Feasibility of real-time magnetic resonance-guided stent-graft placement in a swine model of descending aortic dissection

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Aims To evaluate the pre-clinical feasibility of real-time magnetic resonance imaging (rtMRI) to guide stent-graft placement for experimental aortic dissection (AD) and to alleviate disadvantages of ionising radiation and nephrotoxic contrast media. Endovascular stent-graft placement for thoracic aortic disease is usually performed under X-ray guidance. The feasibility of rtMRI-guided stent-graft placement is currently not known.

Methods and results By using a catheter-based technique, dissections of the descending thoracic aorta were successfully created in eight domestic pigs. Subsequent implantation of commercially available, nitinol-based stent-grafts was performed entirely under rtMRI guidance. By pre-interventional MRI, the mean minimal true-lumen diameter was 0.9 (0.825–0.975) cm. rtMRI permitted not only the successful and safe device navigation within the true lumen from the iliac arteries to the thoracic aorta, but also the precise positioning and deployment of the stent-graft and safe withdrawal of the delivery catheter in seven of eight pigs. This was achieved without any other complications. After the stent-graft placement, MRI demonstrated complete obliteration of the false lumen, which was confirmed at autopsy. All stent-grafts were well expanded resulting in an increase in the size of the true-lumen diameter to 2.05 (1.925–2.1) cm (P = 0.066 vs. baseline).

Conclusion In experimental AD, rtMRI-guided endovascular stent-graft placement is feasible and safe and has the potential for mitigating radiation and contrast-related side effects. Additionally, it allows not only pre-interventional diagnosis and detailed anatomic diagnosis, but also permits immediate post-interventional, anatomical, and functional delineation of procedure success that may serve as a baseline for future comparison during follow-up.

Introduction

Endovascular stent-graft placement is emerging as a promising alternative to medical and surgical treatments of patients with descending aortic dissection (AD).1 The aim of endovascular repair in AD is to obliterate the false lumen by the implantation of a membrane-covered stent-graft into the true lumen across the proximal entry tear.2 Precise placement of the stent-graft, which is currently performed under X-ray, remains challenging, as there are several shortcomings to fluoroscopic guidance, beyond that related to the harmful effect of radiation exposure and nephrotoxic contrast media. With fluoroscopy, it is often difficult to verify the guide-wire position in the true lumen, which is mandatory before the stent-graft placement. Contrast angiography, for positioning of the stent-graft, achieves only brief opacification of the large-caliber aorta and frequent repetition as needed, increases contrast use resulting in greater potential for contrast-mediated renal dysfunction. X-ray angiography will not always show correct location of the entry tears and re-entry tears, and does not allow consistent differentiation of false from true lumen as well as the adequate visualisation of the false lumen. Immediate evaluation of procedure success after stent-graft placement (i.e. thrombosis of the false lumen) is thus not possible. Although transoesophageal echocardiography (TEE) and intravascular ultrasound have been
used as adjunct imaging modalities during endovascular stent-graft procedures to overcome the limitations of fluoroscopy.3–5 Magnetic resonance imaging guidance of vascular interventional procedures offers several potential theoretical advantages over fluoroscopy-guided techniques, including image acquisition in any desired orientation, superior three-dimensional (3D) soft-tissue contrast with simultaneous visualisation of the interventional device, absence of ionising radiation, and avoidance of nephrotoxic contrast media.6,7 Magnetic resonance imaging is often used for pre-operative diagnosis of AD and can provide all relevant information for the planning of endovascular aortic stent-graft procedures8 and for accurate and immediate post-interventional evaluation.9 Recent studies have also suggested that MRI may be equivalent or superior to standard techniques [e.g. computed tomography (CT), TEE] for follow-up examinations.10

The aim of the present study was to evaluate the pre-clinical feasibility of real-time magnetic resonance imaging (rtMRI) to guide stent-graft placement in an animal model of descending thoracic AD, using commercially available stent-graft devices. We envisioned that if this modality can be successfully demonstrated to guide stent-graft placement for AD without increasing risks, a single imaging modality can potentially be used for diagnosis of AD, guiding stent-graft placement for its treatment, ascertaining success and procedure-related complications and for future follow-up of the disease process.

