Cardiac Magnetic Resonance Imaging of Congenital Heart Disease under Sedation: Balancing Efficiency and Image Quality

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Abstract

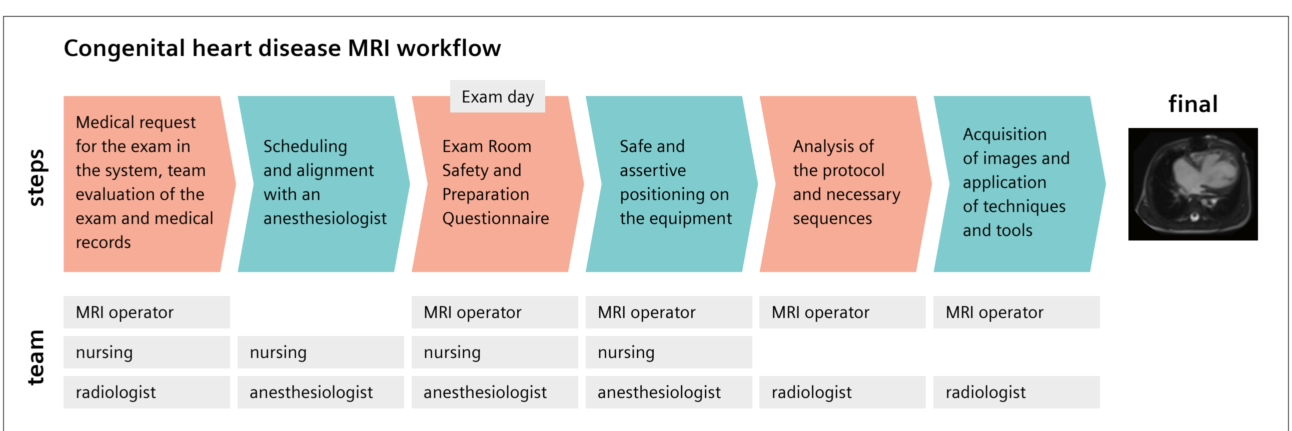
Cardiac magnetic resonance (CMR) is a cornerstone imaging modality for the assessment of congenital heart disease (CHD), providing detailed anatomic and functional information without ionizing radiation. In pediatric[1] patients or those unable to remain still, CMR must often be performed under general anesthesia, which introduces additional complexity and requires meticulous coordination among multidisciplinary teams. This article outlines the workflow and technical strategies adopted at the Heart Institute (InCor), Latin America's leading cardiovascular center, to optimize image quality and procedural efficiency in CMR of CHD performed under sedation. The discussion integrates anesthesia management, nursing preparation, protocol selection, sequence optimization, and emerging technological perspectives. In doing so, it highlights the synergistic role of all professionals involved in achieving diagnostic excellence and patient safety.

Introduction

The Heart Institute (InCor) is one of Latin America's most advanced centers for cardiovascular and pulmonary care, performing approximately 400 magnetic resonance imaging (MRI) studies each month, including about 10 examinations under anesthesia. As a tertiary referral center, InCor manages a wide variety of complex cardiac and pulmonary conditions, particularly congenital heart disease (CHD) – structural abnormalities that alter cardiac morphology and physiology. Early and accurate diagnosis of CHD is essential to guide appropriate therapeutic interventions and improve long-term outcomes.

In pediatric and uncooperative patients, cardiac magnetic resonance (CMR) is typically performed under general anesthesia, with continuous monitoring by a specialized team to ensure ventilation control and procedural safety. CMR is regarded as the gold standard for

[1]*MR scanning has not been established as safe for imaging fetuses and infants less than two years of age. The responsible physician must evaluate the benefits of the MR examination compared to those of other imaging procedures.*



1 Workflow for CMR in congenital heart disease.

comprehensive evaluation of CHD, offering unmatched insights into cardiac anatomy, ventricular function, flow quantification, myocardial tissue characterization, and coronary anatomy. Its value extends beyond diagnosis to include longitudinal follow-up, surgical planning, and postoperative assessment.

This study describes the clinical workflow and technical considerations implemented in pediatric CMR under anesthesia, focusing on strategies to optimize image quality, minimize artifacts, and ensure procedural efficiency. The discussion also emphasizes the critical role of multidisciplinary collaboration across anesthesia, nursing, and imaging teams.

