

5D MRI Halves Scan Time for Congenital Heart Disease Imaging

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Cardiac magnetic resonance imaging (MRI) remains the gold standard for comprehensive assessment of congenital heart disease (CHD), offering unparalleled detail in anatomy, function, and flow. But the lengthy scan times, often requiring sedation for pediatric patients and breath-holds for adults, present a substantial barrier to its widespread utility and patient compliance. This new 5D MRI approach aims to address these critical limitations, promising faster, more accessible imaging. Data supporting this approach is available in the peer-reviewed literature.

KEY TAKEAWAYS

- **The Pivot:** A 5D MRI technique eliminates the need for breath-holds and significantly shortens scan times for cardiac imaging in CHD.
- **The Data:** Scan duration decreased by approximately 50% compared to conventional 2D cine MRI sequences.
- **The Action:** Clinicians should consider advocating for the integration of 5D MRI into cardiac imaging protocols for CHD patients, particularly those with compliance challenges.

Congenital heart disease encompasses a broad spectrum of structural and functional abnormalities present at birth, affecting millions globally. Accurate, non-invasive imaging is paramount for diagnosis, surgical planning, and long-term surveillance, guiding management decisions that span a patient's lifetime. Cardiac MRI provides a wealth of information, from ventricular volumes and ejection fractions to valvular regurgitation and shunt quantification, all without ionising radiation. But its inherent slowness, demanding patient cooperation for extended periods and precise breath-holding, often necessitates general anesthesia for infants and young children, adding risk and cost. For adults, repeated breath-holds can be challenging, especially in those with compromised respiratory function or arrhythmias, frequently leading to suboptimal image quality or incomplete studies.

Conventional cardiac MRI sequences, particularly 2D cine imaging, acquire data sequentially, requiring multiple breath-holds to cover the entire heart. Each slice acquisition is typically gated to the electrocardiogram (ECG) to capture cardiac motion, but respiratory motion remains a significant confounder. Patients with CHD often have complex anatomies, requiring numerous slices and views, which further prolongs the examination. The clinical need for a faster, more robust imaging solution that maintains diagnostic fidelity has been a persistent challenge in pediatric and adult congenital cardiology.

A New Dimension in Cardiac Imaging

The 5D MRI technique, sometimes referred to as 'free-running' or 'self-navigated' cardiac MRI, represents a significant methodological departure from traditional approaches. Instead of acquiring data in discrete 2D slices with strict breath-hold commands, this method continuously acquires data over an extended period, typically several minutes, without any respiratory or cardiac gating signals applied during acquisition. The '5D' nomenclature refers to the three spatial dimensions (x, y, z) plus cardiac motion and respiratory motion, which are subsequently extracted from the continuously acquired raw data using advanced reconstruction algorithms. This approach fundamentally eliminates the need for patient cooperation regarding breath-holds, making it particularly advantageous for pediatric patients, sedated individuals, or those with irregular breathing patterns.

The underlying principle involves oversampling k-space data and then employing sophisticated motion-resolved reconstruction techniques. These algorithms retrospectively sort the acquired data into different cardiac and respiratory phases. For instance, a typical reconstruction might involve sorting data into 20 cardiac phases and 10 respiratory phases, effectively creating a 4D dataset (3D space + cardiac motion) for each respiratory state. This allows for the selection of optimal respiratory phases for image reconstruction, or even the creation of respiratory-motion-corrected images. The continuous acquisition also means that more data is available for reconstruction, potentially leading to higher signal-to-noise ratios and improved image quality, even in the presence of motion.

In a recent evaluation of this technique, a cohort of patients with various forms of congenital heart disease underwent cardiac MRI using both conventional 2D cine sequences and the novel 5D free-running approach. The primary objective was to compare scan efficiency and image quality. The patient population included both adults and children, reflecting the broad demographic affected by CHD. Specific diagnoses ranged from simple shunts to complex single-ventricle physiologies, ensuring a representative sample of the clinical challenges faced in this field. All patients provided informed consent, or parental consent was obtained for minors, with institutional review board approval for the study protocol. The acquisition protocol for the 5D MRI involved a single, continuous scan lasting approximately 5-7 minutes, during which patients were instructed to breathe normally. This contrasted sharply with the conventional protocol, which typically involved 10-15 separate breath-holds, each lasting 10-20 seconds, for a total scan time often exceeding 30-45 minutes for comprehensive cardiac assessment. Image quality was assessed by two independent, blinded expert readers using a standardised scoring system that evaluated factors such as image sharpness, presence of artifacts, and delineation of cardiac structures. Quantitative metrics, including ventricular volumes and ejection fractions, were also derived from both sets of images and compared.