Methods

Animal preparation

In vivo experiments were performed on fully anesthetised domestic pigs (n = 8) weighing 63–98 kg. The experiments were conducted in accordance with all regulations set forth by institutional and governmental agencies. The animals were anesthetised initially by intramuscular injection of a combination of ketamin hydrochloride (30 mg/kg), azaperon (2 mg/kg), and atropine (0.02 mg/kg), followed by an intravenous continuous infusion of propofol (160 mg/h), fentanyl (0.4 mg/h), and midazolam (40 mg/h). The pigs were intubated with an endotracheal tube (6.5–7.5 mm internal diameter), and ventilation was maintained during the experiment using a Dräger UV-2 ventilator (Dräger Medical, Lübeck, Germany) with 100% oxygen. Following the experiments, the animals were euthanised by bolus injection of 80 mg/kg pentobarbital.

Creation of descending AD

We modified a previously described catheter-based technique for non-surgical creation of descending ADs.11 A 10-F introducer sheath (Aranti introducer, Cordis, Miami, FL, USA) was surgically inserted into the left common carotid artery (CCA). A second surgical access to the right common iliac artery (CIA) was obtained for later introduction and advancement of the stent-graft delivery system. Creation of dissection was performed under X-ray in a cardiac catheterisation laboratory. First, a standard 6-F pigtail catheter (Cordis, Miami, FL, USA) was advanced through the left CCA sheath and a digital aortogram of the thoracic aorta was obtained (Figure 1A). Then, the pigtail catheter was exchanged for the 9-F needle of a Colapinto transjugular liver access set (Cook, Bloomington, IN, USA) over a standard 0.035” guide wire with a length of 260 cm (Cordis, Miami, FL, USA). The guide wire was pulled back inside the Colapinto needle and the tip of the needle was positioned against the dorsal wall of the descending thoracic aorta, ~3–4 cm distal to the origin of the left subclavian artery. A 0.014” coronary guide wire (Floppy II, ACS Guidant, Santa Clara, CA, USA) was inserted with its stiff end first until 2–3 cm of the wire end extended beyond the needle tip into the aorta. The needle/wire combination was used in this manner to protect against the inadvertent transmural penetration of the needle tip during the creation of the initial subintimal tear. The needle/wire combination was then advanced inferolaterally against the aorta until the needle tip engaged the aortic wall. Approximately 10 mL of iohexol contrast media (Ultravist 300, Schering, Berlin, Germany) was forcefully hand-injected through the needle to create the initial dissection (Figure 1B). The 0.035” guide wire was then advanced into the thus created subintimal pocket to

Figure 1  Catheter-based creation of experimental descending AD under X-ray fluoroscopy. (A) Pre-interventional digital angiogram of the descending thoracic aorta (anterior–posterior projection). (B) The tip of a 9-F Colapinto needle has engaged the posterolateral wall of the thoracic aorta. The initial dissection pocket (arrow) is created by forceful hand-injection of contrast media. (C and D) The subintimal pocket is enlarged (C) and extended inferiorly to the abdominal aorta (D) by repeated contrast injections and guide-wire manipulations. (E) Digital angiogram of both true (TL) and false lumen (FL) after creation of the dissection showing the undulating dissection flap (arrowheads).
secure the position of the needle tip, and the 0.014" guide wire was removed. Further forceful hand injections of contrast media were performed to enlarge the subintimal pocket (Figure 1C). The needle was exchanged for the 6-F pigtail catheter over the 0.035" guide wire, which was coiled in the dissection sac. A total of 10 000 IU of heparin was given through the pigtail catheter, and the dissection was extended inferiorly by wire manipulation and/or forceful hand-injection of contrast media. Dissections were extended into the distal thoracic or abdominal aorta, resulting in spontaneous creation of a distal re-entry tear (Figure 1D). Angiograms of both true and false lumens were obtained (Figure 1E). After creation of the dissection, the stent-graft delivery system was inserted into the femoral artery and the pigs were transferred to the MR scanner for subsequent stent-graft placement.

Stent-graft device

On the basis of a comprehensive in vitro analysis of MRI characteristics of six commercially available thoracic aortic stent-graft devices, a self-expandable, nitinol-based tubular stent-graft device (GoreTAG, W.L. Gore Inc., Flagstaff, AZ, USA), which—in combination with its delivery system—produced the fewest MR artifacts was chosen for the in vivo experiments (Figure 2). Stent-grafts with lengths of 10 cm and diameters of 2.6 and 2.8 cm, respectively, were available. The loaded stent-graft was constrained by an implantable ePTFE sleeve on the leading end of an 18-F polyurethane delivery catheter. Middle-to-end deployment was initiated by retraction of a GoreTex filament, which rapidly released the stent-graft from the ePTFE sleeve. No modifications of the commercially available stent-graft device were made.

