Exercise Magnetic Resonance Imaging Is a Gas

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Magnetic resonance imaging (MRI) is particularly valuable in the assessment of diseases that affect the right heart. Concomitant physiological provocation may unmask latent pathology and provide incremental information to inform prognosis and guide therapy.\(^1,2\) For example, low-dose dobutamine stress MRI has been shown to unmask right ventricular dysfunction in patients with repaired tetralogy of Fallot.\(^3\) Better than pharmacological stress, exercise-induced changes may aid differentiation of WHO group 1 from group 2 pulmonary hypertension, identification of left heart disease not apparent at rest or inducible pulmonary arterial hypertension, and assessment of right ventricular contractile reserve. MRI permits highly reproducible and accurate measurements of right ventricular volumes and function even during exercise.\(^4\)

In this issue of Circulation: Cardiovascular Imaging, Barber et al\(^5\) elegantly present a new noninvasive cardiovascular assessment modality combining supine ergometer exercise with MRI and respiratory gas analysis. They apply the technique to 3 pediatric cohorts: healthy volunteers, patients with pulmonary arterial hypertension, and patients with repaired tetralogy of Fallot. This study is remarkable in several aspects.

First, the study addresses the underserved pediatric population (mean age just over 12 years). Second, the authors make use of innovative MRI pulse sequences to acquire key physiological, anatomic, and functional MRI data during exercise. Third, the authors and their young patients should be commended for successfully completing a full cardiopulmonary exercise test in the hostile MRI environment. Many people find MRI unpleasant. Imagine having to exercise inside an MRI scanner while wearing a tight-fitting facemask! Acquiring flow and function (phase contrast and cine) MRI data for cardiac output and ventricular volumes usually takes time. The authors surmounted this challenge with an innovative real-time pulse sequence (UNFOLed-SENSE spiral phase contrast) to measure beat-to-beat cardiac output.\(^6\) This is an enviable capability, although the current requirement for manual postprocessing sounds daunting. Hopefully, manual image processing effort can be reduced through further computer automation of segmentation. At other facilities that use commercially available MRI flow pulse sequences, patients would need to exercise at steady state for a few minutes to allow full data acquisition. In this case, multiple cardiac output snapshots using standard phase-contrast sequences should be acquired, using the last snapshot before patient exhaustion for quantification of peak cardiac output. Barber et al\(^2\) used real-time cine imaging (radial k-t SENSE steady-state–free precession) for acquisition of full coverage functional cines in \(\approx 30\) seconds and without breath holding. Indeed, breath holding for cine imaging is not realistic during exercise. However, real-time sequences are widely available that allow diagnostic quality images to be acquired with free breathing, and high-quality ones are now being validated at research centers.\(^7\)

For healthy volunteers and each of the 2 cohorts with right heart disease, the authors described characteristic patterns of anatomic parameters, including cardiac chamber dimensions and septal curvature index; hemodynamic parameters, including cardiac output and pulmonary regurgitant fraction; and metabolic parameters, including oxygen consumption and arteriovenous oxygen content difference. Once established, these different patterns may facilitate diagnosis and guide therapy without the need for invasive catheterization.

It is worth noting that all of the patients in this study were WHO functional class 1 or 2. Patients with more advanced disease and severe symptoms are likely to struggle to exercise for long. It can be difficult to determine the optimal level of exercise for each patient. In this study, patients performed a baseline 6-minute walk test to establish exercise capacity. Once in the MRI scanner, ergometer resistance was increased gradually, and, at the point of exhaustion, resistance was reduced to zero and the patient was asked to continue exercising for as long as possible. This is a smart approach. Although supine exercise may be submaximal, it is almost certainly sufficient to unmask latent symptoms and pathophysiology in patients with advanced disease. All patients in this study exercised to exhaustion achieving a peak respiratory exchange ratio \(\geq 1.1\). In fact, quantifying exercise intensity is perhaps the most important role of continuous respiratory gas analysis in this setting.

The relative diagnostic value of arteriovenous oxygen content, as studied here, versus pulmonary vascular resistance is not clear. It is possible that the addition of a pulmonary artery catheter to measure transpulmonary pressure gradient may afford a more complete physiological assessment. The authors correctly highlight that invasive cardiac catheterization in children usually requires general anesthesia, which precludes exercise. On the other hand, in adults, it is feasible to perform cardiopulmonary exercise testing in an MRI scanner with invasive catheters in situ.\(^8\) Furthermore, catheters can...
be navigated through the cardiac chambers under direct real-time MRI, enabling an entirely radiation-free and MRI-guided catheterization procedure.9

It is important to note that reliable cardiac gating is critical for accurate cardiac output measurement with MRI. The authors report excellent ECG signals during exercise in children. However, in adults, motion-induced ECG noise often completely obscures the ECG signal during exercise in the MRI scanner. In our experience, an invasive arterial waveform is a much more reliable signal. A radial arterial catheter in conjunction with an internal jugular or antecubital pulmonary artery catheter enables comprehensive hemodynamic catheterization and accurate cardiac gating but still permits lower limb exercise.

Ultimately, any new diagnostic modality must demonstrate ability to inform prognosis and guide therapy in specific patient populations and disease processes. For example, at some centers, noninvasive imaging with MRI and echocardiography is considered sufficient to plan surgery in pediatric patients with congenital heart disease, avoiding the need for invasive cardiac catheterization.10 Magnetic resonance augmented cardiopulmonary exercise testing may also offer a noninvasive alternative to cardiac catheterization in selected patients. Barber et al.1 have demonstrated the safety and feasibility of this modality. Now the challenge will be to test the clinical value of this powerful diagnostic tool in other complex cardiovascular diseases.

Disclosures
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References
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