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Integration of 4D-Flow into routine clinical practice of congenital and non-congenital cardiac MRI-18 months experience demonstrating decreased scan times, physician monitoring, and patient breath hold times.

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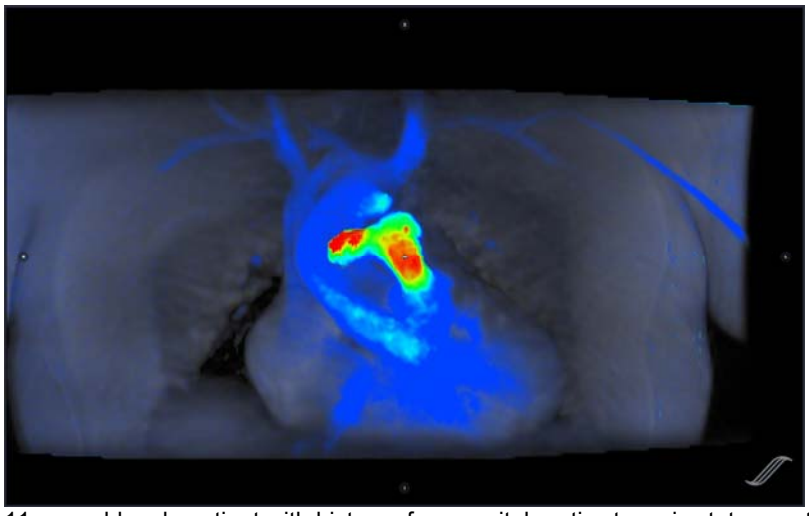
Background: Phase Contrast Imaging is paramount for evaluation of flow dynamics in congenital heart disease as well as valvular disease and is a widely accepted technique in routine clinical practice. Traditional 2D phase contrast imaging is a time-consuming process that requires constant physician monitoring, advanced technologist training, and repetitive scans most commonly requiring patient breath holding. More recent technological advancements in 3D-phase contrast imaging capable of cardiac-phase-resolved whole-volume velocity encoding in three dimensions, referred to as 4D flow, allows for comprehensive flow analysis with ease of acquisition, less physician oversight, and lack of breathholding.

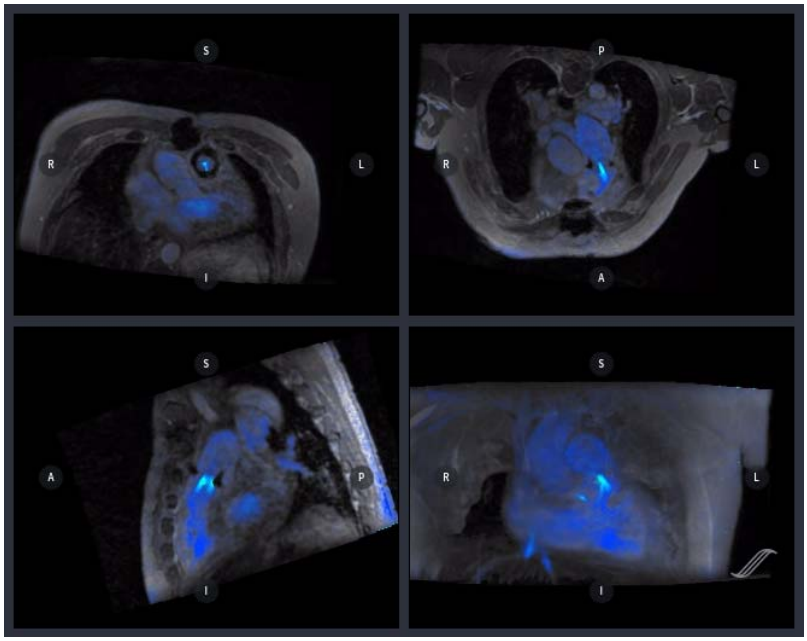
Methods: 237 patients were scanned (189 on a GE 3T Signa Architect system and 48 on a GE 3T 750W) utilizing the 4D-Flow sequence after the administration of intravenous gadolinium or Fereheme. 17 patients received IV Fereheme administered as a 3mg/kg dose diluted as 1 part Fereheme to 4 parts saline via injector at 2cc/sec, among which 1 patient developed diffuse hives after Fereheme injection requiring 50mg IV Benadryl. 215 patients received intravenous Gadovist. 5 patients received dual injection with Gadovist followed by Fereheme. All post-processing (e.g. eddy current phase correction and flow measurements) was performed utilizing Arterys.