MRI scanner and sequences

Scanning was performed on a 1.5 T whole-body MRI scanner (Magnetom Avanto, Siemens Medical Solutions, Erlangen, Germany) equipped with gradients capable of a maximum amplitude of 45 mT/m and a slew rate of 200 T/m s⁻¹. The animals were placed head first in a supine position inside the scanner on a phased-array RF coil, each consisting of two clusters of coil elements activated for signal reception (Tim Technology, Siemens Medical Solutions, Erlangen, Germany). Two body flex phased-array RF coils, each consisting of two clusters of coil elements, were placed anteriorly on the pig.

Pre-interventional MRI evaluation

After creation of descending AD, pre-interventional MRI evaluation was commenced with steady-state free precession imaging with ECG gating and retrospective image reconstruction (TrueFISP retro) within one breath-hold in parasagittal and in axial orientation. Imaging parameters were repetition time (TR) = 40 ms, echo time (TE) = 1.1 ms, flip angle = 77°, field-of-view (FOV) = 380 × 330 mm², matrix = 192 × 192, slice thickness = 6 mm, bandwidth (BW) = 930 Hz/pixel. Image acquisition time was 15 s for a single slice. After data acquisition with an RR-interval of, for example, 680 ms, 20 phases of the cardiac cycle (i.e. one image every 34 ms) were reconstructed retrospectively. The minimal diameter of the true lumen was measured on the TrueFISP retro sequences.

Pre-interventional MRI evaluation further encompassed 3D contrast-enhanced (CE) MR angiography (MRA) with a fast T1-weighted spoiled gradient echo sequence (FLASH) in coronal orientation. An automatic contrast injector (Spectris Medrad Inc., Indiana, PA, USA) was programmed to inject 32 mL of paramagnetic contrast agent (Dotarem, Guerbet, Cedex, France) into an ear vein of the pig, with an injection rate of 2 mL/s followed by a 30 mL saline flush at the same flow rate. Contrast bolus arrival time in the aorta was determined with a test bolus technique that provided one 2D fast gradient echo image per second in parasagittal orientation. Imaging parameters for the 3D CE FLASH MRA sequence were TR = 2.5 ms, TE = 1.0 ms, flip angle = 15°, FOV = 400 × 400 mm², matrix = 384 × 246, BW = 685 Hz/pixel. A coronal slab with an overall slab thickness of 154 mm was acquired and 128 slices with an interpolated slice thickness of 1.2 mm each were reconstructed. Image acquisition time was 18 seconds per slab covering the ascending and the descending aorta as well as the aortic arch. Three successive acquisitions were performed, the first acquiring a native data set for subsequent image background subtraction, the second phase acquiring the arterial contrast phase, followed by the third phase covering the venous phase of the aortic angiogram. Images of the second (arterial) and the third acquisition phase (venous) were post-processed to produce maximum-intensity-projections (MIP) enabling comprehensive 3D angiographic visualisation of the aortic pathology.

rtMRI interventional guidance

For implantation, the delivery system with the mounted stent-graft was advanced from the CIA to the thoracic aorta under rtMRI fluoroscopy without use of guide wires. The MRI fluoroscopy was based on an interactive real-time steady-state free precession sequence (TrueFISP) with radial k-space filling (TR = 3.0 ms, TE = 1.5 ms, flip angle = 80°, FOV = 360 × 360 mm², matrix = 192 × 192, BW = 1530 Hz/pixel, slice thickness = 6 mm) during free breathing and without cardiac triggering. Forty-nine echoes were acquired for each reconstructed image, resulting in real-time radial projection images with a frame rate of seven reconstructed frames per second. Images were displayed without detectable image reconstruction delay (<200 ms). The images were projected with an RF-shielded video projector onto an in-room 60° high-contrast projection screen (MRI screen, MR-Innovation GmbH, Essen, Germany). Image slice position, orientation, and contrast parameters could be changed and adapted interactively from inside the scanner room while the sequence was running. Imaging position was adjusted to a parasagittal orientation for anatomic display of the descending thoracic aorta as derived from the MRI sequence to visualise the longest course of the thoracic aorta including ascending aorta, aortic arch, and descending aorta.