Workflow overview

Upon receipt of the physician's request, the imaging team initiates examination planning. The MRI technologist and the multidisciplinary staff play a pivotal role in ensuring safety, efficiency, and diagnostic quality throughout the process. Each step – from pre-examination preparation to post-processing – requires synchronized communication among all professionals involved.

Anesthesia management

Pediatric CMR under general anesthesia is conducted with a supervising anesthesiologist who is responsible for induction and for maintaining controlled ventilation during image acquisition. Patients arrive in the MRI suite already intubated. The anesthesiologist's primary objective is to maintain hemodynamic stability, avoiding apnea and other complications inherent to complex CHD. Sedation depth is individualized, and neuromuscular blockers may be administered to minimize involuntary movements or spasms that could degrade image quality.

Given the structural and hemodynamic variability in CHD, anesthetic management requires heightened vigilance and individualized dosing. Continuous monitoring of ECG, blood pressure, and pulse oximetry is mandatory, as physiological parameters can fluctuate rapidly. Balanced administration of anesthetic agents and precise real-time monitoring are essential to procedural safety. Collaboration between anesthesia, nursing, and biomedical teams ensures both clinical stability and imaging quality.

Nursing preparation

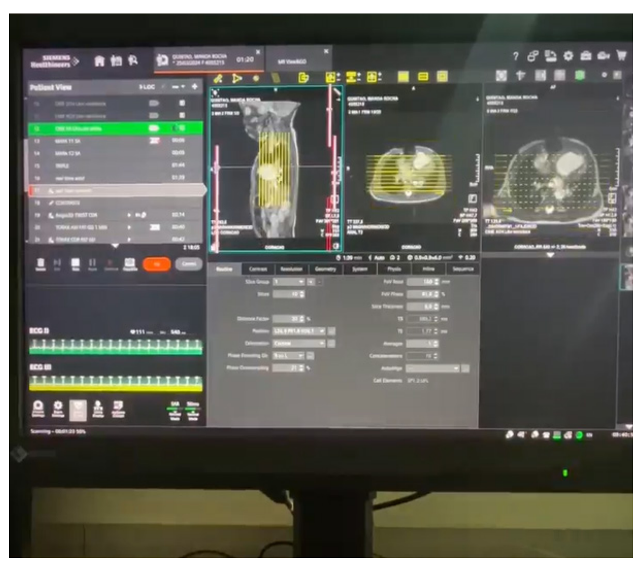
Nursing plays a decisive role in balancing procedural efficiency and image quality. From scheduling to recovery, the team verifies all clinical and logistical requirements – fasting status, allergy history, venous access, and implant[2] safety. On the examination day, nursing staff complete the safety checklist, reinforce instructions to families, monitor vital signs, and ensure correct patient positioning to prevent complications and delays. The nursing contribution combines technical rigor with effective communication and compassionate care, enhancing both workflow fluency and patient experience.

Patient positioning and monitoring

Patients are positioned supine and head-first within the scanner bore. Ventilation tubing and anesthesia lines are secured to prevent accidental displacement during table movement. ECG leads are applied using standardized placement with gauze insulation to prevent skin burns. Monitoring includes MR-compatible ECG, pulse oximetry, capnography, and a pneumatic respiratory cushion to track diaphragmatic motion.

The UltraFlex 18-channel coil is the preferred configuration for pediatric cardiac imaging due to its optimal balance between coverage and signal-to-noise ratio (SNR). Cotton sheets or pads are used to prevent direct coil-skin contact. In infants, additional padding is placed between the coil and chest to reduce pressure. Metallic cuffs or devices near the thorax are isolated with medical tape and positioned outside the imaging field to avoid artifacts.

Throughout the examination, continuous observation of the anesthetized patient is essential, as physiological



