A Synthetic MR-Compatible Guidewire: A Study to Explore New Prospects for MR-Guided Vascular Interventions

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Introduction Though remarkable progress has been achieved in performing vascular interventions under complete MR-guidance, only very few procedures have been performed in humans (1,2). In this context, the largest hurdle to overcome has been the shortage of MR-compatible devices. This is particularly relevant for guidewires, since it is against good clinical practice to advance a catheter in a vessel of a patient without the inclusion of a guidewire. As a possible remedy, a new synthetic and MR-compatible guidewire is proposed in this work. Its capabilities with respect to MR-guided vascular interventions were explored in experiments with a flow phantom. A passive guidewire tracking technique tailored to the specific conditions of interventional peripheral MRA (ipMRA) was developed. Successful application of this method in the flow phantom allowed subsequent balloon angioplasty of an artificial stenosis under complete MR-guidance.

Methods The guidewire is based on a Polyaryletherketone (PEEK) polymer core and coated with another soft polymer, in which small iron particles are embedded. Its composition is illustrated in Fig. 1. The guidewire has a flexible tip and can be used with any 0.035"-compatible catheter. It was manufactured in collaboration with the company BIOTRONIK (Vascular Intervention, Buelach, Switzerland). A passive device tracking technique was designed utilizing a susceptibility artifact induced by the wire in images acquired with a balanced steady-state free precession (b-SSFP) sequence (3) using small flip angles $\alpha \leq 5°$. The method is based on the specific property of the b-SSFP sequence that its signal bands exhibit narrow maxima for small α resulting in confined signal maxima for regions of varying susceptibility. Visualization of the guidewire tip is shown in Fig. 2. The position of the tip was then determined from image intensity maxima and overlayed onto a previously acquired roadmap in near real-time. The following scan parameters were used: TR/TE=4.31/2.14, *matrix*=256x256, square *FOV*=206 mm, slice thickness=10 or 40 mm, α=3-5°, *BW*=930 Hz/pixel, and *NA*=1 yielding a temporal resolution of 0.9 frames/s. Guidewire tracking and balloon angioplasty of an artificial stenosis were attempted in two configurations of a flow phantom. Visualization of the balloon catheter was accomplished by slightly inflating the balloon with a small amount of contrast agent and acquiring MR data with a T_1-weighted fast low angle shot (FLASH) (4) sequence.

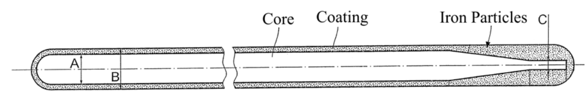

Fig. 1: Schematic of the MR-compatible guidewire illustrating its composition, A and C are the diameter of the PEEK polymer core at the proximal and distal ends, respectively, and B is the total diameter (≈0.035").

Results Successful passive guidewire tracking was performed for all phantom configurations. For the configuration with a single tube, the corresponding results are presented in Fig. 3. Note that the maximum intensity values of each image (within the phantom) are all found in close proximity to the tip of the guidewire. Results from tracking of the guidewire during its placement into and beyond an artificial stenosis in the phantom configuration with a tube bifurcation are displayed in the upper row of Fig. 4. A balloon catheter was then placed into the stenosis using the guidewire under complete MR-guidance. Subsequent balloon angioplasty yielded improved flow conditions, which is illustrated by the images shown in the lower row of Fig. 4. Robustness and accuracy of the tracking technique were sufficient for phantom studies.

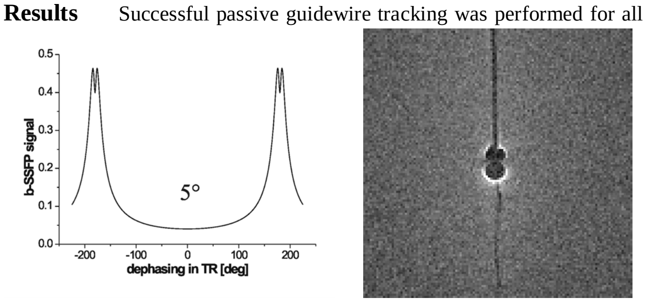

Fig. 2: Visualization of guidewire tip using b-SSFP sequences with small flip angles α. *Left*: Signal amplitude of a b-SSFP sequence versus dephasing θ during each TR period for α=5° and T_2/T_1=65/80. *Right*: Resulting induced artifact at tip of guidewire.

