Possibilities of transesophageal MRI for assessment of aortic disease: A review

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Abstract

The thoracic aortic wall is a common site of atherosclerotic plaque in humans. Tools for serial, non-invasive assessment of these plaques are of value for addressing gaps in our basic understanding of the biology of plaque rupture and its relationship to atherosclerotic disease progression as well as for monitoring response to anti-atherosclerotic interventions in therapeutic clinical trials. Common approaches to assessment of the wall of the thoracic aorta in vivo are limited. Here we discuss some of the challenges and limitations encountered by conventional techniques and review a novel approach, transesophageal MRI (TEMRI). Initial experiences in applying the TEMRI approach to assessment of aortic morphology and pathology are discussed.

Introduction

Magnetic resonance imaging (MRI) offers several potential advantages over ultrasound or X-ray based imaging for demanding applications such as aortic atherosclerotic plaque imaging. Previous non-invasive MRI approaches have focused on refinement of pulse sequences and surface coils to optimize the signal to noise ratio (SNR) at the vessel wall. Others have recognized the SNR advantage afforded by the use of intravascular RF receivers, but this technology is not yet approved for human subjects. Transesophageal MRI (TEMRI) represents a hybrid approach that in principle affords the advantages of non-invasive MRI with the SNR of invasive MRI but without the need to invade a vascular space. The TEMRI approach was first tested in animal models [1]; subsequently its utility for quantitating thoracic aortic atherosclerosis in comparison with transesophageal echocardiography (TEE) and surface-coil MRI was studied in human subjects [2, 27]. TEMRI compared favorably to surface-coil MRI and TEE for the quantitative assessment of atherosclerotic burden, yielding a higher SNR than the former and a more complete assessment of circumferential extent of disease than the latter [2, 3, 27]. TEMRI is emerging as a valuable tool for high-resolution aortic wall imaging and represents a potential bridge toward truly invasive, intravascular MRI.

The presence and characteristics of atherosclerotic disease of the thoracic aorta may be used to predict cerebrovascular events [4, 5], coronary disease/events [6, 7] and death [4, 7]. In addition, from an investigational standpoint, the thoracic aorta represents a valuable opportunity to study atherosclerotic plaque burden and vulnerability [4–10]. It may possibly provide generalizable observations on the behavior and progression of individual atherosclerotic plaques over time and/or in response to therapeutic interventions.
Technical challenges

Current standard techniques for imaging the thoracic aorta include X-ray computed tomography (CT), MRI, TEE, and contrast aortography. Each of these techniques is limited in some important aspect in its ability to provide detailed structural information from the aortic wall. Standard MRI and CT have lacked adequate resolution for precise characterization of aortic atheromata. TEE allows real time imaging, but with the disadvantages of relatively poor tissue characterization [11] and registration as well as an inability to image the entire aortic wall. This results from both the near field dropout effect of ultrasound and the unreliability of contact between the probe and the esophageal surface in certain patients and at certain anatomic locations, most notably in the region of the aortic arch where the esophagus crosses a major rigid airway.

In contrast aortography, which is generally considered a gold standard for aortic imaging, the aortic wall is not visualized directly [12]. Lesions that protrude to focially displace the contrast agent can be detected indirectly as an absence of contrast, but inferences about the thickness and stiffness of the vessel wall are questionable at best.

Intravascular MR

Intravascular MR provides improved SNR compared to standard MRI at the cost of being invasive [13–16]. Martin and Henkelman [15] used an intraaortic catheter coil for aortic imaging in a porcine model, but the coil was relatively large and required aortic ligation. Recently, Atalar et al. [13] developed a nine French (3 mm diameter) catheter coil designed specifically for intravascular imaging and Correia et al. [17] validated its usefulness for quantitation of atherosclerotic plaque burden and intraplaque composition against histopathology in cadaveric human aortae. Intravascular MRI is emerging as a valuable research tool for studying aortic disease, but its implementation for human studies in vivo will require safety testing in vivo in human beings before it can be used routinely. Without invading the actual aortic vascular space, one may obtain similar information by placing the receiver in an adjacent body structure.

TEMRI and related techniques

The history of placing an RF receiver into a body cavity or structure in order to image an adjacent part of the body by MR is summarized elsewhere [1]. In brief, this approach was applied in 1989 to transrectal imaging of the prostate [18, 19], and later to transvaginal imaging of the vagina and paravaginal structures [20], and transscavicular imaging of the aorta [21]. While the latter approach avoids the need to invade the aorta, it necessitates placement of a large caliber catheter into the inferior vena cava, with associated risks. More recently, my colleagues and I described the development of a small caliber loopless RF receiver probe device designed for esophageal placement and transesophageal imaging of the adjacent aorta [1] (Figure 1). The probe is placed transnasally into the esophagus and interfaces with the MR scanner via external tuning and matching circuitry. The circuitry incorporates high-speed diode switching to decouple the antenna during external RF pulses, yet allows signal reception between pulses. This device was tested in animals with demonstrated advantages for aortic imaging [1] (Figure 2).

TEMRI and aortic atherosclerosis

Previous investigators have demonstrated that aortic atherosclerosis, detected by TEE, predicts coronary atherosclerosis [6, 9, 10]. Fazio et al. [6] used TEE to study a group of 61 patients scheduled for coronary angiography and found 95% and 82% positive and negative predictive values, respectively, for predicting a significant coronary lesion, defined as a 70% stenosis of a major coronary artery or 50% stenosis of the left main coronary artery. Two other groups [9, 10] reported similar findings.

