Magnetic resonance imaging (MRI) has long been recognized as a useful technique for guiding diagnostic and therapeutic procedures. Biopsies have been guided by MRI since the 1980s; neurosurgery followed soon thereafter. Excellent soft tissue contrast and accurate spatial localization and display in 3 dimensions were particular advantages of MRI over other modalities in neurological and body imaging. The application of MRI to cardiovascular interventions, however, has been much slower because of the technical challenges related mainly to cardiac motion. More recently, experimental work in animal models of acquired and congenital heart disease has demonstrated the feasibility of MRI-guided interventional cardiac catheterization. In 2003, Razavi et al published the first clinical experience with cardiac catheterization aided by MRI in 16 children and adults with congenital heart disease. In this issue of Circulation, Krueger and colleagues report on extending this concept to another clinical application: MRI-guided balloon angioplasty of aortic coarctation. Using commercially available catheters filled with a diluted solution of iron oxide particles, a homemade nonmetallic guidewire, and passive catheter tracking, the procedure was judged technically successful in all of the 5 patients in whom it was attempted.

The experience reported by Krueger et al highlights a familiar reality for pediatric cardiologists. Because most equipment is designed for adults, pediatric cardiologists frequently operate in a world of imperfect tools, bedside modifications of equipment, and off-label use of devices and diagnostic techniques. Most of the tools used to perform the procedure described in this report were not designed for MRI guidance of catheter intervention in children with congenital heart disease. The catheter equipment and catheterization technique required substantial modifications, and the MRI equipment was similar to that used for general imaging of any body part, thus significantly limiting access to the patient, especially if the patient is a small child. This reality has implications for the safety and efficacy of MRI-guided catheter interventions in children with congenital heart disease.

From an interventional catheterization standpoint, the authors have selected an excellent model for MRI-guided angioplasty, one that minimizes the need for specialized equipment. The thoracic aorta is easily approached and cannulated with little catheter manipulation; the vessel is large and has generally predictable anatomy; and beyond infancy, patients are usually healthy. In the 5 cases described, the initial passage of a catheter through the obstruction was performed with standard equipment in the catheterization laboratory under x-ray guidance. Furthermore, in an attempt to minimize the likelihood of adverse events, the authors chose a conservative dilation strategy. Still, to perform this basic intervention, they had to adapt the procedure significantly. To avoid the use of a standard, metallic guidewire, they developed techniques such as stiffening the catheter shaft with a self-made wire and buttressing it with a long sheath. Using these solutions, they were able to achieve remarkable technical success. However, each of these adaptations has a cost in terms of the efficiency and possibly the safety of the procedure. Ideally, an MRI-safe wire with a sufficiently soft tip and stiff shaft would allow both stabilization and, perhaps more importantly, positional control of the dilating balloon during inflation. Although the combination of nonmetallic guidewire and long sheath serves the purpose for this intervention, it sacrifices control and, as such, the ability of the catheterizer to respond to the imaging information in a useful way. This limitation will likely hinder interventions in patients with more complex anatomy in whom maximal flexibility and control of catheter manipulation are required.

Given that any modification of an established therapy must demonstrate a favorable balance between risks and cost on one hand and benefits on the other, it is important to question what potential benefits, if any, MRI brings to the field of pediatric cardiac catheterization. Reduction or elimination of exposure to ionizing radiation is an immediate tangible benefit. There is a growing body of evidence that exposure to ionizing radiation from medical procedures is associated with an increased risk of cancer. Importantly, infants and children are especially vulnerable because the lifetime cancer risk increases exponentially as age at exposure decreases. Moreover, a recent report by the National Research Council stated, “A comprehensive review of available biological and biophysical data supports a ‘linear-no-threshold’ (LNT) risk model—that the risk of cancer proceeds in a linear fashion at low doses without a threshold and that the smallest dose has the potential to cause a small increase in risk to humans.”

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Thus, in the context of pediatric cardiac catheterization, any reduction in radiation exposure is potentially beneficial.

Another area in which MRI can be beneficial during cardiac catheterization is providing information that is not usually obtained by standard techniques. In the case of transcatheter therapy of aortic coarctation (balloon dilation or stent), detailed evaluation of the affected aortic wall compliance and morphology before the intervention can guide the choice of balloon or stent type and size. After the intervention, high-resolution imaging of the nature and extent of aortic wall injury can be helpful in guiding the decision about further intervention. Notably, such information was not obtained in the study of Krueger et al. In this and in other diagnostic and interventional procedures, the ability to measure blood flow, to image changes to soft tissues (eg, radiofrequency or thermal damage during electrophysiological procedures), and to guide transcatheter delivery of stem cells and other therapeutic agents adds to the list of potential advantages of MRI in the interventional arena.

The road ahead to successful integration of MRI and diagnostic and interventional cardiac catheterization is long and challenging. To progress from the successful proof of concept demonstrated by Razavi et al and Krueger et al to safe and effective clinical application, the diagnostic and interventional cardiac suite of the future must be designed from the ground up. To supplant x-ray angiography, MRI will need not only to provide excellent real-time imaging but also to do so in a way that does not diminish the ability of the catheterizer and anesthesiologist to respond appropriately to unpredictable or adverse events. To achieve that goal, the MRI scanner must allow direct and ready access to the patient; imaging coils must be developed specifically for infants and children; and catheters, guidewires, stents, occluding devices, and other equipment used during the course of the procedure must all be MRI safe. Furthermore, MR image acquisition, reconstruction, and display, as well as the versatility and ease of image manipulation, must improve. In addition to MRI, the diagnostic and interventional cardiac suite of the future should integrate other imaging modalities (eg, ultrasound and newer technologies) in a seamless way that minimizes the need to transfer patients from one area to another and that maximizes patient safety. Clinicians must adapt to operating in a new environment and develop and practice routines that minimize the likelihood of accidents related to operating in the vicinity of a strong magnetic field, which is always on. Finally, clinicians will have to continuously and rigorously evaluate the balance between the risks and costs of these technological advances and their efficacy and clinical benefits.

For these goals to be realized, there must be a concerted effort and close collaboration between industry, granting agencies, scientists, and clinicians. Real progress will require major investments, which may not be profitable in the short run. In the long run, however, it is highly likely that MRI-guided cardiac catheterization will benefit patients with congenital and acquired pediatric heart disease.

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Disclosures

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