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EDITORIAL COMMENT

Getting Closer for High-Resolution Vascular MRI*

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Since the 1980s, investigators have tried to enhance vascular magnetic resonance imaging (MRI) and spectroscopy of deep structures by positioning MRI receiver coils (antennae) inside the body, closer to the tissue of interest (1,2). Unfortunately, intravascular MRI has been largely disappointing because of relatively poor sensitivity profiles of the small catheter antennae and because of motion artifacts.

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In this issue of *iJACC*, the team headed by Paul Bottomley at Johns Hopkins University has elegantly engineered a combination of advances to address some of these limitations (3). They report an "endoscopic" imaging probe that in many ways resembles intravascular ultrasound, achieving a field of view of about a centimeter, a spatial resolution <100 μm, and a frame rate of 2/s or more. The result should prove useful in assessing small structures and atheromata, and in performing MRI-guided interventional procedures.

To appreciate Bottomley's advance requires an appreciation of the challenge. Proton magnetic resonance creates terrific images from minute radio signals. Magnetic resonance images are not acquired directly as a photograph or X-ray pixel matrix, but instead as a frequency spectrum resembling an audio equalizer display. Higher-resolution pictures require sampling a wider range of spatial frequencies, which is time consuming. Unfortunately, motion during these slow acquisitions blurs the pictures. Moreover, imaging small things like blood vessels inside a large body in MRI is especially difficult because the Fourier technique requires taking time to image the entire body and not just the small region of interest. Attempts to speed up this process by reducing the amount of information gathered ("undersampling") suffer from ambiguous encoding of position on spins ("foldover artifact"). Obvious noninvasive approaches to suppress foldover artifact for this high-resolution application—such as blackening ("saturating") structures outside the region of interest, or selectively exciting only the "inner volume" of interest (4)—have been disappointing in moving structures inside the torso.

Intravascular MRI probes can act like a flashlight to detect only nearby tissues. Bottomley's team had noticed earlier (5) that the field of view for intravascular catheters is exponentially larger at 3.0-T than at 1.5-T, in a millimeter-to-centimeter range that is convenient for his application of atherosclerosis imaging. What makes this work compelling is the combination of four critical elements. First, they designed a custom MRI catheter probe that can image a relatively thin "sensitive disk" analogous to the field of view of intravascular ultrasound. To reduce the possibility of heating (a real consideration during rapid imaging at 3.0-T using conductive MRI catheters), they operate their MRI catheter probe in "transmit and receive mode." This allows the radio power used to excite proton spins to be reduced, from the kilowatt range used in standard body-coil excitation, to a subwatt range less likely to heat bystander tissues. Second, from this catheter, they deliver a special adiabatic radiofrequency excitation-pulse waveform that creates a uniform, localized region of excitation. Third, they exploit the narrow sensitivity profile of their local

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MRI catheter probe to reduce the amount of information (number of phase encodes), and therefore the time needed, to create rapid high-resolution images in that narrow field of view. This realizes the promise of noninvasive alternatives to reduce foldover artifact described in the previous text, and may reduce the motion disturbance that has limited previous attempts at local intravascular MRI. Fourth, they integrate simple image control and post-processing steps to create a realistic workflow: intermittent "snap-to" determinations of the position of the moving catheter to ensure the MRI gradients are properly angled for good imaging; cross-correlation of the images to create pictures from the probe point-of-view (which physicians expect); and correction for extra brightness of spins closest to the probe. As they show in vitro, in situ, and in vivo, the resulting pictures are marvelous and fast.

However, 3.0-T has disadvantages compared with lower-field systems. Balanced steady-state-free-precession (SSFP) MRI, the workhorse pulse sequence for interventional MRI, remains poor at 3.0-T compared with 1.5-T. This usually forces 3.0-T interventionists to operate real-time MRI using less-efficient gradient echo techniques that reduce the signal-to-noise ratio benefit of 3.0-T, yet still suffer from the increased specific absorption rate (SAR) and heating at 3.0-T. The conductive MRI catheter probe remains specifically vulnerable to heating during MRI (of the rest of the body) using the body-coil for excitation (2), but here, too, Bottomley has recently reported a promising new "billabong" shield approach (6) to mitigate heating.

Much work remains to miniaturize the reported intravascular MRI probe from the 9-F prototype here, and to optimize MRI scanner protocols that provide high-resolution MRI "endoscopy" images in anatomic context and as part of a clinically relevant workflow. Unfortunately, the coil sensitivity can be expected to degrade with miniaturization.

With the reported tool in hand, one could envision enhanced standalone or contrast-enhanced imaging of atherosclerosis, or lesion planning and assessment during wholly MRI-guided interventional procedures. However, the chief limitation to interventional cardiovascular MRI remains the commercial unavailability of safe and conspicuous MRI catheter devices. We hope this fascinating report brings us one step closer.

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