Magnetic and RF Characterization of Stents using Magnetic Resonance Imaging

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Introduction

The increasing emergence of metallic implants in patients scheduled for MRI has caused manufacturers to provide MR compatibility certificates. Consequently, there is need for MR safety information and several reliable sources and compilations are available [1,2] Typically however, these MR safety certifications focus on direct hazards to the patient and do not include a detailed analysis of imaging artifacts caused by the implants. A closer look, even on a small subgroup of commercially available stents, reveals a wide variety of commonly used materials, such as nitinol, cobalt alloys or high-grade steel alloys, as well as a variety of geometric designs. Both, the material *and* the design, can have a strong influence on the performance of MRI in the lumen of a stent or in its immediate vicinity. Furthermore, the behavior changes with field strength as the resonance frequency changes [3,4]

Material and Methods

The following stents were selected for this study (see Table 1): Absolute (Abbott Laboratories, IL, USA) and Sentinol (Boston Scientific, Natick, MA, USA) are self expanding stents made from nitinol; Wallstent Uni (Boston Scientific) is made from a cobalt alloy with quite a different mesh design (see Fig. 1); Express (Boston Scientific) is an example of a balloon expanding stent made from high-grade steel. All stents had a nominal diameter of 8mm and a length of 35 to 44mm.

MR imaging was performed on clinical 1.5 T and 3 T scanners. Typical imaging sequences like gradient echo, turbo-spin-echo and spin-echo were used to investigate the imaging artifacts. A double flip angle GRE sequence with long T_R was applied to determine the flip angle distribution in the surroundings of the stents [5]. Phase images from a multi-echo gradient-echo sequence were unwrapped and the theoretical field distribution outside an infinite cylinder perpendicular to B_0 was fitted to the unwrapped phase images to determine the effective susceptibility, χ_{eff}, of the stent. Although this method assumes that the observed field distortions is caused by a fictitious homogeneous stent wall, it nevertheless is still a good measure for the effective field disturbance caused by the stent.

Stent type	χ_{eff} relative to water (absolute) in ppm
Sentinol (nitinol)	7.8 (-1.2)
Absolute (nitinol)	7.5 (-1.6)
Express (steel)	26.7 (17.7)
Wallstent (cobalt)	16.8 (7.7)

Table 1: Determined susceptibility coefficients for the stents relative to water (χ_{water}=-9.05ppm) and absolute in ppm.

Results

The resulting flip angle maps are shown in Fig. 1 and the values for χ_{eff} are listed in Table 1. As expected, for the nitinol stents susceptibilities values close to that of water were determined and the resulting artifacts on MR images were not very pronounced, even with sensitive sequences. The cobalt alloy and especially the steel alloy stents exhibited more paramagnetic behavior and caused strong signal cancellations and geometric distortions (image not shown) as well as rf-shielding. The stent Express also exhibited strong rf-shielding, as seen from the very low effective flip angles inside the stent compared to its surroundings. On the other hand, although the Wallstent caused severe susceptibility artifacts, its particular stent design geometry did not lead to severe rf-shielding, as reflected in the flip angle map (see Fig. 1 right). Interestingly, the two stents made from nitinol revealed different behavior: Whereas the stent Absolute exhibited slightly lower flip angles inside, there was a strong decrease of flip angles at 1.5 T for the Sentinol stent, which, however, was strongly reduced at 3 T. The reduced flip angle distribution inside the different stents caused corresponding signal losses on the resulting MR images.

Conclusions

As demonstrated, both susceptibility effects of the stents' material as well as rf-shielding effects determined by the wire structure of the stents influence MR image quality and need to be characterised to predict their behavior on MR images.

References

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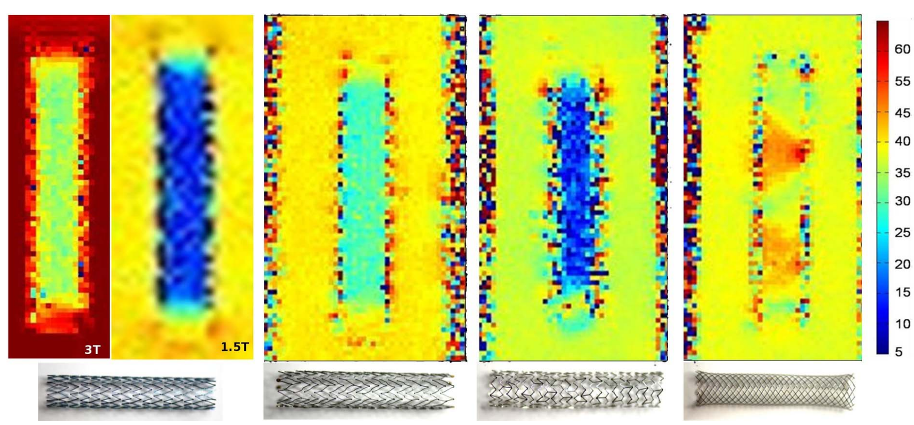

Fig 1: Flip angle maps of stents parallel to B_0 (left to right): Sentinol (3T, 1.5T), Absolute (Nitinol), Express (steel alloy), and Wallstent (cobalt alloy) at 1.5T. The nominal flip angle was 45° at 1.5 T, and 60° for the 3 T data. Below the maps, photographs of the stents are shown.