Rapid Prototyping of Stent Design by Means of Efficient Simulation of Intra-Voxel Dephasing

T. H. Jochimsen[1], T. Scheuermann[2]

[1]Lucas MRS/I Center, Stanford University, Palo Alto, CA, United States, [2]Boston Scientific, Munich, Bavaria, Germany

Introduction

Using magnetic resonance imaging (MRI) to study the vicinity of metallic implants, such as stents, would allow follow-up MRI studies, e.g. to identify potential restenosis in the stent lumen. However, this is usually hampered by the field distortions generated by the implant [1] which cause artifacts and signal loss due to RF shielding and intra-voxel dephasing (IVD). Novel designs and materials can minimize stent-related artifacts [2] for better diagnosis using MR imaging. Developing such stents requires long design-and-test cycles if a prototype is manufactured and actual measurements are used to study the effect of a particular design. Another approach is to virtualize the whole design process: Calculating the electromagnetic fields around the stent and using the results to simulate MRI by numerical solution of Bloch equations [3] allows rapid prototyping of different designs. The fast and accurate simulation of IVD is thus crucial for this approach being useful.

Materials and Methods

The static magnetic field B_0 and the electromagnetic RF field B_1 around and in the stent lumen were calculated on a rectangular grid using HFSS™ and MAXWELL™ from Ansoft Corp. (Pittsburgh, USA) based on an computer-aided design (CAD) model, taking into account magnetic susceptibilities, permittivity and conductivity of stent and surrounding tissue. For the MRI simulation, a magnetization vector is placed at each grid point and simulated by iterative solution of Bloch equations [3]. This approach usually requires a large number of grid points for an accurate simulation [4,5]. Therefore, a novel technique has been suggested recently [6]: In magnetization-gradient based simulation of intra-voxel dephasing (MAGSI), not only the evolution of the magnetization vector is traced, but also its linear dependency upon spatial position, i.e. the magnetization vectors gradient. This allows efficient and accurate simulation of IVD for any MRI sequence. The MAGSI algorithm has been integrated into the ODIN framework [7], validated with a simple cylinder model [8] and then applied to a number of stent designs. A gradient-echo and a spin-echo sequence with TE = 15 and 20 ms, TR = 500 ms were used for the simulation and a measurement at 3 T for comparison.

Results

Exemplarily, Fig. 1 shows the rendered CAD model of a simplified stent and Fig. 2 and 3 display the calculated B_0 and B_1, respectively. This longitudinal cross-section was used for MRI simulation with the gradient-echo sequence, giving the result in Fig. 4. An actual measurement of the same stent design is shown in Fig. 5. The signal loss in the stent lumen due to the Faraday cage effect and IVD around the stent material was reproduced properly by MAGSI.

Discussion and Conclusions

It could be demonstrated that predicting MRI of stents by simulations is possible. Using MAGSI, a good correlation between simulation and real-world results was presented. Further model refining may help to increase correlation.

Fig. 1

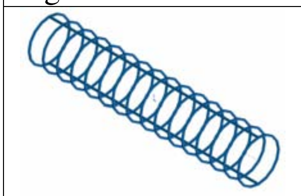


Fig. 2

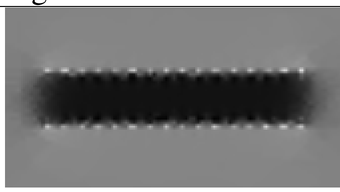


Fig. 3

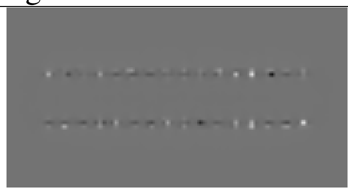
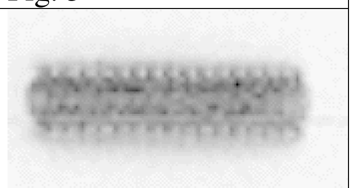


Fig. 4

Fig. 5



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