The Promise of MR for TEVAR and EVAR

Obtaining both force and anatomic imaging and how this might affect endovascular repair.

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Endovascular aortic aneurysm repair (EVAR) has emerged as a potential treatment modality for many patients in the field of vascular surgery. Since the first endovascular procedures were described by Parodi et al[1] in 1991 for abdominal aortic aneurysms (AAAs) and by Dake et al[2] in 1994 for thoracic aortic aneurysms (TEVAR), the number of new endovascular techniques and endovascular devices has been growing exponentially. The endovascular frontier is still developing: more experience is gained with the use of fenestrated and branched endografts, and several new devices have been introduced with new dimensions and characteristics. Endovascular repair is likely to expand its potential even further in the future.

However, the first-choice treatment will be determined by balancing the risks and benefits of the treatment for each individual patient. Endovascular repair is, unfortunately, associated with a relatively high incidence of device-related complications after the procedure, such as endoleaks, graft migration, graft kinking, graft thrombosis, and aortic aneurysm rupture. Many of the patients with these complications need a reintervention, which carries additional risk.[3-6]

Detailed insight into the mechanisms that play a role in the development of these complications is not a simple task, and we cannot predict which patients will develop complications. All patients are requested to undergo several follow-up examinations after the endovascular procedure to detect complications early.

Further improvements in endograft design and more precise understanding of the mechanisms that are involved in the development of complications will possibly expand the applicability of EVAR and TEVAR to patients with a wider range of characteristics. More developments and insight in the pathological mechanisms of complications are not only likely to expand the applicability of EVAR and TEVAR but are also likely to reduce the risk of complications in patients and improve their prognoses.

Since the application of angiography, several new imaging techniques have been introduced, such as CT and MR imaging. MR imaging has undergone important improvements during recent years with regard to both image quality and the range of applications for clinical use and research. This article discusses the potential of MR imaging and how it may change EVAR and TEVAR in the future.

MR IMAGING

MR imaging, which is a noninvasive technique, is considered to be among the safest ways to provide images of the human body. No radiation exposure is required for this high-resolution imaging modality. However, it has some limitations: the scanning time is relatively long, and it is essential that patients do not move during the scan.[7] Some patients may have contraindications for MR, including metallic biomedical implants or devices (such as pacemakers) and claustrophobia. Contrast administration is often not required but may enhance the image quality. The gadolinium-based contrast medium is relatively safe.

Allergic reactions occur in <1% of the patients, and the risk of renal complications is much lower than in patients who are administrated iodinated contrast for conventional angiography or CT.[8] However, systemic nephrogenic sclerosis has been described in recent years as a complication of gadolinium-based contrast, especially in patients with renal insufficiency.

DYNAMIC CINE MR

A sequence of images throughout the cardiac cycle can be obtained by combining the MR images with an ECG that has been made simultaneously during the scanning time. These images have three spatial dimensions and one temporal dimension, the time between the subsequent images. This technique is called dynamic MR imaging or cine MR. Several useful applications of dynamic MR imaging for patients undergoing EVAR and TEVAR or after the procedure have been described and will be discussed.

Preoperative Workup

Gebker et al described two MR techniques that can be used for MR diameter measurements without needing contrast administration.[9] Two noncontrast two-dimensional (2D) techniques (a breath-hold black-blood cardiac-triggered 2D turbo spin echo and a free-breathing noncardiac-triggered 2D-balanced steady-state free precession examination) have been compared with a three-dimensional (3D) contrast-enhanced MR angiography (CE-MRA) examination using the current contrast-enhanced MR imaging standard 3D technique in 100 patients. No significant differences were found between these two MR imaging modalities with regard to diameters of the aorta at several different levels of the thoracic aorta.

Van Herwaarden et al[10] studied aortic wall movement with dynamic MR. There was considerable visible aortic motion during the cardiac cycle, with diameters changing up to 11.5%, especially at the level of the aneurysm neck. AAAs with relatively large distensibility may be at increased risk of proximal endoleak and migration and may possibly benefit from slightly more oversizing than the routinely recommended 10% to 15%.

