley[1], G. E. Gold[1], and B. A. Hargreaves[1]**
[1]Radiology, Stanford University, Stanford, California, United States, [2]Electrical Engineering, Stanford University, Stanford, California, United States

**INTRODUCTION:** The visualization of articular cartilage is a challenging problem that requires advanced MRI techniques. In order to follow the changes to tissue in early osteoarthritis and after cartilage repair we require the capability to show morphological and biochemical properties of cartilage. Two techniques with this capability may include T2-mapping and diffusion-weighted imaging (DWI) [1].
The Fast Acquisition Double Echo (FADE)[2] sequence (also known as DESS or MENSA) has been used to generate approximate T2 maps with a single acquisition, and called DESS-T2d [3]. The diffusion sensitivity of this sequence has also been described in [4]. Here we study the effect of diffusion sensitivity on the accuracy of the T2 maps, and potential DWI characteristics of the images obtained.
**THEORY:** The DESS sequence consists of two echoes separated by a spoiler gradient per repetition of the RF pulse. The first echo ($S^+$) is a "FISP" echo, while the second one ($S^-$) is a "PSIF" echo [5]. This $S^-$ echo corresponds to refocused $S^+$ echoes from previous RF pulses. It has been shown that the T2 dependence between echoes differs approximately by *exp*[-2*(TR-TE)/T2]. The PSIF echo can thus be considered a diffusion- and T2-weighted version of the FISP echo. This relationship can be approximated as $ln(S^+/S^-)=2(TR-TE)/T2+bD$.
Based on this, two acquisitions with different *b*-values would provide different estimates of T2 if the diffusion effects are ignored. It is important to note that for steady-state sequences the *b*-values are a complex function of TR, T1, T2, and the flip angle as well as of the gradient area and duration [6], and are therefore very difficult to estimate. If we keep the spoiler gradient duration, TR, and flip angle constant across acquisitions, we can assume the *b*-value will increase monotonically with the spoiler gradient amplitude G for the range of T1 and T2 values expected in cartilage. The PSIF echo has a different *b*-value from the FISP echo, and this difference should also increase monotonically with G.
**METHODS AND RESULTS**: We acquired all our data on a 3T GE Signa whole-body scanner (GE Healthcare, Waukesha, WI) and with a commercial 8-channel knee coil. We scanned 5 subjects in the sagittal plane using a 3D DESS sequence with TE/TR = 7.4/23.7 ms, a matrix of 512×256, receiver bandwidth ±62.5kHz, 14×14 $cm^2$ FOV, slice thickness of 3mm, 40 slices, and a scan duration of 4 min. Fat suppression was achieved with a spectral-spatial RF pulse. We obtained images of both echoes from two sequential acquisitions with a 2ms spoiler gradient duration, one with a gradient amplitude of 4.0G/cm and a second one with a gradient amplitude of 1.2G/cm. Based on an average apparent diffusion coefficient (ADC) for cartilage of 0.001$mm^2/s$ [7], the difference in the *b*-values for the FISP echoes was determined experimentally to be approximately 40$s/mm^2$, while the difference in *b*-values for the PSIF echo was measured to be approximately 206$s/mm^2$.
From these acquisitions we generated T2 maps and compared them to a product T2 mapping fast spin-echo (FSE) sequence with the same FOV and resolution as the DESS acquisitions, and echo times of 7.7, 15.5, 23.2, 30.9, 38.7, 46.4, 54.1, and 61.9ms. In every case the T2 values obtained with smaller gradient amplitudes were closer to those of the FSE sequence than the ones generated with larger gradients.
We used the estimated differences in *b*-values to determine a relative-ADC map. Since the Δb values are estimates, the resulting map is an estimate of the ADC of the tissue.
**DISCUSSION:** The difference between the signal levels of the FISP and PSIF echoes is clearly dominated by the T2 decay between the two echoes. However, the diffusion due to the spoiler gradients has a small but measurable effect (the T2 values from a cartilage region of interest still differ by 3ms in average when using the smallest gradient). Of the two acquisitions the one with the smallest gradient amplitude generates the more accurate T2 map and a T2-weighted image, while the one with the largest gradient amplitude provides a diffusion-weighted image. Both acquisitions are necessary to estimate a relative-ADC map.
A more accurate determination of the *b*-values of this sequence is still necessary to generate a precise ADC map, and to correct the T2 maps considering the diffusion effects.