Post-interventional MRI evaluation

After stent-graft placement, the pre-interventional MRI protocol, including parasagittal and axial TrueFISP retro sequences as well as contrast enhanced 3D FLASH MRA in three phases, was repeated to evaluate procedure success. Additionally, post-contrast
T1-weighted 3D volume interpolated breath-hold examination (VIBE) sequence was acquired in axial orientation to evaluate and confirm post-interventional thrombus formation in the false lumen of the treated dissection. Imaging parameters for the 3D VIBE sequence were TR = 3.1 ms, TE = 1.3 ms, flip angle = 12°, FOV = 400 × 400 mm², matrix = 256 × 134, BW = 560 Hz/pixel, fat saturation, slice thickness = 3 mm, 128 slices acquired within 21 s. Similar to pre-interventional evaluation, minimal true-lumen diameter was measured on TrueFISP images. Images were assessed qualitatively for grade of false-lumen thrombosis and compared with macroscopic examination of the ex vivo aorta.

Statistical analysis
Continuous variables are presented as medians and inter-quartile ranges. Diameters of true lumen before and after stent-graft placement are compared using the non-parametric Wilcoxon signed-rank test.

Results

Pre-interventional MRI evaluation
Descending ADs were successfully created in all eight pigs. In the first three pigs, pre-interventional MRI evaluation revealed that non-communicating, subadventitial dissections of the descending thoracic aorta were created, probably because of deep needle penetration, highlighting the limitation of creating an experimental AD under flouroscopy. In one of these pigs, transmural perforation with haemothorax occurred, but the pig survived for the duration of the experiment. In the remaining five pigs, classic double-barrel dissections were created. Pre-interventional MRI showed the typical aspect of communicating true and false lumen with an undulating dissection flap. Dissections extended to the distal thoracic aorta in three and to the abdominal aorta in two pigs, respectively. The minimal diameter of the true lumen was 0.9 (0.825–0.975) cm. The maximum diameter of the aorta (true and false lumens) was 2.45 (2.175–2.65) cm.

Stent-graft placement under rtMRI
rtMRI allowed for visualisation of both vessel lumen and delivery system with the mounted stent-graft, providing image quality sufficient for successful intervention. Susceptibility artifacts caused by the stent-graft mounted on the delivery system enabled adequate determination of the position of the loaded stent-graft in relation to the surrounding anatomy, but caused no undue image distortion. In one pig, the delivery system was inadvertently inserted into the false lumen. This was immediately detected by MRI during advancement of the delivery system (Figure 3, see Supplementary material online, Movie S1) and corrected. After repositioning the device into the true lumen, the pig developed severe arrhythmias with haemodynamic instability, and was euthanised before stent-graft placement could be attempted. In the remaining seven of the eight pigs, MRI verified the correct delivery system position within the true lumen. Subsequently, successful and safe navigation of the stent-graft delivery system to the thoracic aorta was well monitored by rtMRI (Figure 4). The susceptibility artifacts of the loaded stent-graft in combination with the simultaneously visible dissection flap allowed for adequate positioning over the proximal dissection tear (Figure 4, see Supplementary material online, Movie S1). Subsequent

Figure 3 (A) rtMRI in parasagittal orientation showing that the stent-graft delivery system (arrows) is inadvertently positioned within the false lumen (TL, true lumen; FL, false lumen; arrowheads pointing at the dissection flap). (B) The delivery system position in the FL (arrow) is confirmed by the corresponding axial MRI plane (TL, true lumen). For this purpose, image orientation was changed to an axial slice position from inside the scanner room while the real-time sequence was continuously running.
Stent-graft deployment was successfully completed in seven of the eight cases and was well visualised by MRI (Figure 4, see Supplementary material online, Movie S2). After stent-graft deployment, withdrawal of the delivery system was also adequately visualised under rtMRI. No other complications occurred. MRI time for navigation, positioning, and stent-graft deployment was 2 (2–4) min.

Post-interventional MRI evaluation
Post-interventional MRI evaluation demonstrated correct position of the stent-graft in all seven cases. All stent-graft were well expanded. The minimal diameter of the true lumen had increased to 2.05 (1.925–2.1) cm after stent-graft placement (P = 0.066 vs. baseline). MRI showed complete coverage of the proximal dissection tear and thrombosis of the false lumen (Figures 5–7) as was confirmed by macroscopic examination of the ex vivo aortae (Figures 7 and 8) in all seven pigs.

