

Feasibility and image quality of Bright-blood and black-bLOOD phase SensiTive inversion recovery (BOOST) sequence in clinical practice using for left atrial visualization in patients with atrial fibrillation

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Abstract

Purpose: The aims of our study are to investigate the feasibility of the 3D whole-heart bright-blood and black-blood phase sensitive (BOOST) inversion recovery sequence in patients with atrial fibrillation (AF) scheduled for ablation or electro cardioversion, as well as to analyze the correlation between image quality and heart rate and rhythm of patients.

Methods: BOOST was performed for assessing pulmonary veins (PV) both with T2-preparation pre-pulse (T2prep) and MT-preparation (MTC) in 45 patients with paroxysmal or permanent AF scheduled for ablation or electro cardioversion. Image quality analyses were performed by two independent observers. Qualitative assessment was made using Likert scale,

for quantitative analysis signal to noise ratios (SNR) and contrast to noise ratios (CNR) were calculated for each PV. Heart rate and rhythm was analyzed based on standard 12-lead ECGs.

Results: All MTC-BOOST acquisitions achieved diagnostic quality in the PVs, while a significant proportion of T2prep-BOOST images were not suitable for assessing PVs. SNR and CNR values of the MTC-BOOST bright-blood images were higher if patients had sinus rhythm. We found a significant or nearly significant negative correlation between heart rate and the SNR and CNR values of MTC-BOOST bright-blood images.

Conclusion: 3D whole-heart MTC-BOOST bright-blood imaging is suitable for visualizing the PVs in patients with AF, producing diagnostic image quality in 100% of cases. However, image quality was influenced by heart rate and rhythm.

1. Introduction

Imaging of left atrium (LA) in atrial fibrillation (AF) can provide insights into the etiology, risk stratification, and influences the therapeutic management of patients. Assessment of LA function and structure has a predictive value in the occurrence of AF and the risk of stroke (1). Thromboembolism is the most severe complication of AF. To exclude LA appendage thrombus before an electro cardioversion or ablation therapy of AF is particularly important (2,3). Visualizing LA anatomy including the pulmonary veins (PV) is important for planning the procedure of pulmonary vein isolation with ablation (4). The PV anatomy is conventionally assessed before ablation using computer tomography or 3 dimensional (3D) contrast-enhanced cardiac magnetic resonance (CMR) imaging (5,6).

CMR imaging is an excellent method for evaluating cardiac anatomy and function. 3D contrast enhanced CMR angiography (CMRA) is applicable for the assessment of LA dimensions and PV anatomy, whereas 2D cardiac cine imaging are useful for evaluating LA function. Contrast-enhanced CMRA acquisitions are performed during the patient's breath-holding and are taken

in time with the first-pass of a contrast agent. Inadequate timing of image acquisition or problems with the patient's breath-holding may result in poor image quality. Another option is an contrast-enhanced electrocardiographic (ECG) and respiratory gated 3D (bSSFP or GRE) sequence, which helps to depict the pulmonary veins even if the patient is unable to hold their breath (7). The biggest downside of this technique is the quite long and unpredictable acquisition time which highly depends on the patient's breathing pattern. Due to the long scan time, this acquisition cannot be repeated when the image quality is poor.

A novel MRI sequence, a 3D whole-heart bright-blood and black-blood phase sensitive (BOOST) inversion recovery sequence that needs no contrast administration and is performed during free-breathing using image-based navigation has been introduced recently (8,9). One of the biggest advantages of BOOST is that it acquires 2 differently weighted bright-blood volumes in an interleaved fashion. The two bright-blood images can be combined using a subtraction based approach (iT2prep) (10) or a Phase Sensitive Inversion Recovery (PSIR)-like reconstruction in order to provide both bright- and black-blood volumes. Initial validation has proven the clinical applicability of the technique, showing that simultaneous bright- and black blood whole heart MRI with T2 preparation (T2-prep) can help to identify the coronary lumens and thrombi (9). The same study tested the feasibility of BOOST for simultaneous black-blood LGE assessment and bright-blood coronary angiography (11). Additionally, Magnetization transfer (MTC) prepared BOOST (MTC-BOOST) is possible for the imaging of PVs, which provide excellent image quality and offer good depiction of the intracardiac and vascular anatomy at congenital heart disease patients which is comparable the standard T2-prep bSSFP sequence, as shown by earlier studies (12). MTC-BOOST was compared with the standard T2-prep bSSFP technique in pulmonary vein visualization, where MTC-BOOST overperformed the standard technique. This study was based on the examination of 11 healthy subjects and only 4 patients with AF (8) and they concentrated to present the advantages of non-rigid motion

corrected algorithms. Nevertheless, there is limited data available on the applicability of the BOOST sequence in clinical practice based on studies of larger numbers of patients.

