Feasibility of Stent-Graft Placement with Real-Time MR Fluoroscopy in a Nonrigid Aortic Phantom

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PURPOSE: To evaluate the feasibility of using real-time magnetic resonance (MR) fluoroscopic guidance to place a stent-graft mounted on a guide wire in a nonrigid aortic phantom.

MATERIALS AND METHODS: Real-time fast low-angle shot and true fast imaging with steady-state precession MR imaging sequences were used for device tracking. A modified fiber-optic guide wire and catheter embedded with titanium oxide in predefined positions were used for navigation in a homemade silicone thoracic aortic phantom.

RESULTS: Susceptibility artifacts caused by the modified guide wire and catheters mounted in the descending thoracic aorta of the phantom were found to enable adequate determination of the guide wire position in relation to the surrounding anatomy and to cause no image distortion. Real-time MR imaging enabled visualization of both the vessel lumen and the delivery system with the mounted stent-graft, providing an image quality sufficient for successful localization of the lesion and deployment of the stent-graft.

CONCLUSIONS: The results of this study prove the possibility of passive guidance in MR imaging–guided stent placement in vitro. The modified guide wire can be used with interventional commercial catheters and recent implant devices with selective tracking in the surrounding anatomy.

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Abbreviations: FLASH = fast low-angle shot, MIP = maximum intensity projection, 3D = three dimensional, RF = radiofrequency

Endovascular stent-graft placement is emerging as a promising alternative to medical therapy and surgery in the treatment of patients with diseases of the descending thoracic aorta (1).

Stent-graft implantation is usually performed under radiographic fluoroscopy, which has several shortcomings beyond the ionizing radiation and nephrotoxic contrast material. For example, fluoroscopy is a one-plan projection image that does not enable consistent differentiation of the different aortic structures. In addition, immediate evaluation of procedural success after stent-graft placement (ie, thrombosis of the false lumen) is not possible. Some authors use fluoroscopy in combination with transesophageal echography to detect postimplantation endoleaks (2,3).

Magnetic resonance (MR) imaging guidance of vascular interventional procedures offers several potential advantages over fluoroscopically guided techniques, including image acquisition in any desired orientation, superior three-dimensional (3D) soft tissue contrast with simultaneous visualization of the interventional device, absence of ionizing radiation, and avoidance of nephrotoxic contrast media (2).

The feasibility of MR imaging–guided vascular interventions has been demonstrated for a variety of procedures, including peripheral and coronary stent placement (4), selective embolization (5), and implantation of atrial septal closure devices (6).

MR imaging guidance may be particularly useful for aortic stent-graft placement because it can provide all relevant information for the preinterventional planning of such procedures and can be used in the postinterventional evaluation of treatment success (7). Several studies have suggested that MR angiographic techniques may even be superior to standard techniques (ie, computed tomography) for detecting endoleaks during follow-up as well as for evaluating aneurysm sac exclusion and graft patency (8).

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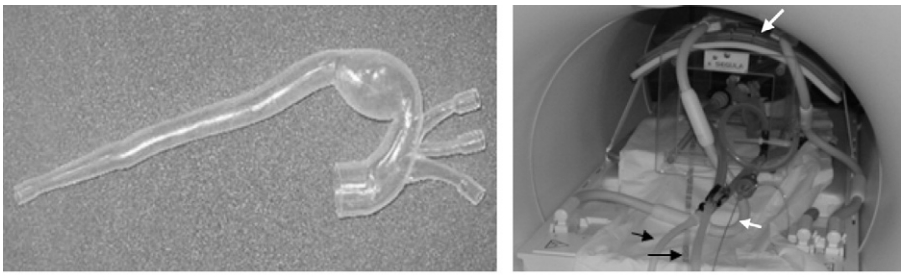

a. b.

Figure 1. **(a)** Life-size, soft, transparent silicone cast of the aortic aneurysm. This model was used, under perfusion by an extracorporeal circulation pump, to test in vitro stent deployment. **(b)** Experimental set-up. The modified guide wire and catheter (right arrow) are mounted in the silicone phantom with a localized aneurysm of the descending thoracic aorta, which was connected to an artificial cardiac pump in an autonomic circle (left arrows). The phantom was placed, with its longitudinal axis parallel to the main magnetic field of the magnet, above the spine phased-array RF coil. A body phased-array RF coil was placed on top of the phantom (top arrow).