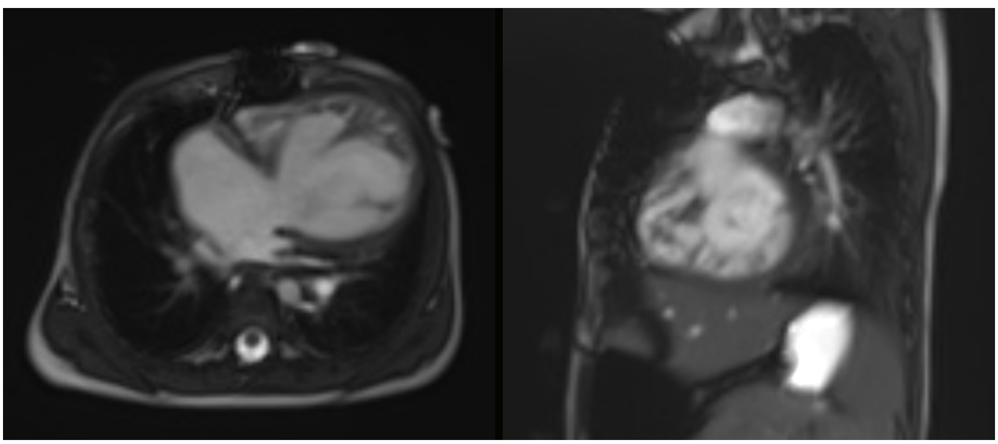
2 CMR acquisition for CHD using our 1.5T MAGNETOM Altea system.

[2]*The MRI restrictions (if any) of the metal implant must be considered prior to patient undergoing MRI exam. MR imaging of patients with metallic implants brings specific risks. However, certain implants are approved by the governing regulatory bodies to be MR conditionally safe. For such implants, the previously mentioned warning may not be applicable. Please contact the implant manufacturer for the specific conditional information. The conditions for MR safety are the responsibility of the implant manufacturer, not of Siemens Healthineers.*

changes can occur abruptly. Specific absorption rate (SAR), body temperature, and vital signs are monitored in real time, in constant communication with the anesthesia team. Short pauses between acquisitions are recommended, even during free-breathing scans, to limit radiofrequency (RF) energy deposition.

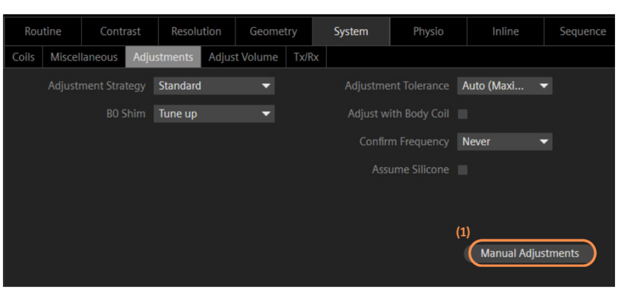
Protocol design and image acquisition

After reviewing the medical request and defining objectives, the technologist registers the patient and organizes the imaging sequences. The standard CMR protocol for CHD includes cine imaging, T1 mapping, time-resolved angiography with interleaved stochastic trajectories (TWIST angiography), late gadolinium enhancement (LGE) imaging, and phase-contrast sequence for flow quantification in major vessels and intracardiac shunts. Protocol customization is guided by the anatomic and functional complexity of each case. The axial T2-weighted sequence is acquired first to delineate cardiac chambers, great vessels, and structural variations, informing subsequent angulations. This approach is particularly relevant in transposition of the great arteries and hypoplastic left heart syndrome, where major morphological deviations require tailored slice planning.

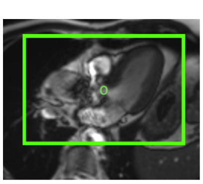


3 Patient with hypoplastic left heart syndrome at 10 months, demonstrating complex CHD anatomy in TRUFI cine sequences (4-chamber and short-axis views).

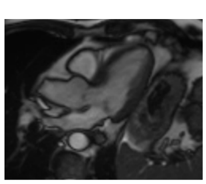
Reducing cine flow artifact by adapting volume shim and using manual adjustments.



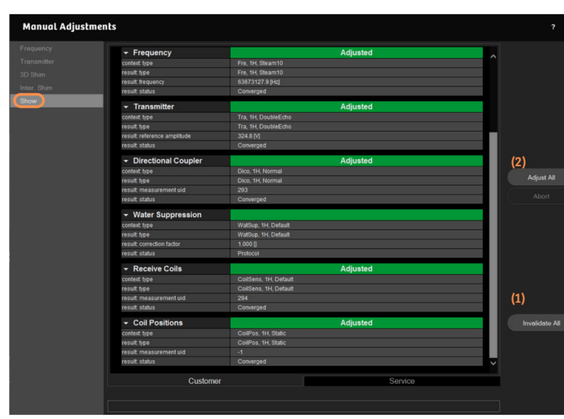
1. In the System tab and the Adjustment subfolder, select this item (1) to adjust the calibration manually. It is important that the adjustment volume (green box) is adjusted to the heart (Example 1).



