Krishnamurthy et al. Journal of Cardiovascular Magnetic Resonance 2014, 16(Suppl 1):W8
http://www.jcmr-online.com/content/16/S1/W8

Journal of Cardiovascular Magnetic Resonance

WORKSHOP PRESENTATION Open Access

Unsupervised free-breathing 3-dimensional imaging of morphology, function and flow in congenital heart disease under 30 minutes: pilot study

Rajesh Krishnamurthy[1*], Ramkumar Krishnamurthy[1], Elijah Bolin[2], LaDonna Malone[1], Myriam E Almeida-Jones[1], Amol Pednekar[3]

From 17th Annual SCMR Scientific Sessions
New Orleans, LA, USA. 16-19 January 2014

Background

Cardiac MRI for congenital heart disease (CHD) is an operator dependent and time-intensive examination requiring real-time decision making regarding choice of sequences, planes, and acquisition parameters to adapt to unique morphological and functional variables in a given patient.

Objective

To evaluate technical feasibility, image quality and quantitative integrity of a free-breathing (FB) protocol following administration of blood pool contrast agent, utilizing 3-dimensional (3D) imaging of morphology, function, and flow without physician supervision in a cohort of patients with CHD.

Methods

Five patients with CHD were included in this pilot study (table 2 in Figure 2). The FB MR studies were performed on a Philips Acheiva 1.5T magnet using a 5-channel phased array coil (see Table 1 in Figure 1) 1. Respiratory synchronized [1], time-resolved MRA 2. Equilibrium phase MRA 3. 3D cine SSFP 4.4D phase contrast (PC) flow imaging 5.3D whole-heart single phase SSFP (coronary) Comparative data was obtained using conventional 2D cine RT SSFP sequences [2] in the VLA, 4 chamber and short axis planes, and 2D PC imaging. Data Analysis: Image quality assessment and quantitative volumetric and flow analysis were performed by three blinded, experienced users. MRA images were graded using a semi-quantitative scale from 1-5 for relevant imaging targets in CHD [1], with 1: excellent, no limitations, and 5: non-diagnostic. The clinical scoring system for 2D and 3D cine SSFP was based on blood-myocardial contrast, endocardial edge definition and inter-slice alignment [2]. Paired t-test analysis was performed on LV and RV volumes obtained by an experienced observer using the same software

Results

All FB 3D sequences were technically feasible in all 5 patients. Average time for completion of 5 FB 3D sequences was 29 minutes. Average score for first-pass MRA was 1.9/5. Average score for equilibrium MRA was 1.3/5. Clinical scores for 2D SSFP were consistently better than 3D-SSFP, but 3D SSFP images were adequate for recognition of pathology in all cases (2D vs 3D: 1.5 ± 0.5 vs 1.6 ± 0.9) and had better inter-slice alignment (1.4 ± 0.5 vs 1 ± 0). Average percentage difference between 2D and 3D cine SSFP volumetric data is shown in table 3, and Figure 2. Comparative flow analysis between 2D PC and 4D PC data revealed broad correlation (Figure 2, table 3) though the stroke volume, forward and backward flows through the aorta were not statistically different ($p > 0.35$; paired Student's t-test)

Conclusions

The free breathing first pass MRA, equilibrium MRA, 3D cine SSFP, and 3D single-phase SSFP exhibit significant clinical utility. We demonstrate the feasibility of performing an observer independent comprehensive CMR in CHD utilizing FB 3D acquisitions for morphology, function and flow within 30 minutes using a 5-channel phased-array coil. Better acquisition hardware (eg., 32 ch coil) will lead to superior image quality.

[1]Radiology, Texas Children's Hospital, Houston, Texas, USA
Full list of author information is available at the end of the article

