Evaluation of a Ultra High Dielectric Constant (uHDC) Package for Enhanced Cervical Spine Imaging

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Introduction: Previous work examined the use of dielectric materials for enhancing SNR and reducing transmit power in cervical spine imaging at 3T [1]. The study used flexible pads incorporating a mixture of water and barium titanate beads (E_r ~ 400–500). One drawback to this work was the volume of dielectric material necessary, with a number of these pads placed on top of and below the volunteer's upper chest and neck. Up to a limit, the RF field enhancement usually increases with higher permittivity. Ultra high dielectric materials (uHDC) [2-3] may offer a means of enhancing performance with a reduced volume of material, which could ease eventual adoption of these materials for clinical usage. This work evaluates the use of monolithic dielectric blocks (E_r ~ 800) to enhance cervical spine imaging, with both simulation and scans of a group of healthy volunteers.

Methods: The uHDC configuration is depicted in Fig 1. Monolithic blocks (Fig. 1a) were shrink wrapped in plastic to form a package of 5 blocks. This uHDC package was then placed within a Siemens 4 channel neck matrix (Fig. 1b), flush with the inner surface of the coil. Simulation: This configuration was simulated with xFDTD 7. From the calculated B1 fields with and without the uHDC package present, enhancement maps were computed. Experiment: A group of 3 healthy subjects was scanned. Quantitative evaluation of SNR improvement utilized multi-slice gradient echo images with an integrated noise scan to calculate SNR scaled images [4] and correction for magnitude bias in low SNR regions [5]. To quantify the changes in the B_1^+ distribution, B_1^+ maps were collected with a slice selective Bloch-Siegert [6-7] sequence. System power was recorded from the scanner's power measurement unit. All data sets were collected with and without the uHDC package present, on a Siemens 3T Trio (Erlangen, Germany). Reception utilized a Siemens 4 channel neck matrix and the posterior half of a Siemens 12 channel head matrix.

Results: Calculated enhancement maps (given as Field with uHDC / Field without uHDC) are displayed in Figure 2. The uHDC package enhances both B_1^+ and B_1^-. Figure 3 displays a representative B_1^+ transmit efficiency map. The dielectric strongly enhances the transmit field within the region the package surrounds. In this example, the efficiency is increased by ~75% locally. Figure 4 is an example of the ROI placement for calculation of SNR. SNR increases were measured in the discs C1 to C6 and within adjacent regions in the spinal cord. Average SNR increases across the 3 volunteers are listed in Table 1. The increases fell within a range of 30 – 40% upon discs C1-C3, with diminishing returns further down the spine. The average system power reduction was 64.18%, and the power reduction of individual subjects ranged between 59 to 70%.

Discussion: The use of a uHDC package offers SNR increases between 20-40% on discs C1-C4, with lower gains and even slight losses on discs C5-C6. This behavior was due to the dimensions of the individual block (101 mm x 77 mm x 14 mm) – the block length corresponds to a length spanning about 4 of the cervical discs. The average power reduction in our previous study [1] was about 46%, and we have improved upon that with higher permittivity uHDC. The significant power reduction follows from the strongly enhanced and focused B_1^+ field in the region bounded by the package (Figure 2 & 3). The use of the shrink wrapped ceramic blocks also offers important handling benefits – they fit within the constraints of our neck receive coil and allow for quick placement by the scanner technician. We are currently evaluating this dielectric package for clinical evaluation of patients with suspected multiple sclerosis in a separate study [8]. The enhanced SNR is potentially useful for improving visualization of lesions within the spinal cord. This work was performed with uHDC materials available to us, and improved performance should be expected with geometry advances, optimal permittivity, and low loss material.

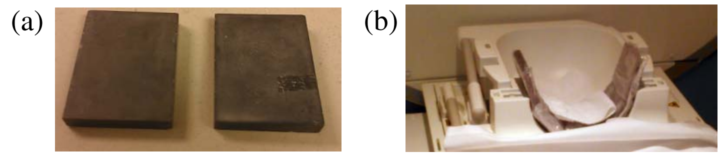

Figure 1 (a) Dielectric material utilized in this study (Lead Zirconate Titanate monolithic blocks). (b) Blocks configuration for scanning – 5 blocks were shrink wrapped into a package and placed with a Siemens 4 channel neck matrix.

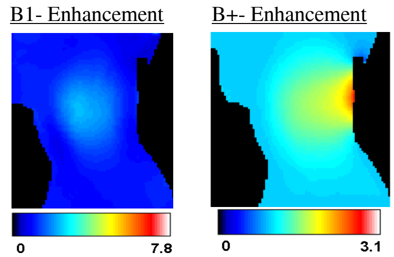

Figure 2 Simulated maps of the B_1^+ enhancement on the left, and B_1^- enhancement on the right. The enhancement was calculated as (Field with uHDC / Field without uHDC)

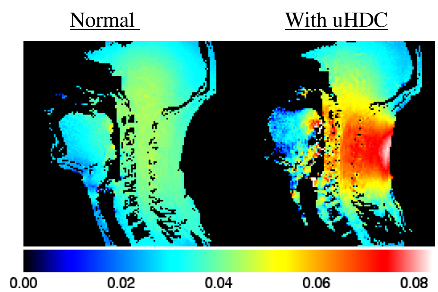

Figure 3 Transmit efficiency maps for the case without uHDC (left) and with uHDC (right). Units are in uT/Volt. Strong enhancement was observed in a region bounded by the package.

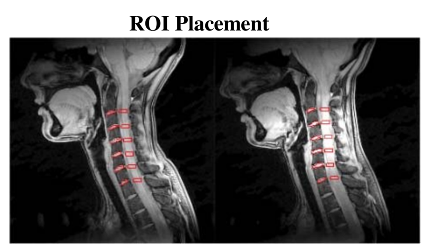

Figure 4 Example SNR map defining the ROI placement for SNR calculation. SNR was measured in discs C1 – C6 and in adjacent regions within the spinal cord.

Table 1: Average SNR increases across 3 volunteers within discs C1 to C6 and adjacent regions of the spinal cord. Average power reduction is given at the bottom.

Average SNR Increase for 3 Volunteers [Given in %]			
C1 Disc	34.84	C1 Cord	39.58
C2 Disc	38.46	C2 Cord	40.43
C3 Disc	30.38	C3 Cord	36.95
C4 Disc	23.24	C4 Cord	19.58
C5 Disc	10.44	C5 Cord	8.62
C6 Disc	-8.05	C6 Cord	-6.69
Average Power Reduction (%)			64.18

References: [1] Yang et al., JMRI 2013. [2] Sica et al., ISMRM 2013. [3] Rupprecht et al., ISMRM 2013. [4] Kellman et al., MRM 2005. [5] Constantinides et al., MRM 1997. [6] Sacolick et al., MRM 2010. [7] Jankiewicz al., ISMRM 2012 [8] Nguyen et al, RSNA 2013