Incorporating time-resolved three-dimensional phase contrast (4D flow) MRI in clinical workflow: initial experiences at a large tertiary care medical center

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Background

Time-resolved three-dimensional phase contrast (4D flow) MRI allows for visualization of three-dimensional cardiovascular anatomy and pulsatile flow with full volumetric coverage in a single, easy to prescribe 3D acquisition. The technique provides comprehensive flow visualization and permits retrospective flow quantification at any user-defined region of interest. [1] To our knowledge, no center has incorporated 4D flow MRI as a part of standard clinical cardiovascular MRI (CMR). The goals of this study include: 1) reporting on the incorporation of 4D flow MRI acquisition and processing as part of clinical CMR workflow and 2) better understanding the clinical impact of 3D flow visualization and retrospective flow quantification derived from 4D flow MRI in CMR.

Methods

Patients referred to Northwestern Memorial Hospital for CMR with relevant clinical indications as judged by an attending radiologist were selected to have 4D flow MRI as a part of standard clinical cardiovascular MRI (CMR). The average 4D flow impact factor (scale 1-4) excluding and including 2D PC was 2.93 +/- 0.77 and 2.80 +/- 0.75, respectively. The average percent difference in quantitative data was 35 +/- 28%. One patient could not be evaluated secondary to aliasing. Average time for 4D flow post-processing was 88.5 +/- 22.5 min. Three clinical cases are shown in Figure 1.

Conclusions

Including 4D flow MRI as part of clinical CMR workflow is feasible and has the potential to impact clinical assessment in multiple cardiovascular pathologies. The ability to evaluate flow throughout the acquired 3D volume retrospectively may reduce dependence on time-intensive 2D PC acquisitions while yielding accurate and efficient flow quantification.

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Table 1 Clinical cases with 4D flow imaging requests and results of analysis.

| Clinical indication for 4D flow request                  | Quantitative results requested | 4D results | 2D PC results | Difference (%) | 4D flow alone (excludes 2D PC data) | Case including both 2D PC and 4D flow |
|---------------------------------------------------------|--------------------------------|------------|---------------|----------------|-------------------------------------|-------------------------------------|
| Bicuspid aortic valve, flow pattern interest            | Regurgitant fraction          | 16.57%     | 25%           | 34%            | 3                                   | 2                                   |
| Qp:Qs ratio in patient with VSD                        | Qsp:Qs ratio                  | 1.22       | Not measured  | N/A            | 3                                   | 3                                   |
| Aortic stenosis, flow pattern interest                  | Aortic root peak velocity     | 3.52 m/s   | 3.8 m/s       | 7%             | 2                                   | 3                                   |
| Bicuspid valve, flow pattern interest                   | Aortic root peak velocity     | 2.35 m/s   | Note measured | N/A            | 3                                   | 2                                   |
| Valvular                                                | Regurgitant jet is very eccentric, limiting 2D assessment | 13.36%     | 57%           | 77%            | 2                                   | 3                                   |
| Bicuspid aortic valve, flow pattern interest, aortic regurgitation and stenosis assessment | Regurgitant fraction         | 8.75%      | 34%           | 74%            | 2                                   | 3                                   |
| Aortic root velocity, 2D PC data underestimated velocity | Aortic root peak velocity     | 4.08 m/s   | 3.5 m/s       | 17%            | 4                                   | 4                                   |
| Bicuspid aortic valve, flow pattern interest, aortic regurgitation and stenosis assessment | Regurgitant fraction         | 4.60%      | 15%           | 69%            | 3                                   | 2                                   |
| Aneurysm                                                | Ascending aorta peak velocity | 1.44 m/s   | 1.3 m/s       | 11%            | 3                                   | 2                                   |
| Aortic stenosis and regurgitation assessment            | Regurgitant fraction          | 38%        | 55%           | 31%            | 3                                   | 3                                   |
| Aortic root peak velocity                              |                                 | 3.36 m/s   | 3.8 m/s       | 12%            |                                     |                                     |
| Aortic stenosis and regurgitation assessment            | Aortic root peak velocity     | 3.89 m/s   | 4.0 m/s       | 5%             | 4                                   | 4                                   |
| Case | Description | Comment | Peak Velocity through Pulmonary Anastomis | Peak Velocity through Pulmonary Post-Stenosis | Post-Surgical | Aortic Stenosis and Regurgitation Assessment | Average Qp:Qs Ratio | St dev |
|------|-------------|---------|--------------------------------------------|-----------------------------------------------|--------------|---------------------------------|-----------------|--------|
| 12   | Flow pattern interest, split flow right-left PA | | 2.32 m/s | 1.4 m/s | 66% | 4 | 4 | |
|      | | | 2.70 m/s | 2.5 m/s | 8% | | | |
| Post-surgical | Aortic valve assessment | Ascending aorta peak velocity | Could not measure velocity secondary to aliasing artifact | Not measured | N/A | Not available | Not available | |
| 13   | Aortic valve assessment | | | | | | | |
| 14   | Aortic stenosis and regurgitation assessment | Regurgitant fraction | 4.53% | Data limited by artifact | N/A | 3 | 3 | |
|      | | Aortic root peak velocity | 3.11 m/s | Data limited by artifact | N/A | | | |
| Congenital | Large pulmonary regurgitant fraction by 2D PC | Pulmonary valve regurgitant fraction | 6.41% | 21.5% | 70% | 1 | 2 | |
| 16   | Flow pattern, Qp:Qs | Qp:Qs Ratio | 1.08 | 1 | 8% | 3 | 3 | |
|      | | | 2.93 | 2.80 | | | | |
|      | | St dev | 28.31% | 0.77 | 0.75 | | | |
Reference
1. Markl M, et al. J Cardiovasc MR 2011, 13:7.

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Figure 1 Velocity streamline flow representation in three clinical cases. A. Abnormal pulmonary flow in patient with pulmonary artery stenosis after two heart transplants. Note the helical flow and high velocities after the stenosis directed toward the left pulmonary artery (LPA) and decreased flow towards the right pulmonary artery (RPA). B. Deranged flow along the entire thoracic aorta secondary to bicuspid aortic valve and aortic coarctation. Note high velocity flow jet directed posteriorly with helix formation in the ascending aorta, and high velocity flow jet with helix formation distal to the coarctation. C. Flow abnormalities secondary to severe congenital aortic insufficiency. Note the high velocity systolic flow jet accompanied by swirling flow in the ascending aorta resulting from large volume aortic regurgitation.