The most striking finding was the substantial reduction in total scan time. The 5D MRI sequence reduced the acquisition time for comprehensive cardiac assessment by approximately 50% compared to the conventional 2D cine sequences. For a typical study, this translated to a reduction from 30-45 minutes down to 15-20 minutes of actual imaging time. This efficiency gain directly impacts patient comfort and throughput, particularly in busy clinical settings. The elimination of breath-holds was a key factor in this time saving, as it removed the pauses and repetitions often associated with patient non-compliance or suboptimal breath-hold execution.

Image quality assessments revealed that the 5D MRI technique produced diagnostic images comparable to, and in some cases superior to, conventional methods. The mean image quality score for the 5D technique was 4.2 out of 5, compared to 3.8 out of 5 for 2D cine ($P=.01$). This improvement was particularly noticeable in patients who struggled with breath-holding during the conventional scan, where motion artifacts were significantly reduced in the 5D images.

The ability to retrospectively correct for respiratory motion meant that even patients with irregular breathing patterns yielded high-quality images, a scenario where traditional methods often fail.

Quantitative measurements of left ventricular ejection fraction (LVEF) and end-diastolic volume (LVEDV) showed strong agreement between the two techniques. The mean LVEF measured by 5D MRI was 58.3%, compared to 57.9% by 2D cine ($P=.12$), indicating no statistically significant difference in these critical functional parameters. Similarly, LVEDV measurements were highly correlated ($r=0.92$; $P<.001$). The clinical implications of this efficiency gain are considerable. For pediatric patients, reducing scan time often means reducing or eliminating the need for general anesthesia. This carries substantial benefits, including lower procedural risks, faster recovery times, and reduced healthcare costs. For adult patients, the removal of breath-hold requirements alleviates patient burden, improves comfort, and can lead to a higher success rate for complete studies, especially in those with comorbidities like pulmonary hypertension or chronic lung disease. The technique also shows promise for patients with arrhythmias, as the continuous acquisition allows for retrospective cardiac gating, potentially mitigating artifacts caused by irregular heartbeats.

Still, the 5D MRI technique is not without its complexities. The reconstruction algorithms are computationally intensive, requiring significant post-processing power and specialised software. This can add to the workflow burden in a busy radiology department, although advancements in computing power and automated reconstruction pipelines are rapidly addressing this. The acquisition sequence itself is also more complex to set up initially compared to standard 2D cine, demanding a higher level of technical expertise from MRI technologists. Training and standardisation of protocols will be essential for widespread adoption.

The field also needs further validation in larger, multicenter studies across a broader range of CHD complexities. While the current evaluation showed promising results, specific subgroups, such as those with highly turbulent flow or very small shunts, may present unique challenges for retrospective motion correction. The long-term impact on clinical outcomes, such as reduced re-scans or improved diagnostic accuracy leading to better patient management, also warrants prospective investigation. The open-label nature of the image acquisition, though necessary for comparing techniques, is an obvious caveat, but the blinded assessment of image quality helps mitigate potential bias in interpretation.

For a comprehensive overview of cardiac imaging and congenital heart disease management, readers may find the Oxford Handbook of Cardiology an invaluable resource.

CLINICAL IMPLICATIONS

The advent of 5D MRI for congenital heart disease imaging represents a tangible step forward in patient care, particularly for the most vulnerable populations. Reducing scan times by half and eliminating breath-holds means fewer children will require general anesthesia, a clear win for patient safety and resource allocation. This directly addresses a long-standing clinical bottleneck, allowing for more efficient use of expensive MRI scanner time.

For adult congenital heart disease specialists, the improved image quality in non-compliant patients or those with respiratory compromise is equally significant. It means fewer inconclusive scans and more reliable data for complex surgical planning and ongoing surveillance. The consistency of quantitative metrics with established methods provides confidence that this is not merely a faster scan, but one that maintains diagnostic integrity. But the computational demands and the need for specialised training are real hurdles for widespread adoption.

Radiology departments will need to invest in both hardware and personnel education to fully leverage this technology. The industry must also ensure that these advanced reconstruction tools are integrated seamlessly into existing PACS and reporting systems, rather than creating new workflow silos.

The next step is to see this technology move beyond research settings and into routine clinical practice, supported by robust, vendor-agnostic platforms. The benefits for patients, particularly those with complex CHD who face a lifetime of imaging, are too substantial to ignore. This is not a 'nice to have' improvement; it is a fundamental enhancement to a critical diagnostic tool.

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