The aims of our study are to investigate the feasibility of the BOOST sequence in patients with AF scheduled for ablation or electro cardioversion, analyze the image quality with both quantitative- and qualitative methods and compare the results with those patients who had sinus rhythm. Finally, we want to investigate the correlation between image quality and heart rate and rhythm of patients.

2. Methods

2.1. Patients

Forty-five patients with paroxysmal or permanent AF scheduled for ablation or electro cardioversion in the Heart and Vascular Center of Semmelweis University were prospectively involved in the study. Patients with pacemakers or implanted cardioverter defibrillators, or with any contraindications of CMR examination were not involved in the study.

A standard 12-lead ECG (25 mm/s and 10 mm/mV) was obtained within one hour before or after the CMR examination while all patients were in a supine position during quiet respiration. Thirty patients had sinus rhythm, 12 patients had AF, two patients had atrial flutter and one patient had atrial tachycardia at the time of the CMR examination. Patients with AF, atrial flutter and atrial tachycardia were analyzed together as a group of patients with atrial tachyarrhythmias.

Informed consent was obtained from each patient. Ethical approval was obtained from the Medical Research Council (IV/4962-3/2021/EKU), and this study was performed in accordance with the ethical standards in the 1964 Declaration of Helsinki and its later amendments.

2.2. CMR protocol

CMR examinations were performed on a 1.5 T MR scanner (MAGNETOM Aera, Siemens Healthcare, Germany). An ECG triggered 3D whole-heart bright-blood and black-blood bSSFP (BOOST) prototype sequence was performed both with T2-preparation pre-pulse (T2prep) and MT-preparation (MTC) as previously described (8,9). Image navigation (iNAV) was used for respiratory motion estimation and compensation which allows measurements to be taken under free-breathing conditions and ensures 100% scan efficiency and predictable scan time (13). Imaging parameters included: subject-specific mid-diastolic ECG-triggering, coronal orientation, resolution: 1.4x1.4x1.4mm, Field of View (FOV):320x320x64-96mm, flip angle: 90°, TR/TE= 3.5ms/1.6 ms, MTC preparation as described in (8). In order to define the phase during a cardiac cycle with least motion we applied an automated cardiac resting-phase detection algorithm (14), which was based on a free-breathing 4 chamber view. The image acquisition window was 100 msec at each patient. The BOOST measurements were performed with the coverage of LA including the ostia of PVs and the appendage. The non-rigid motion corrected magnitude T2Prep inversion recovery (IR) BOOST and reference T2Prep BOOST volumes were combined in a phase-sensitive IR (PSIR) reconstruction (15) to obtain a PSIR BOOST black-blood volume (11). Similarly, the magnitude MTC-IR BOOST and reference MTC BOOST volumes were combined in a PSIR-like reconstruction to obtain a black-blood PSIR BOOST (8).

2.3. Image analysis

Image quality analyses were performed by two independent observers (Obs1 and Obs2) who were blinded to the heart rate and rhythm of patients. Qualitative assessment was made using Likert scale as follows: 1 point indicated poor image quality, PVs are not detected, 2 points indicated good image quality, artifacts in the PV(s), and 3 points indicated excellent image quality, no artifacts (Figure 1).



3: Excellent image quality, no artefacts 2: Good image quality, artefacts in the pulmonary vein(s) 1: Poor image quality, pulmonary veins are not detected
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For quantitative analysis regions of interest (ROI) were signed in all four PVs to measure signal intensities (SI). The mean background SI and the standard deviation (SD) of background SI were measured in the lung tissue. Signal to noise ratio (SNR) were calculated in each PVs: mean SI of a PV/SD of background SI. Contrast to noise ratio (CNR) were also calculated in each PVs: absolute value of (mean SI of a PV-mean background SI)/SD of background SI.