Results: Of the 237 patients, the 4D flow sequence failed on 4 patients due to severe cardiac arrhythmia. 4 scans demonstrate aliasing, limiting image processing. The flow analysis successfully processed on the remaining 229 patients. 25 patients had previous cardiac MRI exams utilizing 2D phase contrast. Average total exam time with 4D Flow was 52 minutes. Average total exam time of the prior studies utilizing 2D phase contrast was 71 minutes.

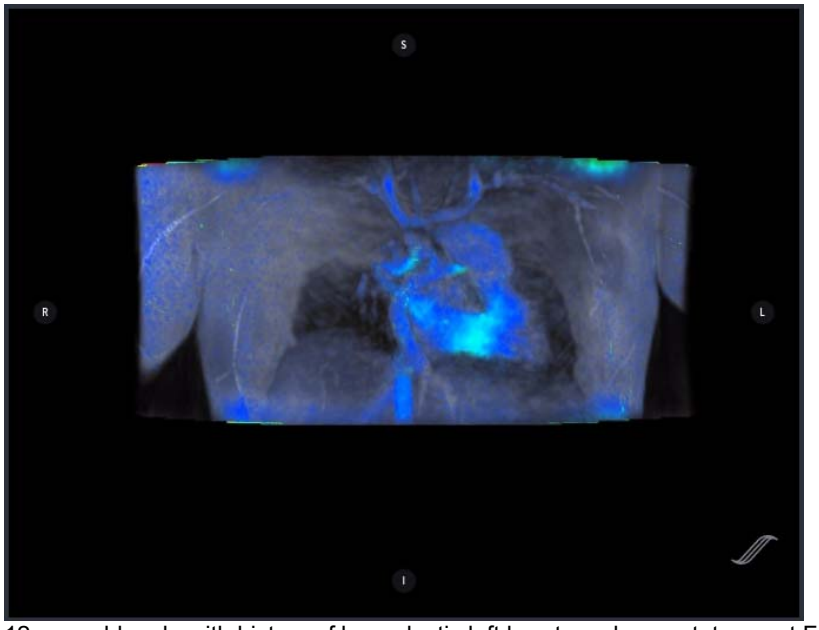
Conclusion: 4D-Flow imaging is an invaluable tool for acquiring flow data, in adult and pediatric congenital heart disease as well as in valvular heart disease, that has been integrated into our routine clinical outpatient practice. We found decreased exam time most notable in our adult and pediatric congenital population and significantly improved flow imaging with reduced failure rate compared to conventional 2D phase contrast. The utilization of Fereheme allows for improved contrast and resolution over Gadovist; however, both agents afford the ability to evaluate flow dynamics and function in the entire volume set. For patients requiring both delayed enhancement imaging and flow, the dual injection protocol is a time effective way to acquire both data sets. The integration of 4D flow with free breathing acquisition has allowed us to image younger patients without anesthesia and reduced the need for physician monitoring.



11 year old male patient with history of congenital aortic stenosis status post Ross procedure. 3D image demonstrates mild pulmonic stenosis. The total imaging time utilizing 4D flow was 36 minutes. The prior examination utilizing 2D phase contrast took 81 minutes for a total time savings of 45 minutes.



56 year old male with history of Tetrology of Fallot status post repair and pulmonic valve replacement 6 years prior. End-systolic images demonstrate mild pulmonic regurgitation and trivial aortic regurgitation. Scan time for this study was 30 minutes. The prior examination required 58 minutes.