An important prerequisite for performing stent-graft placement under MR guidance is the magnetic MR compatibility of the guiding devices, delivery mechanism, and endografts with respect to device visibility, image artifacts, and postdeployment visualization of the expended stent-grafts and their lumens (4).

We performed this study to evaluate the feasibility of thoracic stent deployment with use of a passive tracking guide wire in real-time MR imaging interventional guidance in a nonrigid aortic phantom.

MATERIALS AND METHODS

In Vitro Phantom Set-up

Experiments were performed with a 1.5-T whole-body MR unit (Magnetom Sonata; Siemens Medical Solutions, Erlangen, Germany) equipped with gradients capable of a maximum amplitude of 40 mT/m and a slew rate of 200 $T.s.m^{-1}$. The MR system is equipped with a real-time image reconstruction system and online monitor display. The signal is projected from the monitor console with a radiofrequency (RF)-shielded video projector within the magnet room for direct visualization and control of the MR imaging–guided intervention.

We used a nonrigid, silicone, homemade phantom (Segula Technologies, Saint Priest, France) with a localized aneurysm of the descending thoracic aorta that is connected to an artificial cardiac pump in an autonomic circle. A 3D MR angiography dataset derived from a 60-year-old patient with aortic arch aneurysm was segmented, meshed, and converted to STL format (9). A rapid prototyping technique established a stereolithographic model to produce a replica of the entire aorta, including the arch aneurysm and supraaortic arteries. The final model was made by pouring silicone rubber to obtain a sturdy, life-size, soft, transparent plastic cast that accurately reproduced both the internal and external anatomy of the aortic aneurysm (**Fig 1a**).

The nonmagnetic phantom was designed to allow assessment of the delivery device and stent-graft artifact properties during manual advancement and subsequent stent deployment. The phantom was directed with its longitudinal axis along the axis of the main magnetic field and placed above the spine phased-array RF coil with two coil elements activated for signal reception. A body flex phased-array RF coil consisting of two elements was placed anteriorly on the phantom (**Fig 1b**). No institutional review board existed at the time the study was initiated, and the principles of the Declaration of Helsinki were followed.

Guide Wire and Catheter Devices

A dedicated fiber-optic guide wire (SEDI, Couronnes, France) and commercial catheters with embedded paramagnetic compounds were tracked on the basis of signal void artifacts (dark spots) induced by magnetic susceptibility effects. The vascular guide wire was 5 feet (200 cm) long and had an outer diameter of 0.035 inch. The markers were placed at predefined positions. The 0.5-cm-long markers were placed at the distal end of the guide wire at 0.5- and 2-cm intervals along the basic body and at 5-cm intervals for tracking (**Fig 2**).

The material of the markers was water-based paint with 5% weight of titanium oxide (Magpaint Europe, Veldhunten, The Netherlands). An outer sheath of varnish (spray, clear lacquer, fast drying) was sheathed to fix and protect the marker layers.

The guide wire was examined for the desired physical features, including flexibility (rigid proximal part and flexible 3-cm distal end), torque transmission, tractability and compatibility with MR imaging.

A conventional commercial angiographic 5-F catheter (Terumo, Tokyo, Japan) was used. The 0.5-cm-long markers were placed at the distal end at 2- and 5-cm intervals along the basic body and at 10-cm intervals for tracking.

Stent-Graft Device

A Valiant stent-graft (Medtronic Vascular, Santa Rosa, California)—a self-expandable, nitinol-based tubular stent-graft device—and its delivery mechanism were used. No modifications were made to the stent-graft.

MR Imaging Protocol

Localizer images were obtained for orientation and prescription of the following sequences. Two different MR imaging sequences and protocols for near-real-time tracking of endovascular devices were assessed.

A two-dimensional fast low-angle shot (FLASH) sequence with online subtraction was used with the following parameters: 2.36/0.83 (repetition time msec/echo time msec), 25° flip angle, 300-mm^2 field of view, 128 × 256 matrix, 256 square reconstruction matrix, 20-mm-thick sections, 6/8 partial phase Fourier, 700 Hz per pixel receiver bandwidth, 0.2-second acquisition time per measure, and 0.5-second delay between two successive measures.