Montgomery et al. [22] used TEE to categorize atheromatous lesions of the thoracic aorta by size and presence of adherent thrombus and then
documented the natural history of these lesions over time. Tomochika et al. [23] imaged aortas in patients with familial hypercholesterolemia, before and after a trial of cholesterol-lowering therapy, using biplane TEE to produce semiquantitative scores of both atheroma burden and circumferential aortic wall stiffness and found a decrease in both after therapy. TEMRI has several potential advantages over TEE in such applications, perhaps the most important of which is that MRI can reveal more lesion detail and information about plaque composition [11, 24–26], which is a strong predictor of plaque stability and therefore clinical events.

Because satisfactory animal models of complex atherosclerotic plaque formation do not exist, and because we felt confident that we could do so with little risk to the study subjects, we proceeded directly to studies in human subjects with the approval of our Institutional Review Board [3].

Figure 1 demonstrates typical scout images obtained by TEMRI in a human subject, used as maps to obtain oblique slices axial to the aorta (aortic short axis slices). Figure 4 is an aortic short
Figure 2. TEMRI from a rabbit. Images are ECG-gated with a 61 ms delay from the detection of the QRS complex, fast spin echo (fse) at 8 cm field of view (FOV), 256 x 256 matrix, flip = 15°. Image A is a 3 mm longitudinal slice through the aorta from the arch to well below the diaphragm parameters: (A) single breath-hold, number of excitations (NEX) 8, repetition time (TR) 600 ms, echo time (TE) 19.6 ms. Images B–D are 3 mm short axis slices at high, middle, and low positions within the descending thoracic aorta (7.8, 5.4, and 4.6 cm from the distal tip of the probe, respectively); (B–D) single breath-hold, NEX 8, TR/TE 600/11.8 ms. In image D, the TEMRI antenna device can be seen in the esophagus at the gastroesophageal junction. In images B and C, the aortic wall can be seen separating lung and aortic blood, demonstrating that this technique can resolve the aortic wall, which in a rabbit is ±0.2 mm thick. Figure appeared in Ref. [1] is reproduced with permission of the publisher. Ao – aorta, Es – esophagus, De – TEMRI antenna device and GEJ – gastroesophageal junction.
axis slice at the level of the descending thoracic aorta in a normal human subject, demonstrating lack of aortic wall thickening. The imaging and display parameters were selected to optimize the gray-scale at the aortic wall for wall thickness measurements using a black-blood technique and a relatively small field of view, contributing to the noisy appearance. Figure 5 is a similar slice at the level of the aortic arch from a patient with a prior stroke, demonstrating aortic atherosclerosis. In an ongoing study, aortic plaque thickness and circumferential extent of plaques are assessed and when possible, compared to similar measurements by TEE as depicted in the schematic shown (Figure 6). Over 20 subjects have been studied by TEMRI and patterns of disease are beginning to

Figure 3. Technique of localizing oblique slices axial to the aorta by scout imaging. A series of coronal images are obtained from anterior (left) to posterior (center). From the slice containing the descending thoracic aorta, a plane is prescribed longitudinal to the aorta (shown by the gray dashed line in the center image). The resulting 'candy cane' view (right) allows perpendicular slices to be prescribed (shown by the gray dashed line in the image on the right), which are necessary for accurate aortic wall thickness measurements. Imaging parameters: SPGR, 32 cm FOV, 10 mm thick, 256 × 256 matrix, TR/TE 50/3.1 ms, NEX 1, without ECG-gating.

Figure 4. Oblique slice axial to the descending thoracic aorta (aortic short axis) obtained by TEMRI in a normal human subject: Imaging parameters: single breath-hold, ECG-gated, fse, echo train length (ETL) 8, 8 cm FOV, 10 mm slice thickness, TE 15 ms, 4 NEX, blood suppression. Ao – aorta.

Figure 5. TEMRI from the distal aortic arch of a 77 year old male patient with a prior history of stroke, demonstrating diffuse atherosclerotic thickening. Imaging parameters: single breath, ECG-gated, fse, blood suppression, 12 cm FOV, matrix size 256, 10 mm thick, TR,TE 1600/15 ms, NEX 4. Ao – aorta.
emerge, for example, smooth regular thickening without tissue heterogeneity vs. irregularly bordered, heterogeneous plaque. Whether morphologic markers of plaque vulnerability to rupture can be measured and modified remains to be determined.

**Limitations of TEMRI**

Every novel technique has limitations and TEMRI is no exception. As opposed to TEE, it is not portable to the patient’s bedside and does not currently allow true real-time imaging. The acquisition cost of an MRI machine compared to a TEE probe and ultrasound machine is considerable. Compared to surface-coil MRI, TEMRI is slightly more invasive and therefore carries more potential risk. In principle, TEMRI can be combined with phased array torso coil MR imaging to further enhance the SNR at the aortic wall. Studies are ongoing to rigorously compare the SNR obtainable at the aortic wall using TEMRI vs. the best available phased array torso coil to determine the incremental benefit of TEMRI over the more conventional MR technique.

**Conclusions**

TEMRI demonstrates potential as an important tool for the assessment of atherosclerotic plaque in the thoracic aorta. Using TEMRI, the entire circumference of the thoracic aorta can be visualized at any desired level and orientation. TEMRI may prove ideal for serial studies given its minimally invasive nature and its suitability for detailed assessment of plaque composition.

**References**


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