Example 1
Before



Example 2
After



2. Open the Show tab. Make sure there are no sequences in scan. Invalidate all (1) and then adjust all (2). This generates new calibrations for the region, which reduce the artifact (Example 2).

4 Example of flow artifact correction using manual adjustments and adjustment volume.

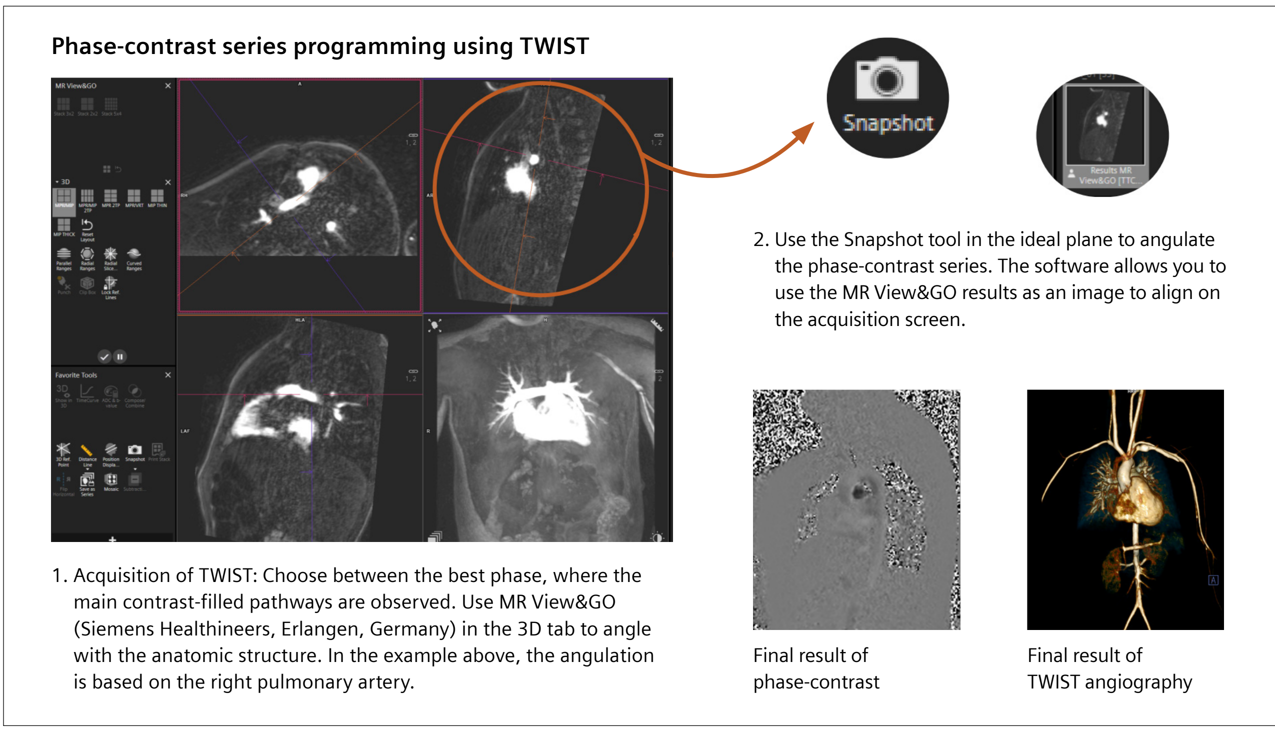
Parameter optimization

In pediatric imaging, a reduced field of view (FOV ≈ 260 mm) is typically required. To compensate for SNR loss, parameters such as phase resolution, bandwidth, and matrix size are optimized. Respiratory motion, inevitable under anesthesia, is mitigated by increasing averages – commonly four averages – which improves SNR and overall image quality. A slice thickness of 6 mm and a 20% gap are used to achieve detailed anatomic visualization.