12 year old male with history of hypoplastic left heart syndrome status post Fontan. 3D image demonstrating a patent Fontan. This examination required 51 minutes to complete. The prior examination was completed in 55 minutes with limited phase contrast data due to patient's inability to breath hold and motion.

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Utilization of 4D Flow for evaluation of adult congenital heart disease: a case of congenital pulmonary atresia status post repair

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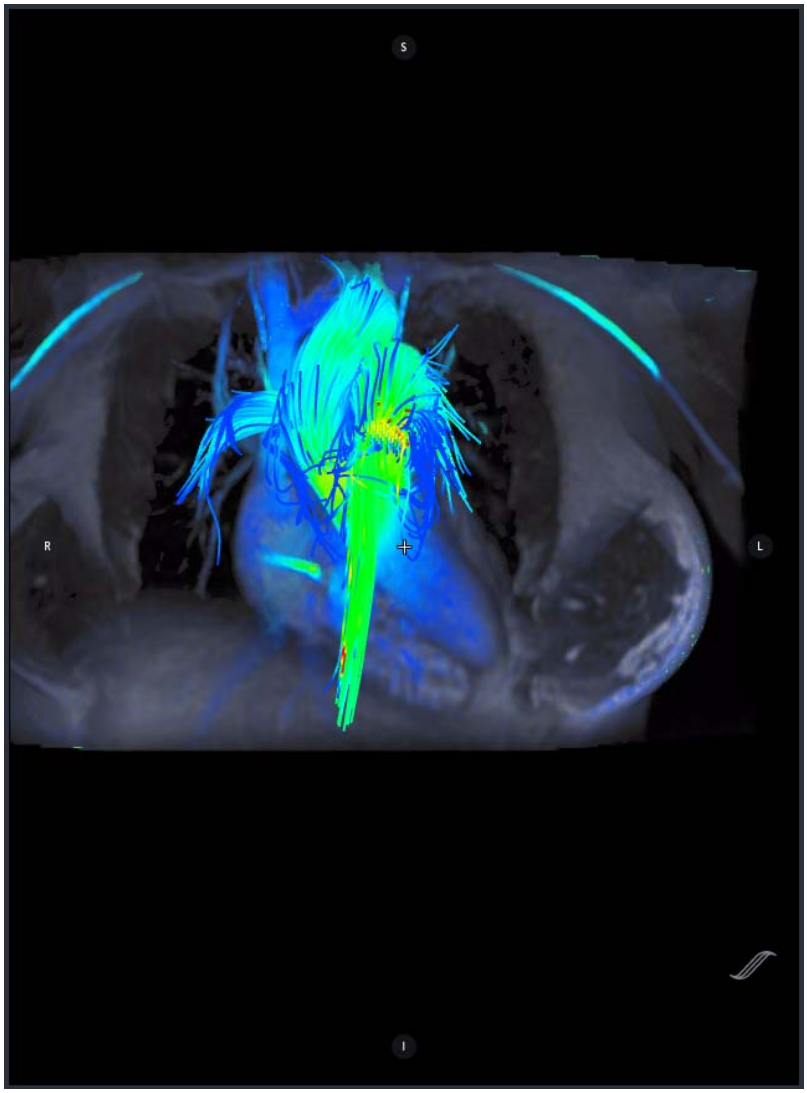
Description of Clinical Presentation: 28 year old female patient with history of congenital pulmonary atresia and neonatal hypoplastic right ventricle status post balloon atrial septectomy, balloon pulmonary valvotomy and BT shunt placement. This was followed by BT shunt takedown, atrial septal patch, and surgical pulmonary valvotomy with excellent results. A recent echocardiogram demonstrated mild right ventricular dilatation, tricuspid regurgitation and pulmonic regurgitation. The patient was sent for cardiac MRI to evaluation ventricular volumes, pulmonary regurgitant fraction, tricuspid regurgitant fraction, central pulmonary artery evaluation, and evaluation of scar.