30 minute Free-Breathing protocol for 3D imaging of morphology, function and flow				
No.	**Imaging Sequence**	**Duration (min)**	**Acquisition Parameters**	**Grading methodology/ 2D vs 3D comparison**
1	3 Plane Localizer	< 2	Multi-slice 2D single phase bSSFP acquisitions, 5 slices each in coronal, saggittal and axial planes; Voxel: 2.5 * 2.5 * 7-8 mm^3 ;	N/A
Contrast (Gadosfosveset) Injection; Dosage - 0.03 mmol/kg; Injection rate - 2-4cc/s using a power injector				
2	First Pass MRA	< 1	Saggittal; 3D spoiled GRE; Voxel: 1.1*1.1*2.4 mm^3; 7-9 dynamics; CENTRA –k-space filling, keyhole: 25%; SENSE: 1.5 -2 (both Phase and Slice Encoding directions)	Qualitative Assessment; 1-5; 1 – Excellent; 5 – Non-Diagnostic
3	Equilibrium MRA	2.5 – 4	~2 minutes after contrast. Coronal; 3D spoiled GRE; Voxel: 0.8 * 0.8 * 1.6 mm^3; ; 1 dynamic; SENSE: 1.5 -2 No. of signal averages- 2;	Qualitative Assessment; 1-5; 1 – Excellent; 5 – Non-Diagnostic
4	Respirator Triggered 3D Cine SSFP	4.5 – 7	Saggittal acquisitions; TR/TE/α = 3/1.5/60°; voxel size: 1.5-1.9 * 1.5-2.1 * 7-8 mm^3 ; SENSE: 1.5 -2 ; CMR[42] used for 3D reconstruction, volumtery; Temp Resolution: ~35 ms	Quantitative Volumetric comparison; Qualitative comparison of Edef, BMC and ISA
5	Navigator guided 4D flow	6 - 12	Sagittal 4D PC: Covering aorta PA, proximal branch pulmonary arteries, atria and ventricles. 18-26 phases/cardiac cycle, V_{enc} - 150 cm/s; Voxel (iso): 1.6-2.8 mm^3	Quantitative Stroke Volume, Forward Flow, Backward Flow comparison
6	Navigator guided 3D SSFP Whole Heart	5 - 7	Single Phase; Voxel: 1 * 1* 2 mm^3 ; TR/TE/α = 3/1.5/60°; SENSE: 1.4;	Qualitative Assessment; 1-5; 1 – Excellent; 5 – Non-Diagnostic

Table 1: Imaging protocol and acquisition parameters used for obtaining an unsupervised 3D free-breathing acquisition in patients with congenital Heart Disease.

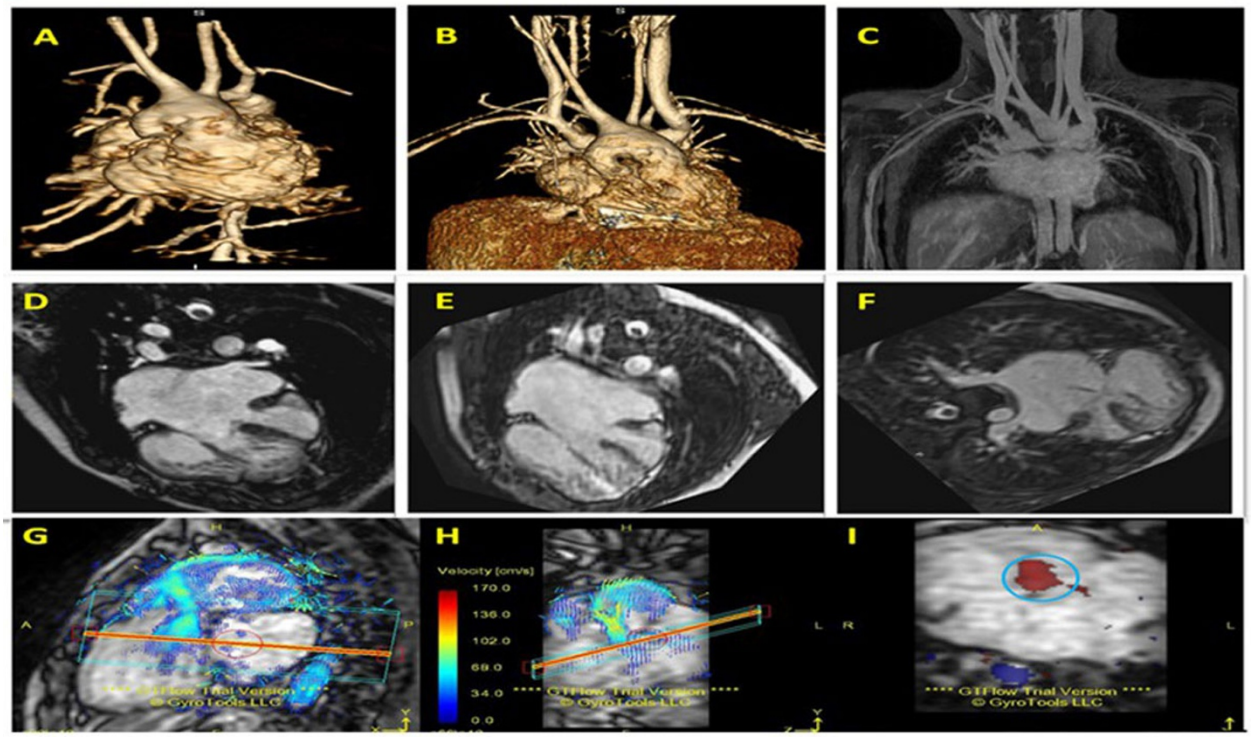

Figure 1 Representative images of patients acquired using the FB 3D protocol. First pass MRA 3D MIP acquired immediately after administration of blood pool contrast agent is shown in (A). (B) and (C) are equilibrium MRA images acquired ~2-3 minutes after contrast injection. Additional vasculature is clearly see in equilibrium MRA wrt first pass MRA images. (D) is a 2D SSFP 4-chamber cine image; (E) and (F) are reconstructed 3D images obtained in a similar imaging plan. Regurgitant jet is clearly seen in (F) that could not be clearly visualized using 2D acquisition. (G), (H) and (I) demonstrates feasibility of capturing complex anatomic details/flow (pulmonary stenosis) using 4D flow imaging. Whole heart SSFP imaging (not shown) post contrast also demonstrated significant clinical utility.

