Dielectric Materials & Resonators

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HIGHLIGHTS

- dielectric materials can improve magnetic resonance imaging
- high field mri coils can be build from water with very little effort
- modes of dielectric materials for cylinders can easily be estimated

TARGET AUDIENCE

researchers and engineers working in the field of high and ultra high field MRI.

OUTCOME

This talk will inform you about dielectrics, their effects on MRI and how to use them to improve imaging. After this talk you should have a general understanding about dielectrics. You will be able to build a simple microscopy coil for your ultrahigh field mri just using destilled water, a bucket and a pickup probe made from ordinary coaxial wire. You will understand how to use dielectric bags to homogeneize your RF field and thus improving data quality on 3.0, 7.0 Tesla and even higher field strength experiments.

PURPOSE

Why do we need Dielectric Materials and Resonators?
Since the introduction of 3.0 Tesla mri wavelength effects in the human body can no longer be neglected as the high field strength also means a higher frequency is needed for the B1 field (1). However this leads to decreased homogeneity in the body trunk at higher field strength due to the shorter wavelength. Already in standart clinical applications on 3.0 T this effect leads to areas of local signal voids and thus uneven image brightness for example in breast and abdominal imaging (2). Dielectric resonators are interesting alternatives to lumped element mri volume coils especially at higher field strengths (3) and can also be used as surface coils (4). We can summarize the main challenges in high field MRI as:

- Inhomogeneous B_1^+
- Increased SAR
- Shading artifacts
- Areas of poor contrast

This leads to poor image quality (figure 1) already at 3T in the abdomen and in the head also visible in the head.

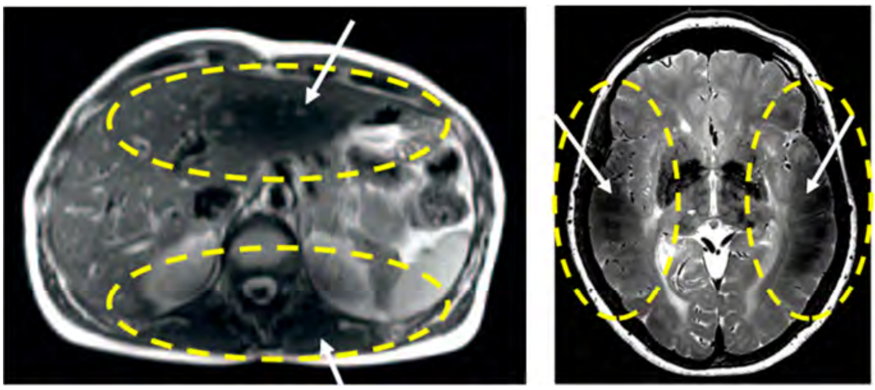

Figure 1 Image artifacts due to wavelength effects on 3.0 T (left) showing shading in abdominal imaging anterior and posterior and at 7.0 T heag imaging (right) showing central brightning while poor lateral signal.

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RESULTS

Due to the decreased wavelength of the B_1 radio wave at higher field strength the wave becomes so short that we get standing wave patterns inside the human body. This effect can be clearly shown with an electromagnetic field simulation in the human head for different field strength (figure 2).

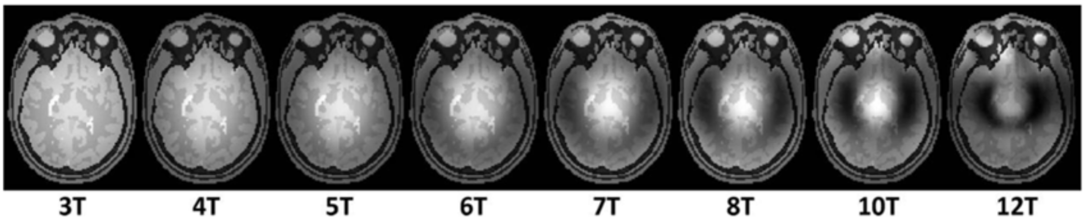

Figure 2 Simulated gradient-echo images, assuming a low tip-angle excitation, as a function of field strength using a birdcage coil with ideal current distributions in the rungs. Figure courtesty of A. Webb (5).