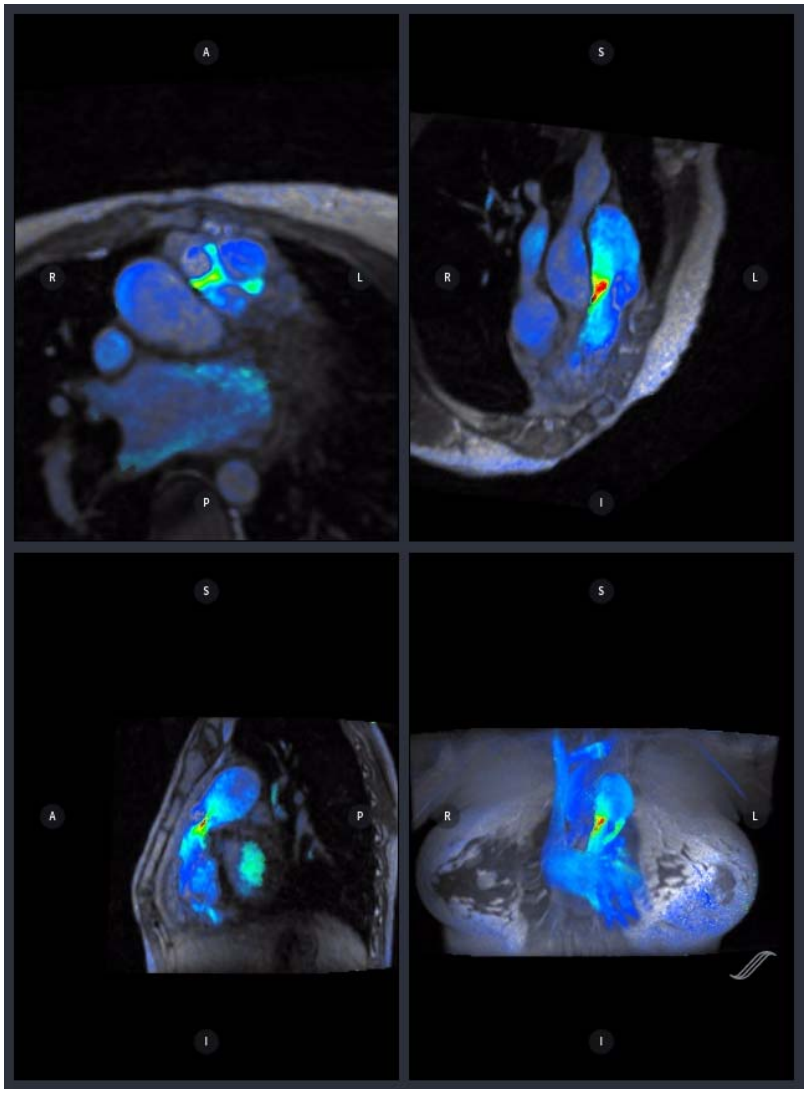
Diagnostic Techniques and Their Most Important Findings: 3T MRI on a GE Signa Architect Magnet was performed utilizing multiplanar Fiesta Imaging, 4D Flow, post-contrast dynamic MRA, and phase sensitive MDE. A dual injection of 20ccs gadobutrol and 5.5ccs (3mg/kg) of Ferumoxytol was utilized. Scan time 41 minutes. Post-processing performed via Arterys. 4D flow produces both magnitude and phase images reconstructable in any 3D plane in a scan time in this patient of 9 minutes 53 seconds. The utilization of a blood pool agent allows for improved contrast and resolution which affords for better myocardial contouring for functional analysis from the 4D Flow sequence. The function was calculated utilizing both traditional short axis fiesta images and the 4D flow sequence demonstrating no significant difference in volume or functional measurements. Pulmonary regurgitant fraction and tricuspid regurgitant fraction were also calculated via 4D Flow.

