On the Role of Dielectric Resonance in Parallel MRI

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INTRODUCTION: Ultra-high field strengths (B_0) and parallel imaging (PI) are expected to form a considerable synergy. This has recently been emphasized both by theoretical investigations (1-3) and practical experiments (4,5). However, a key concern raised by these studies is whether or not dielectric resonance interferes with the efficient use of PI at ultra-high B_0. This concern is typically based on the following hypotheses: In the presence of a significant dielectric resonance, coil sensitivity profiles have significant contributions from resonant modes of the object. These are specific for the geometry of the object rather than for the positioning and geometry of the coil (6). Accordingly, coil sensitivities become more similar, which may be expected to hamper PI. In order to study these effects, parallel SENSE imaging (7) has been performed in the presence of dielectric resonance on a 7 Tesla MRI system.

METHODS: Two phantoms of different symmetry were chosen: a 3 liter glass flask of spherical symmetry and a 1 gallon (3.785 liters), approximately cuboid plastic container of mirror symmetry. The dielectric resonance spectra of the water-filled phantoms were measured using a small search coil connected to a calibrated HP 4396A network analyzer as suggested in Ref. (8). By replacing small amounts of distilled water (ε_r=79 at 300MHz) by ethanol (ε_r=24 at 300MHz), the frequency of a nearby resonant mode was adjusted to the 7 Tesla Larmor frequency. The effect of conductivity on resonance damping was investigated by introducing small amounts of sodium chloride to achieve saline concentrations of 20mM and 50mM; a 50mM saline water solution corresponds approximately to average in-vivo brain conductivity at 300MHz (9). All imaging experiments were performed on a 7 Tesla magnet (Magnex Scientific, UK), equipped with a Varian Inova console (Palo Alto, CA). Data acquisition was performed with an 8-element, straight-line, microstrip TEM transceive coil array (4,10). Tuning and matching could be performed robustly in all situations. Images were acquired using a gradient-recalled echo (GRE) sequence (TR=50ms, TE=5ms, 3mm slice thickness, matrix=256x256). PI performance was quantified by calculating the local g factor for reduction factors R in the range between 1 and 5 with noise correlation taken into account (7).

RESULTS: Figure 1 shows the dielectric resonance patterns in the two phantom geometries, as revealed by single-coil images in the case of 0mM and 20mM salinity: For the spherical flask (upper part) data from four different coil elements are shown in a central transverse slice. For 0mM a two-lobe mode can be clearly appreciated. Small additional modulations near the surface are due to destructive interference during RF excitation, reflecting non-ideal transmit phase adjustments. For the cuboid container (lower part), a coronal slice is shown. Again, for 0mM a clear higher-order resonance pattern can be appreciated. However, unlike the spherical phantom the resonance does not change significantly with the coil position.

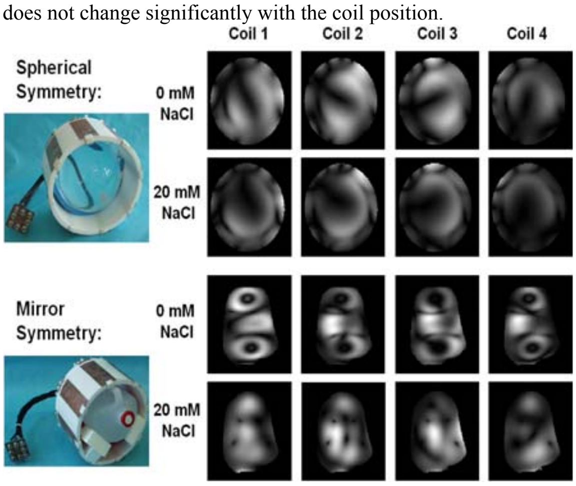

Figure 1: *Single coil images in the presence of dielectric resonance.*

Figure 2 compares calculated mean g-factors between the spherical (left) and the cuboid phantom (right) in a central transverse slice. Three different saline concentrations are shown: 0mM (black solid line), 20mM (blue dashed line) and 50mM (red dotted line). For the spherically symmetric phantom, the calculated g-factors are all in the same range. However, for the mirror-symmetric container the g-factor improves significantly from 0mM to 20mM and remains approximately constant for higher salinity.

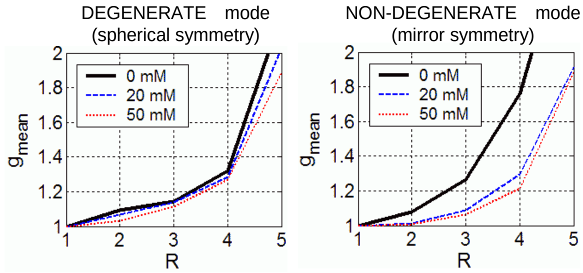

Figure 2: *PI performance in the presence of dielectric resonance.*

DISCUSSION: The discrepancy in PI performance between the two phantom geometries (Fig.2) can be related to characteristics of the specific dielectric resonance patterns (Fig.1). For the spherically symmetric flask, the excited dielectric mode appears to be spherically degenerate, with the consequence that the resonance pattern in the coil sensitivities still depends on the coil position. In particular, in the 0mM images shown in Fig.1 (upper part) it can be recognized that the corresponding coil elements are consecutively rotated by 45º. Accordingly, in this degenerate mode, the individual coil sensitivities are similarly orthogonal for 0mM, 20mM and 50mM salinity, resulting in almost identical, favorable g-factors (Fig.2 left). Conversely, in the mirror-symmetric container a non-degenerate mode was excited. In the case of 0mM salinity, the single-coil images differ only by small sensitivity variations, while the underlying mode structure is the same for all coil elements (Fig.1 lower part). Correspondingly, the coil sensitivity profiles are less orthogonal, resulting in still moderate but enhanced g-factors for the lossless case. However, inducing conductive losses by adding 20mM sodium chloride significantly improves the g-factor. Further increasing the saline concentration to 50mM leaves the g-factor nearly unchanged (Fig.2 right).

The human head exhibits only approximate mirror symmetry. Therefore, non-degenerate resonance modes are expected for brain imaging, indicating the less favorable g factor behavior. However, according to the right plot in Fig.2, the intrinsic tissue conductivity may be expected to sufficiently dampen dielectric resonance modes in the head to a level sub-critical for PI.

In summary, it can be concluded that: (I) The impact of dielectric resonance on PI performance appears to depend on the degeneracy of the resonant mode. A high level of mode degeneracy was observed to be favorable for PI. (II) Independent of the dielectric mode degeneracy, minor amounts of sodium chloride stabilize the g-factor at usual values. This suggests that under in-vivo conditions dielectric resonance may not be a major problem specifically for PI.

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