However the wavelength is not the only variable leading to this undesired artifacts. One can also clearly show with electromagnetic simulation that the dielectric constant ε_r of the object in which the wave is traveling has a major impact.

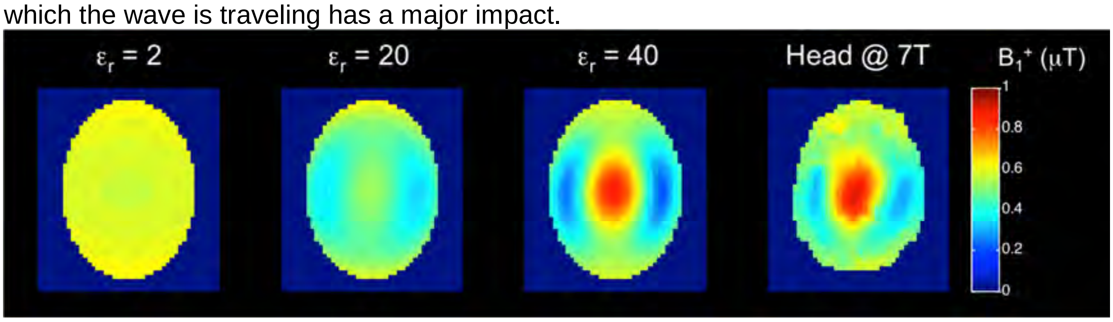

Figure 3 Influence of the dielectric constant on a eliptical phantoms. The B1 field is given using a birdcage coil with ideal current distributions in the rungs. Figure courtesty of W. Brink.

We can combine this knowlege to produce a secondary B1 field by using a bag filled with a high dielectric that „fills up“ the lateral voids in the head if positioned right.

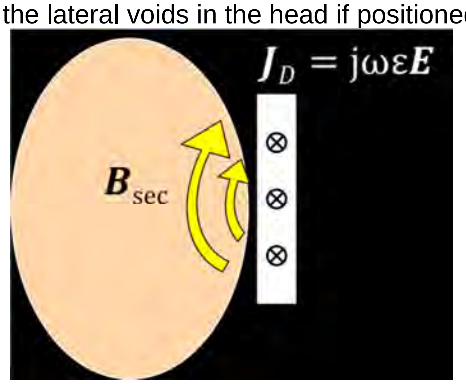

Figure 4 A secondary B field can be created by putting a dielectric material lateral to the head. The B1 field produced by the transmit coil will cause a current to flow in the dielectric material thus creating a secondary B field

It is then possible to design pads with the right shape and dielectric constant to improve the B1 field in a selected reagion in our sample with the help of electromagnetic simulations (figure 5) for example targeted for imaging of the inner ear.

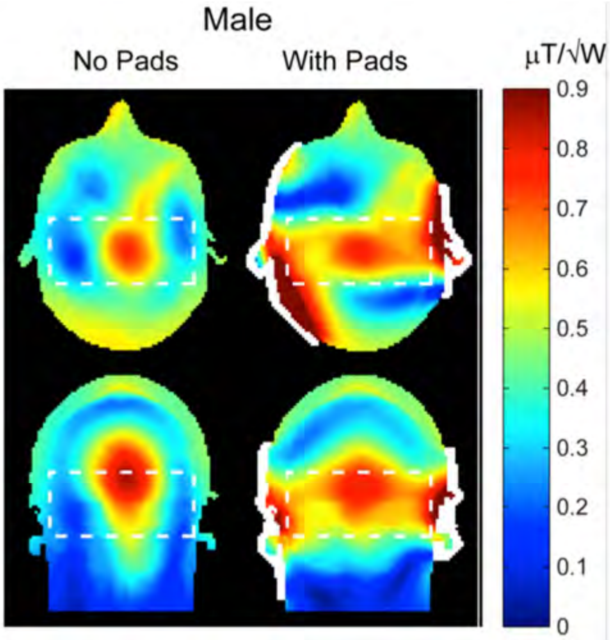

Figure 5 Improving the B1 field for imaging of the inner ear. Simulation data is shown for a human head with and without pads. Image courtesy of W. Brink (6).