In addition to endograft sizing, dynamic MR can be used for other purposes in the preoperative workup, as well. Preservation of the artery of Adamkiewicz, a structure that is responsible for the main blood supply of the anterior spinal artery, is important to reduce the risk of
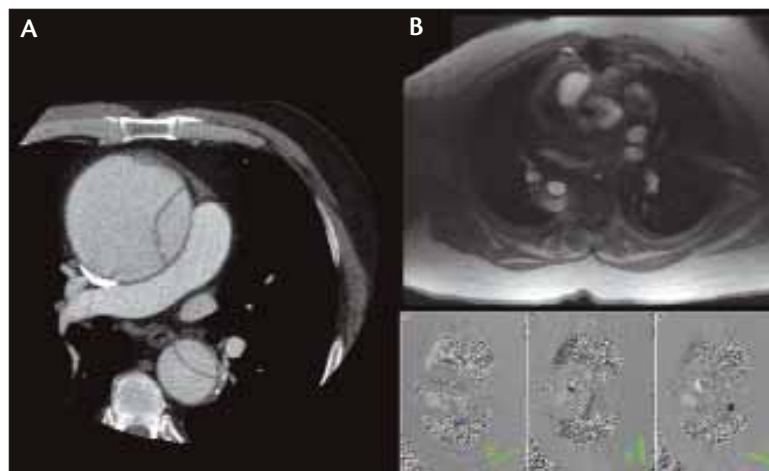
Figure 1. Imaging obtained using a regular gated CT, showing the true and false lumen of a dissected aorta (A). A four-dimensional (4D) MR image, without contrast administration to the patient, showing the true and false lumen of the dissected aorta and the distribution of blood flow velocity for every imaged pixel in the x-, y-, and z-axes (B).

spinal cord ischemia after TEVAR. Hyodoh et al reported a very good sensitivity rate (84%) using dynamic MR for the detection of the artery of Adamkiewicz.[11] The endovascular procedure could subsequently be changed to provide maximum protection of the spinal cord. None of the 42 patients in the study by Hyodoh et al experienced neurological complications after the procedure.

Improved Classification of Endoleaks

Several investigators have shown the advantages of classification of endoleaks using dynamic MR imaging. Van der Laan et al[12] could classify six of 23 patients with endoleaks using dynamic MR, patients who could not be classified with standard MR imaging. Comparable results were presented by Lookstein et al,[13] who showed that dynamic MR is an excellent imaging technique compared with conventional angiography for the classification of endoleaks after endovascular aortic repair. Endovascular aortic repair slightly decreases the aortic wall motion.[14] Many patients with type I endoleaks appear to have different aortic motion compared to patients without endoleaks, especially with regard to the pulsatility of the aortic wall. A change of the normal aortic wall motion was not found for patients with type II endoleaks. A significant difference in aortic wall movement in patients with a type II endoleak was not discovered.

THE PROCEDURE
Real-Time Imaging With MR

Two groups of investigators have shown the feasibility of real-time imaging with MR for endovascular aortic

procedures in experimental settings. Eggebrecht et al[15] showed that three endovascular thoracic devices used nitinol-based stents, and their delivery systems may already be suited for imaging with real-time MR during the procedure.

Guttman et al[16] proceeded even further and performed MR-guided EVAR in swine. Real-time MR offers several interactive features during the procedure, such as color highlighting of the device, adaptive projection techniques, live 3D renderings, and other features. Because real-time MR imaging offers these advantages and is a relatively safe technique, it may become part of the routine endovascular procedure in the future.

Dynamic Imaging After EVAR and TEVAR

A considerable increase of the longitudinal movement of the aortic aneurysm after endovascular stent grafting was found by a Dutch study group; this movement was likely due to downwardly exerted forces.[17] During the cardiac cycle, increased angulation of the endograft was revealed during the systolic phase. This angulation may theoretically worsen the proximal fixation of the graft and result in complications, such as endoleaks, graft migration, and even aortic aneurysm rupture. The gained insight is likely to be valu-

Figure 2. The aortic blood flow, measured with 4D MR in the aorta of a healthy volunteer. The arrows represent both height and direction of the blood-flow velocity for every imaged pixel.

able for design improvement of future stent grafts.