Discussion During all experiments no adverse effects using the MR-compatible guidewire in the MR scanner were detected. Except for the desired susceptibility artifact, no other artifacts were observed. Benefits of the presented tracking scheme include its simplicity and ease of use. No additional hardware was required, and all data analysis procedures were readily integrated into the image reconstruction software of the scanner. Due to an inconsistent portrayal of the susceptibility artifact inherent to most passive tracking techniques precision of tip localization was limited (~1 cm). This could be easily improved by modifying the distribution of iron particles within the coating of the wire to obtain a more distinct and spatially more confined artifact pattern. In addition, the tracking method could benefit from a more elaborate detection algorithm and the addition of a slice tracking capability. Another alternative is the use of an adaptive subtraction technique as recently proposed in (5). However, based on the encouraging results from this study, it is concluded that the new guidewire is certainly well-suited for clinical application due to an absence of the risk of core fracture and its atraumatic flexible tip. It opens novel prospects for the realization of MR-guided vascular interventions in humans that need to be explored in future studies.

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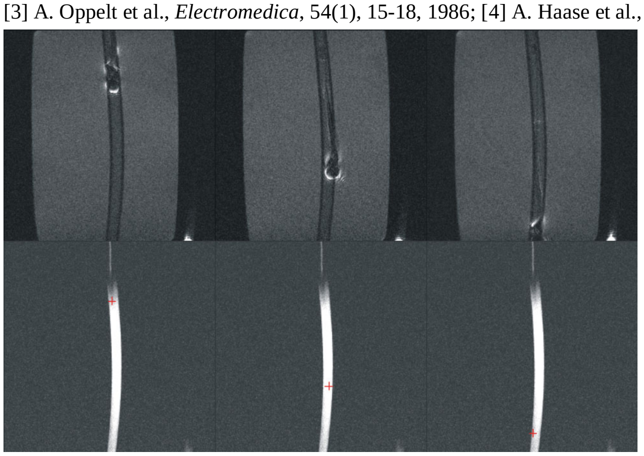

Fig. 3: Passive guidewire tracking applied to flow phantom with single tube. *Upper row*: Images from b-SSFP acquisitions with flip angle α=5° for three different positions of the guidewire; *Lower row*: roadmap with resulting image overlays indicating respective position of guidewire tip along the tube.

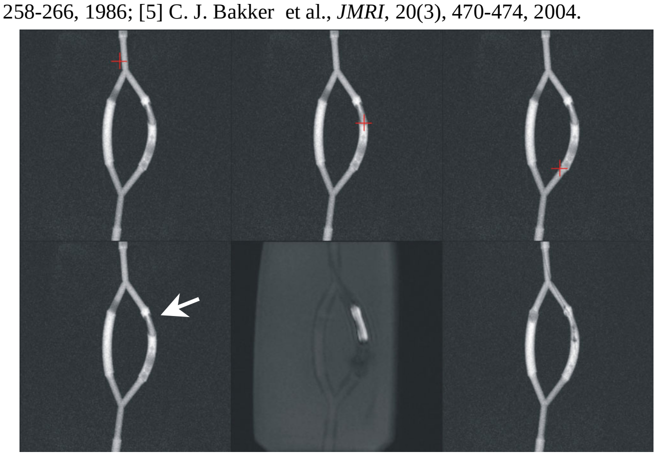

Fig. 4: MR-guided balloon angioplasty of an artificial stenosis in flow phantom with tube bifurcation. *Upper row*: Roadmap with resulting image overlays indicating placement of the guidewire into and beyond stenosis. *Lower row*: Stenosis (arrow) before, during, and after balloon angioplasty.