The images demonstrate mild right ventricular dilatation with an end diastolic volume index of 111 ml/m2. The pulmonary regurgitant fraction was calculated to 22%. The tricuspid regurgitant fraction was calculated to 22% utilizing the valve tracking feature on Arterys. There is no residual pulmonic stenosis or branch pulmonary artery stenosis.

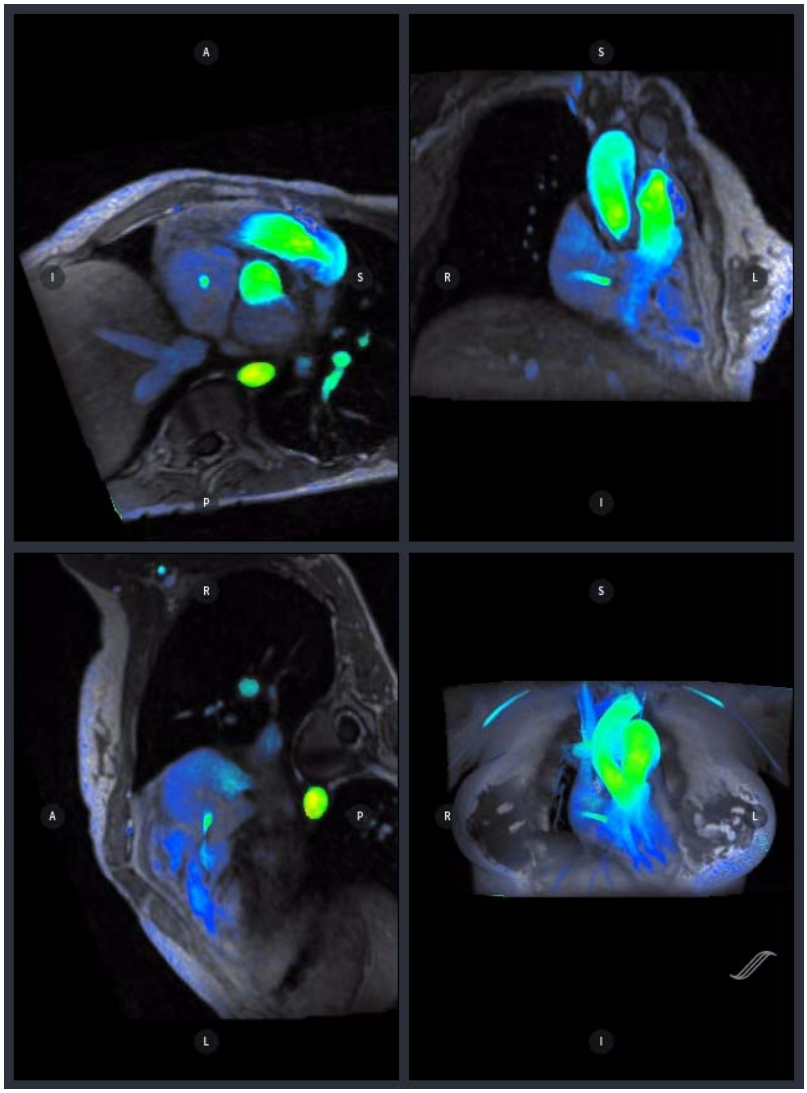
Learning Points from this Case: Utilizing 4D Flow for acquisition of all flow data allows for decreased scan time, requires less physician supervision, requires no breath holding, and allows for accurate flow analysis. In addition, given the whole heart coverage, flow can be measured at any data point in the coverage window after the fact. Although function was calculated utilizing both 4D flow and traditional short axis fiesta images, additional scan time could be saved by only acquiring function via the 4D Flow sequence.



4D flow 3D images demonstrating mild right ventricular dilatation and tricuspid regurgitation.



3D and oblique 4D flow images demonstrate pulmonic regurgitation with a regurgitant fraction of 22%. No significant residual pulmonic stenosis.



3D and oblique 4D flow images demonstrating tricuspid regurgitation with a regurgitant fraction of 22%.