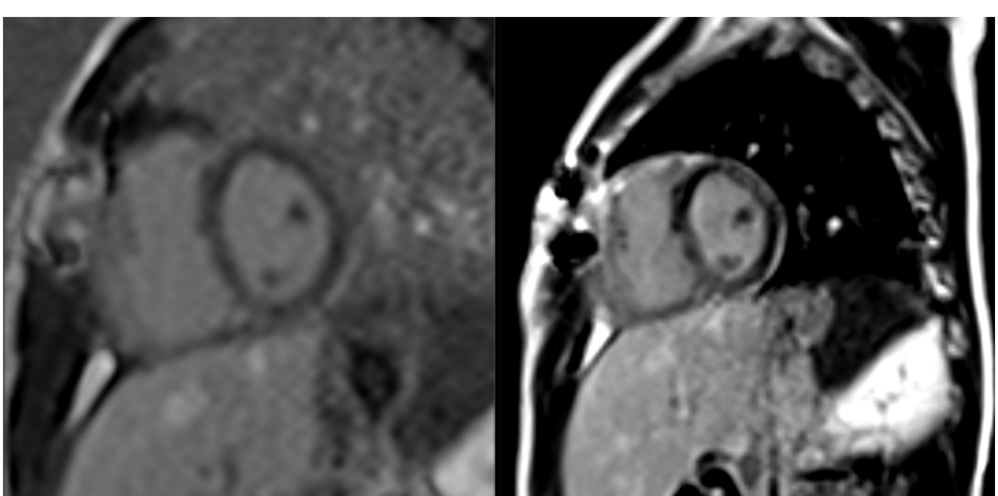
In cases of stenosis or coarctation, high-velocity flow can cause artifacts that affect adjacent structures. Magnetic field homogeneity is improved using manual adjustments and the adjustment volume, especially in cine sequences, to minimize distortions.

Advanced techniques

The TWIST sequence plays a pivotal role in CHD assessment by enabling time-resolved contrast angiography, which guides the planning of phase-contrast flow studies (Fig. 5). Slice angulations are optimized using maximum intensity projection (MIP) reconstructions and 2D snapshots for accurate alignment with target vessels.



5 Coronal TWIST angiography illustrating angulation planning for flow quantification.



6 Short-axis late enhancement in a 6-year-old patient

For LGE imaging, free-breathing phase-sensitive inversion recovery (PSIR) or single-shot sequences are recommended at least five minutes after contrast administration. Although their spatial resolution is lower than high-resolution breath-hold PSIR, they minimize motion artifacts and provide diagnostically adequate images in sedated pediatric patients with variable respiratory stability.

Medical imaging specialists' perspective

High-quality CMR in CHD requires seamless collaboration among anesthesiologists, nurses, technologists, and medical imaging specialists. Each professional contributes uniquely to patient safety and diagnostic precision – from pre-examination preparation and sedation management to image acquisition and interpretation. The integration of clinical and technical expertise ensures a balance between efficiency, image quality, and procedural safety.

The medical imaging specialist role extends beyond image interpretation, encompassing an active partnership with technologists and physicians to ensure appropriate protocol selection and parameter optimization for each specific case.

Customizing acquisition strategies has a decisive impact on image clarity and diagnostic confidence. Modern MRI platforms now provide real-time optimization tools, including arrhythmia detection, dynamic averaging, phase resolution, and adaptive bandwidth, enabling immediate compensation for rhythm irregularities or respiratory motion.

Conclusion

Looking ahead, several technological innovations are beginning to emerge, although they have not yet been integrated into routine clinical practice. Among them, 4D flow MRI stands out for its potential to provide comprehensive and detailed hemodynamic information in patients with congenital heart disease. Soon, artificial intelligence is expected to play a pivotal role in real-time adaptation of CMR examinations – automatically recognizing respiratory patterns in anesthetized patients, integrating anthropometric data, and dynamically adjusting parameters such as averages and field of view. These advances have the potential to increase acquisition efficiency, significantly shorten total scan time, and consequently reduce the duration of sedation.

Reflecting on the practical experience at InCor, it becomes clear that the role of the MRI operator extends far beyond technical execution. It requires a multidirectional and critical perspective – one that considers the patient's physiological variables, clinical stability, and the specific technical challenges inherent to each case. This integrated mindset is essential to ensure diagnostic quality, procedural safety, and excellence in patient care.

In this context, CMR in congenital heart disease transcends its technical boundaries, representing a synthesis of precision, adaptability, and collaboration. When technology and clinical reasoning converge with purpose, CMR becomes not only a diagnostic tool but a true instrument of care, reaffirming its vital role in advancing cardiovascular medicine.

References

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