Discussion
The present study shows the pre-clinical safety and feasibility of endovascular stent-graft placement for descending AD performed entirely under rtMRI in a swine model. This was achieved using commercially available catheter devices without any modifications made. Beyond detailed pre-interventional anatomic diagnosis of AD that facilitated treatment planning, rtMRI permitted (1) verification of delivery system position within the true lumen, (2) successful and safe device navigation to the thoracic aorta, (3) precise stent-graft positioning, (4) stent deployment, and (5) safe catheter withdrawal. After stent-graft placement, functional imaging with dynamic contrast MRA complemented the anatomic imaging for immediate confirmation of treatment success. In fact, procedural success as identified by complete obliteration of the false lumen was observed in all cases by MR, and was further confirmed by macroscopic examination of the ex vivo aorta at necropsy.

Recently, the feasibility of rtMRI-guided interventions has been demonstrated for a wide range of vascular interventional procedures in animals, including percutaneous transluminal angioplasties,13 selective embolisation procedures,14 placement of atrial septal closure devices,15 peripheral as well as coronary stent placements,16 and most recently, for stenting of aortic coarctation.17 For peripheral stent placement, the feasibility of MRI guidance has also been shown in patients.18 In terms of endovascular aortic stent-graft placement, which is an emerging treatment option for patients with descending thoracic aortic disease, MRI appears to be particularly useful as it can provide (1) comprehensive pre-interventional diagnosis and evaluation of the vascular aortic morphology and pathology for planning of the intervention,8 (2) interventional image guidance and monitoring of the therapy itself,6 and (3) immediate evaluation of treatment success and ascertainment of procedure-related complications and follow-up examinations.10 Mahnken et al.6 demonstrated the general feasibility of MRI-guided aortic stent-graft placement. They implanted commercially available stent-grafts into
the infrarenal aorta of healthy pigs under MRI guidance.\textsuperscript{6} Very recently, Raman \textit{et al}.\textsuperscript{19} showed that endovascular repair of experimental abdominal aortic aneurysm can, indeed, be successfully performed under rtMRI. Our experiments extend this paradigm to the successful navigation of the stent-graft delivery system up to the descending thoracic aorta and confirm its feasibility under rtMRI guidance even in dissected aortas. Real-time TrueFISP imaging sequences with radial k-space filling provided excellent intrinsic blood contrast within the aorta to allow reliable identification of true and false lumens and further for successful treatment of complex aortic pathology. Such steady-state sequences, when used with high-excitation flip angles, provide high instrument to background contrast, even without administration of a contrast agent which make the stent-graft conspicuous in the MR image.\textsuperscript{20} The temporal resolution of seven reconstructed images per second, displayed without detectable image reconstruction delay on an in-room high-resolution projection screen, proved sufficient for direct control of the catheter instruments and allowed for precise positioning of the stent-grafts. Stent-graft deployment was also adequately depicted. Neither respiratory or cardiac triggering nor breath-hold was required to obtain images without visual degradation by motion artifacts.

Collection of precise 3D information about soft tissue anatomy and reliable visualisation of catheter instruments in relation to the surrounding anatomy, represent the pre-requisites for safe and successful performance of vascular interventions under MRI guidance.\textsuperscript{21} In contrast to ultrasound, X-ray fluoroscopy, or CT, visualisation of interventional instruments by MRI has, however, proved to be difficult.\textsuperscript{20} The optimal MRI technique to visualise vascular instruments should provide high spatial and temporal resolution, and should also provide a high-contrast instrument signature, making it easy to pick out the instrument in the MR image.\textsuperscript{22} A number of approaches have been developed for depicting vascular instruments by MRI. Active device tracking is accomplished by incorporating small RF receiver coils or antennas into the tip or distal end of a catheter device, which are connected to the receiver ports of the MR scanner with miniaturised

![Figure 6](image_url)  
(A) Pre-interventional 3D CE MRA (anterior–posterior projection) showing true and false lumen (arrowheads). (B) Corresponding contrast-enhanced 3D MRA after stent-graft placement showing that the false lumen (arrowheads) is completely obliterated.