The acquired data with and without pads clearly shows the benefit of putting dielectric bags into use (figure 6).

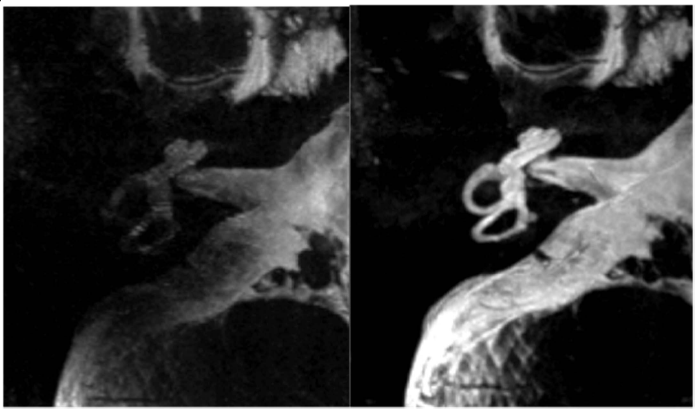

Figure 6 Imaging of the inner ear at 3.0 T without dielectric pads (left) and with dielectric pads (right) showing a dramatic improvement in image quality. Image courtesy of W. Brink (6).

METHODS

How to make and use high dielectric bags to improve imaging.
The production of high dielectric bags is very simple: the bag that usually contains a slurry made from a high dielectrics ceramics power such as barium titanat ($BaTiO_3$) gets mixed with water, preferably this should be deuterized if you do not want to see your bag later on the image, and then put into a sealable plastic bag. The application is also simple: for the head at 7 Tesla for example one places the bags just around the backside of the head approximatley from ear to ear (7). On 3 Tesla cardiac and abdominal imaging, one simply puts the bag suspine on the patients chest beneath the coil (see figure 1).

Figure 7 Putting a dielectric bag on the chest to improve cardiac imaging at 3.0 T

Once one realises the effect of dielectrics on mri, especially the central brightning in the head, one can assume that it also be possible to use this standing wave effects in dielectric materials to ones advantage and build a resonator based on this principle. Indeed this is possible and has been first shown by Wen et al. (8). The feasibilty of these resonators has been shown also at ultra high fields by Neuberger et al. (9) Further designs have been presented in recent years by dutch groups (3,4,10–13).

CONCLUSION

Relevance to clinical practice

Understanding dielectric materials, their properties and how they interact with modern MR systems is an important part of ultra high field mri. The usage of high dielectric bags helps easily to improve image and data quality while reducing SAR. It is now already used on a routine basis at 3 Tesla (14) and for research studies at 7 Tesla field strengh.The principle of how these dielectric bags work has been understood and concerns about negative influence on SAR have been neglected in previous studies (15).

Relevance to to future research

Dielectric materials will continue to be an interesting topic in the future of MRI. The basic concept has been addressed (5,16,17) and one can anticipate ongoing improvement of dielectric pad composition and geometry for example by using a target field simulation approach. The integration of dielectric materials in selected coils for ultra high field MRI seems to be the next logical step. Different pads for different body geometries might be required to get optimal results. Future work will show if there is a „one size fits all“ solution or those pads should be more personalized for maximum benefits in contrast-to-noise ratio, homogeneity of B_1 and the reduction of the specific absorption rate.

Dielectric materials can be used to build novel RF coils (8,12,13) for MRI. The intuitive way to build a simple dielectric resonator from destilled water (8,10) for example for microscopy experiments makes them a usefull skill for researchers working on high Field MRI systems. The high radio frequency nature of ultra high field MRI systems allows for a multitude of new concepts for novel resonators designs for volume and surface coils and has also found its way into traveling wave MRI (11).

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