Age in years	Sex	Sedation	Indication for MRI
20	F	IV sedation	Down syndrome, s/p Tetralogy of Fallot repair
14	F	None	Diamond Blackfan syndrome s/p VSD repair, with severe aortic and pulmonary regurgitation.
40	F	None	Dextrocardia, {I,L,D} transposition of great arteries, large unrepaired ASD and mild pulmonic stenosis
5	F	IV sedation	Heterotaxy, right dominant common AV canal, interrupted IVC, s/p Damus Kaye Stansel and bilateral bidirectional Glenn procedures, for pre-Fontan evaluation
2	M	IV sedation	Shone syndrome, s/p Norwood 2 repair, with moderate tricuspid regurgitation, for pre-Fontan evaluation

Table 2: Clinical data for the 5 patient imaged using the free-breathing protocol is listed above. The group had 5 sedated and unsedated patients with various indications for MRI

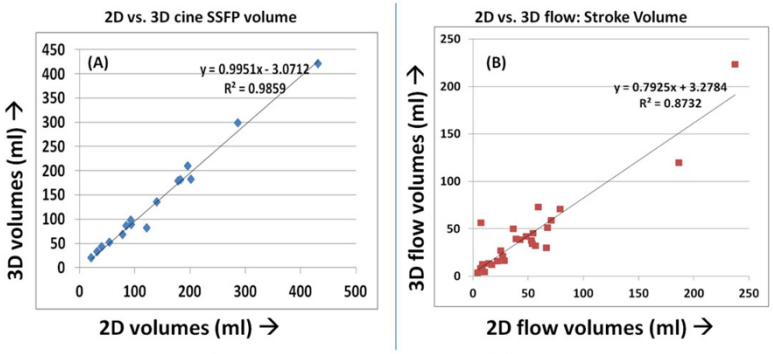

Figure 2: Plots showing results from 2D and 3D cine and flow imaging. (A) shows the 2D vs 3D comparison between volumes (EDV, ESV) obtained for both LV and RV. A significant co-relation is seen indicating the clinical utility of 3D cine imaging. (B) shows the stroke volume measured across different flow structures (aorta, MPA, RPA) in the patients. A broader co-relation between 2D and 3D flow is seen here.

	Cine 3D SSFP - Volumetry						Flow Analysis (Aorta)		
	LV (ml)			RV (ml)			SV (ml)	FF (ml)	BF (ml)
	EDV	ESV	EF	EDV	ESV	EF			
2D	241 ± 173	86 ± 54	64 ± 6	163 ± 92	89 ± 65	56 ± 11	38.8 ± 13	54.8 ± 34	12.6 ± 25
3D	240 ± 168	85 ± 51	63 ± 5	162 ± 94	79 ± 62	55 ± 9.4	36.6 ± 22	53.9 ± 36	17.3 ± 23
% Change	0.2 ± 6.5	-0.2 ± 3.5	0.3 ± 4	0.8 ± 6.2	8.8 ± 15.5	-11.3 ± 15	11.5 ± 24	4.3 ± 38	-38 ± 52

Table 3: Quantitative volumetric values comparing 2D vs. 3D cine imaging and flow in 5 patients. From the cine images, the end-diastolic volume (EDV), end-systolic volume (ESV) and ejection fraction (EF) of both the ventricles are listed, and the change in values between 2D and 3D is listed. It can be seen that 2D and 3D results are comparable, and they are not statistically significant. The Flow analysis results are also enlisted (only for aorta). There is a broad co-relation between 2D and 3D acquisition though this corelation is poorer for other image vasculature. A poorer spatial resolution (3D) and more appropriate imaging planes can both be attributed for this.

Figure 2

Funding

None.

Authors' details

[1]Radiology, Texas Children's Hospital, Houston, Texas, USA. [2]Radiology, Baylor College of Medicine, Houston, Texas, USA. [3]Clinical Science, Philips Healthcare, Houston, Texas, USA.

Published: 16 January 2014

References

1. *JCMR* 2010, **12**(Suppl 1):O31.
2. *JCMR* 2013, **15**(Suppl 1):O98.

doi:10.1186/1532-429X-16-S1-W8
Cite this article as: Krishnamurthy *et al.*: Unsupervised free-breathing 3-dimensional imaging of morphology, function and flow in congenital heart disease under 30 minutes: pilot study. *Journal of Cardiovascular Magnetic Resonance* 2014 **16**(Suppl 1):W8.