![Figure 7](image_url)  
(A and B) Pre-interventional high-resolution MRI (TrueFISP retro) in axial orientation showing dissection of the thoracic (A) and abdominal aorta (B), with true and false lumens (+) and the undulating dissection flap. (C and D) Corresponding post-interventional MRI (post-contrast T1-weighted 3D VIBE) showing the stent-graft within the true lumen (C) while the false lumen is completely thrombosed (+). False lumen thrombosis (+) extends down to the abdominal aorta. (E and F) Corresponding macroscopic slices at the level of the in vivo stent-graft position (E, stent-graft removed) and at the level of the abdominal aorta (F) confirming complete thrombosis (+) of the false lumen (FL).
coaxial cables running through the catheter body. The use of active catheter tracking techniques may be potentially hazardous for the patient as long as no safety-tested and commercially available active devices are available. In contrast, passive device tracking by MRI uses metal-induced susceptibility artifacts of the interventional instrument for visualisation. Passive tracking requires no hardware or instrument modifications and thus appears to be promising in terms of potential clinical applications. However, passive visualisation requires MR-compatible instruments with satisfactory susceptibility artifacts. The artifact has to allow adequate visualisation of the dimensions of the interventional device in relation to the surrounding tissue (i.e. aortic lumen), but should not obscure relevant parts of the FOV. The artifact should be as small as possible while maintaining adequate conspicuity. The passive commercial stent-grafts used in the experiments of Raman et al. were difficult to visualise with MRI, limiting operator confidence in positioning and deployment. Home-made active stent-grafts were found to facilitate device visualisation and thus positioning. On the basis of a previous comprehensive in vitro evaluation of six current thoracic aortic stent-graft devices, a nitinol-based endoprosthesis, which in combination with its delivery system produced the least artifacts, was chosen for the present experiments. As shown by the present study, the artifact of the device did not obscure visualisation of the thin and undulating dissection lamella. Therefore, rtMRI allowed adequate visualisation of the delivery device position in relation to the true or false lumens. Verification of true lumen position of the device is mandatory before stent-graft deployment, but is often difficult by X-ray fluoroscopy alone.

Finally, the occurrence of non-communicating, subadventitial experimental dissections of the descending thoracic aorta, probably due to deep needle penetration, highlights the limitation of catheter-based creation of experimental AD under fluoroscopy. This is because X-ray does not permit differentiation of various aortic layers, thereby providing no guidance with respect to the depth of the needle insertion for creating a tear in the wall. Whether MRI would allow a more reliable and consistent creation of AD, as it allows definitive delineation of the various parts of aortic wall, needs to be determined in future research.

Limitations

In the present experiments, 18-F stent-graft delivery systems were easily navigated to the proximal descending thoracic aorta without the use of guide wires. Continuous monitoring of the delivery system with simultaneous depiction of the aortic anatomy by MRI allowed for safe stent-graft navigation and prevented complications, such as aortic perforation, despite the presence of ADs. However, the chief obstacle to clinical translation of our findings is the current unavailability of guide wires suited for interventional MRI. Localised increases in the RF specific absorption rate near metallic implants are important potential safety hazards associated with MRI examinations. The local electric field can be amplified; especially if the implants are composed of long conducting structures that potentially can couple significantly with the RF transmit energy of the body coil. This might lead to excessive local tissue heating if standing resonant waves are generated, thus rendering conventional metallic guide wires as well as guide wires with a nitinol core incompatible for MR-guided interventions. These resonance effects occur only when the length of wire-like structures or longitudinal implants exceeds one-half of the RF wavelength, that is, around 26 cm for 1.5 T in human tissue. For implants that are small compared with the RF wavelength (e.g. stents, coils, clips, endografts, etc.), RF resonance is considered unlikely. All endografts used in this study were 10 cm in length; consequently, no significant heating of these devices is expected.

We used a rather simple model of AD in healthy, non-atherosclerotic swine. This and more complicated surgical models cannot completely mimic the complex 3D anatomy and tortuosity encountered clinically in patients with AD. However, the expected benefits of detailed soft tissue contrast and 3D representation by MRI may be even more dramatic in these patients. In particular, safe traversal of tortuous vascular access routes, one of the procedural challenges of stent-grafting, might be simplified by using rtMRI to visualise device-related anatomic distortion and to guide operator adjustments.

Conclusions

The present experiments demonstrate that endovascular stent-graft placement for experimental descending AD performed solely under rtMRI guidance is feasible. We used entirely commercially available catheter devices for passive visualisation with no hardware modifications to facilitate MR imaging. MRI provided detailed pre-interventional evaluation of the dissection, satisfactory monitoring of stent-graft navigation, positioning, and successful deployment, as well as immediate anatomical and functional confirmation of treatment success after stent-graft placement that are not available with conventional X-ray. These advantages of MRI are complimentary to its potential advantage against the harmful effects of fluoroscopic guided procedure including radiation exposure and nephrotoxicity of contrast media.
Supplementary material
Supplementary material is available at European Heart Journal online.

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