The changes of aortic stiffness and elastic modulus after aortic aneurysm repair has been reported by Van Herwaarden and colleagues.[18] Endovascular AAA repair was associated with more aortic stiffness and a higher elastic modulus. Dynamic MR imaging after EVAR and TEVAR possesses the ability to reveal other mechanisms in the future that may be associated with complications.
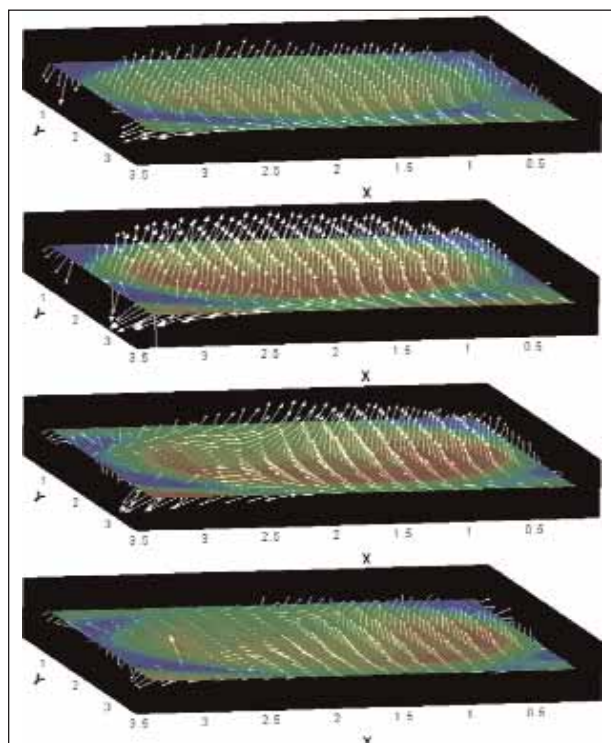
4D Phase-Contrast MR Velocity Mapping

Recent advances in MR imaging make the assessment of 3D blood flow velocities possible.[19-21] Whereas gated CT (Figure 1A) revealed only anatomic information, 4D phase-contrast MR provides both imaging of the anatomy and quantitative assessment of the blood-flow velocities and associated forces in all three spatial dimensions for every imaged pixel (Figure 1B). When the measured blood-flow velocities of the x-, y-, and z-axes are combined, vectors can be calculated that represent the direction and height of the velocity during the heart cycle at each location in the aorta (Figure 2).

Whereas color Doppler has a relatively low resolution and only shows two dimensions, 4D phase-contrast MR velocity mapping offers high-resolution results for all spatial dimensions. If our insight into blood-flow patterns improves, we could predict complications after EVAR and TEVAR, bettering a far more comprehensive manner and potentially reduce the burden of many follow-up examinations, as well as improve the patient prognosis.

Because 3D blood-flow velocities can be obtained for every pixel, wall shear stress can be precisely calculated. Several studies have reported the successful use of 4D phase-contrast MR velocity mapping for assessing blood flow in the aorta.[22,23]

Quantitative analysis of blood-flow velocities, locations, and extent of velocity jets, helices, reverse flow, and turbulence can be obtained in every patient without contraindications for MR imaging. Antegrade and retrograde blood flow is shown in the ascending and proximal descending aorta of healthy subjects. Helical flow streams in the ascending aorta and aortic arch, and flow vortices in the aortic sinuses are normal findings in healthy subjects.[23,24]

Because the force of the aortic blood flow is very high in the aorta, small changes of the normal anatomy can have major influences on the local blood flow. Several investigators have reported their findings from 4D phase-contrast MR-velocity images made in patients with aortic aneurysms. Hope et al described that helices were larger in patients with ascending aortic aneurysms (n=13) than in healthy volunteers.[25] The retrograde flow occurred earlier and lasted longer in the patients with ascending aor-

tic aneurysms. The blood-flow velocity increased from the ascending to the transverse level of the aorta in patients with ascending aortic aneurysms, while the velocity decreased in healthy volunteers. In infrarenal aortic aneurysms, major retrograde blood flow and formation of vortices were seen. The higher the patent lumen, the more retrograde blood flow and vortex formation were detected.[26] One case described 4D phase-contrast MR-velocity mapping after open aortic repair with a Dacron graft.[27] Complex and significantly changed hemodynamics were visualized in the graft. A comparison of blood flow of the aorta and its side branches before and after EVAR and TEVAR has not yet been performed.

CONCLUSION

4D phase-contrast MR velocity is a new, promising, and safe technique with many features. This technique allows physicians to assess hemodynamics before and after EVAR and TEVAR. Application of this promising technique may provide more insight in the mechanisms of disturbed blood flow and complications after endovascular repair. ■

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