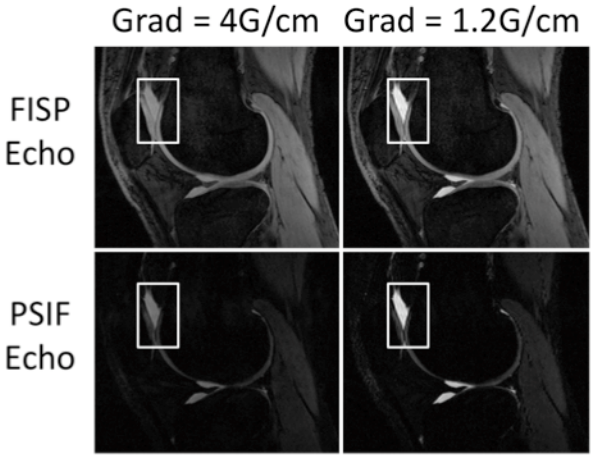


***Figure 1**: Knee images from both echoes of DESS acquisitions with different gradient amplitudes. The rectangle marks an area with fluid and cartilage where the differences in contrast are clearly visible. The differences between the echoes of any acquisition are mostly due to T2 weighting, while the differences across acquisitions are due to diffusion weighting.*

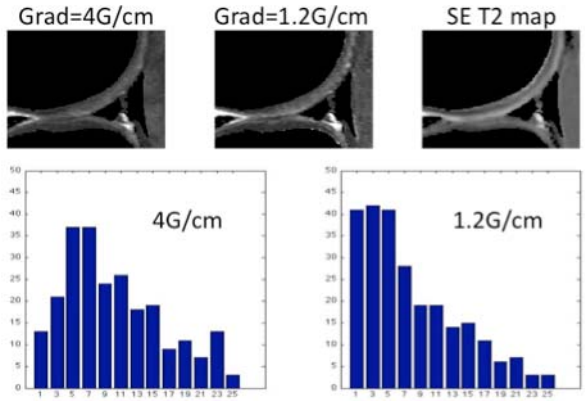


***Figure 2**: Detail of DESS-T2d maps obtained with different spoiler gradient amplitude and a spin-echo (SE) product T2 map. The histograms show the number of pixels from the DESS-T2d maps that differ from the SE T2 map by increasing values of difference (between 1 and 26 ms). Lowering the spoiler gradient amplitude decreases the number of pixels with larger differences and increases the number of pixels with smaller errors.*

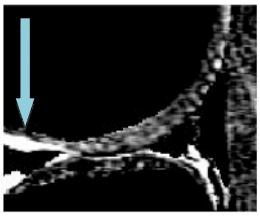

***Figure 3**: Detail of a relative ADC map obtained with the estimated differences in* b*-values. This map was generated by averaging the results of the ADC estimations from both echoes. The arrow shows an area with fluid, and high ADC.*

**CONCLUSION:** We presented a method to obtain a diffusion-weighted image and a relative ADC map, together with a T2-weighted image and T2 maps of knee cartilage by means of two sequential DESS acquisitions with different spoiler gradient amplitude.

**REFERENCES:** [1]C. Glaser, *Radiol. Clin. N. Am.*, **43**:641-653, 2005 [2]T.W. Redpath *et al.*, *Magn. Reson. Med.*, **6**:224-234, 1988 [3]G.S. Welsch *et al.*, *Magn. Reson. Med.*, **62**:544-549, 2009 [4]E.X. Wu *et al.*, *JMR*, **90**:243-253, 1990 [5]K. Scheffler, *Concepts in Magn. Reson.*, **11**:291-304, 1999 [6]R.B. Buxton, *Magn. Reson. Med.*, **29**:235-243, 1993 [7]K.L. Miller *et al.*, *Magn. Reson. Med.*, **51**:394-398, 2004

**ACKNOWLEDGEMENTS**: GE Healthcare