Magnetic resonance (MR) angiography has revolutionized imaging of pediatric vascular and congenital heart diseases by allowing repeated vascular imaging without the need for ionizing radiation (1,2). Gadolinium-enhanced MR angiography overcame many limitations of the noncontrast techniques (3,4), making thin-slice 3-dimensional (3D) imaging possible without in-plane saturation or slice misregistration artifacts. As scanner technology improved, short-echo-time 3D gadolinium-enhanced acquisitions (using phase encoding for 2 dimensions) reduced flow artifacts and reduced artifacts from surgical clips, stents, sternal wires, embolization coils, and other ferromagnetic hardware commonly found in congenital heart disease patients. The 3D acquisition can have a single center of k-space for capturing the brief arterial phase of a gadolinium bolus injection that is shorter than the scan duration. Alternatively, the center of k-space can be repeated multiple times (5) or even sampled with every repetition time using projection or spiral imaging (6,7) to obtain time-resolved MR angiography at temporal resolutions that are faster than what is possible based on the desired spatial resolution.

However, gadolinium-enhanced MR angiography still has limitations. Timing the gadolinium bolus for a perfect arterial phase can be challenging even with fluoro-triggering (8,9) or automated bolus triggering (10,11). Timing is especially problematic in the chest, where pulmonary arteries, pulmonary veins, aorta, and upper and lower extremity veins all enhance at different times. This creates a high likelihood of ringing or Maki artifact in at least 1 set of vessels from excessive enhancement of low spatial frequency lines of k-space relative to the center of k-space (12). After 1 large bolus of gadolinium, redistribution of gadolinium into the tissues limits the utility of additional injections. The brief duration of the arterial phase places a finite limit on the scan duration, thereby limiting the maximum resolution and spatial coverage. Although parallel imaging has expanded spatial resolution and coverage of gadolinium-enhanced MR angiography, there is a signal-to-noise ratio penalty related to the parallelization g-factor that cannot be compensated for by the improved signal-to-noise ratio from the gadolinium when g-factors are large. The addition of electrocardiographic (ECG) gating has been shown to significantly improve the sharpness of the ascending aorta, a portion of the aorta that is subject to a great deal of blurring caused by cardiac motion (13), but this also increases scan duration or sacrifices resolution.

In this issue of *JACC: Cardiovascular Imaging*, Naehle et al. (14) describe a major advance in pediatric MR angiography using a blood pool contrast agent, gadofosveset trisodium, which has just become available in U.S. The authors combine an arterial-phase contrast-enhanced MR angiography together with longer, higher-resolution, free-breathing navigator-gated, steady-state MR angiography in the blood pool phase. Their data show improvements in vessel sharpness and reduction in artifacts on steady-state blood pool imaging, with additional clinical information identified in 20% of patients on gadofosveset blood pool phase
images compared with first-pass imaging. The additional information regarding venous anatomy and coronary ostia was of particular clinical importance. Many factors likely contributed to the increased image quality, including the high relaxivity and blood pool distribution of the gadofosveset trisodium as well as the longer scan duration and ECG gating. The utility in this 8- to 18-year-old population suggests that the technique has great promise in infants and younger children as well.

Gadofosveset trisodium is a gadolinium chelate that reversibly binds to serum albumin (15), similar to gadobenate dimeglumine and gadoxetate disodium but with a higher, approximately 90% binding fraction, such that gadofosveset effectively stays within the blood pool. Albumin binding lowers the rate of molecular tumbling of the gadolinium such that there is better rotational correlation with water protons and a resulting 5- to 6-fold greater R1 relaxivity at 1.5-T (16) compared with conventional gadolinium chelates. This greater relaxivity allows gadofosvet to be administered at a 3-fold lower dose while still conferring greater vascular enhancement. This is especially useful in infants because their cardiac output is high relative to their body mass, and contrast agent volumes are small (1 ml or less in newborns) so contrast is more diluted in the arterial phase.

With regard to nephrogenic systemic fibrosis (NSF), the slower excretion time might be expected to increase risk. On the other hand, it is administered at a lower dose, has less access to the interstitial space, 10% biliary excretion, and an ionic molecular structure, all of which might be expected to decrease the probability of NSF. Thus far, no cases of NSF have been reported with gadofosveset trisodium, despite being on the market 5 years in Europe and entering the U.S. market in January 2010, with an estimated number of doses in excess of 100,000. There is also an emerging theory that infants and toddlers are not susceptible to NSF. To date, there have been no reported NSF cases with any gadolinium agent in patients at an age younger than 6 years (17), despite extensive use of high-dose gadolinium in infants and neonates, who may have immature kidneys with low glomerular filtration rates (18).

The MR angiograms presented by Naehle et al. (14) are already excellent using existing MR imaging technology. However, recent advances in MR pulse sequencing and image reconstruction offer the potential to further expand on this approach. In particular, cartesian projection reconstruction or vastly undersampled isotropic projection, spiral, and other techniques that oversample the center of k-space can be combined with golden ratio (19) sampling to seamlessly transition from lower-resolution arterial-phase scans to super-high-resolution steady-state phase scans using sliding window reconstructions. With this approach, one can decide retrospectively when arterial, venous, and steady-state phases are occurring, so that bolus timing is no longer necessary. Respiratory and cardiac self-gating (20) may allow respiratory and cardiac motions to be handled without the need for placing electrodes and other monitoring devices on the patient. Post-processing techniques that use information from the high-resolution steady-state phase to constrain the arterial phase may allow an acceleration of time-resolved MR angiography without the normal tradeoff in spatial resolution (21). Naehle et al. (14) have demonstrated that blood pooling with longer higher-resolution ECG-gated steady-state MR angiography is a major advance in the long and continuing series that has revolutionized noninvasive vascular imaging and will continue to do so.

Reprint requests and correspondence: Dr. Martin R. Prince, Columbia University Medical Center, 416 East 55th Street, New York, New York 10022. E-mail: map2008@med.cornell.edu.

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