The image quality analyses were performed both on the magnitude and PSIR images.

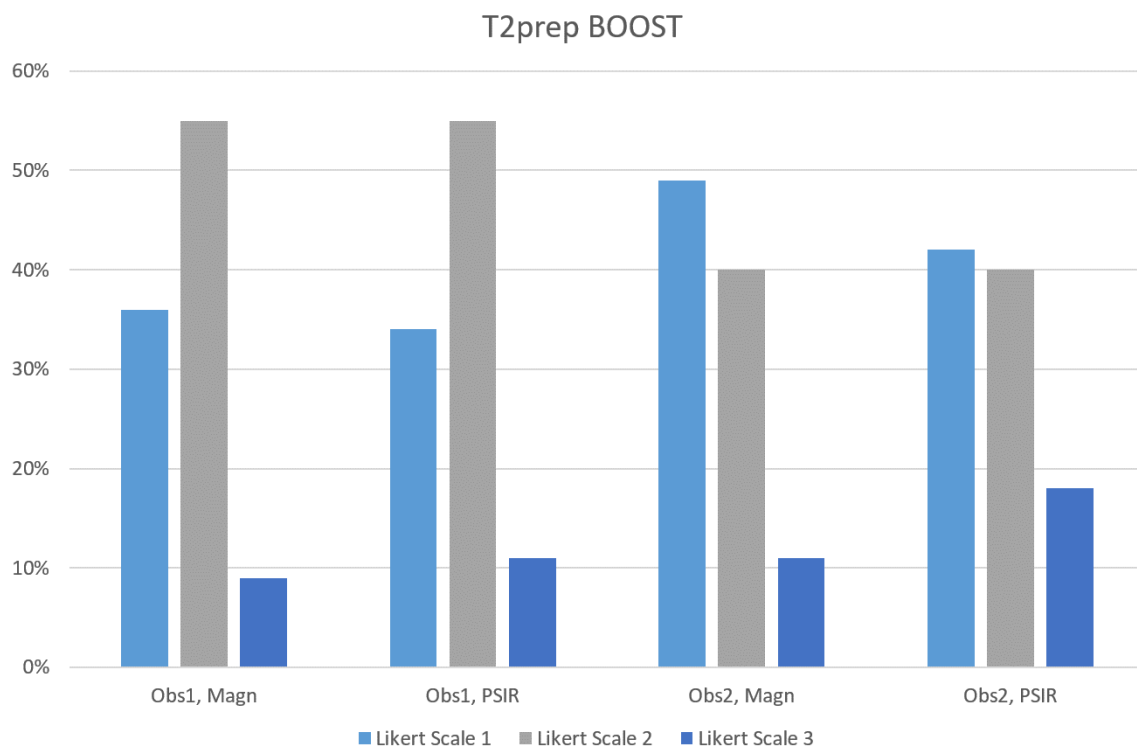
2.4. Statistical analysis

Continuous data are expressed as the mean $\pm$ standard deviation (SD). The normality of the distribution of the data was investigated with the Shapiro-Wilk test. Group characteristics were compared with an independent t-test or Mann-Whitney test, as appropriate. The correlation between heart rate and the SNR and CNR values was calculated with Spearman's correlation analysis. The interobserver agreement was examined with the intraclass correlation coefficient (ICC score). Differences were considered statistically significant when $p < 0.05$. All analyses were performed by using MedCalc software (version 17.9.5).

3. Results

3.1 Image quality of T2prep BOOST

A significant proportion of T2prep BOOST images were not suitable for assessing PVs, or artifacts were in the PVs. Only a small proportion of the images had excellent image quality without artifacts in the PVs (Figure 2). Because of this result, further quantitative image quality analysis was not performed on the T2prep BOOST images.



3.2 Qualitative assessment of image quality of MTC BOOST

Among the MTC BOOST images examined, there were no images of poor quality in which the PVs could not be adequately assessed. Both observers rated 42% of the magnitude images as excellent image quality without artifacts (Likert scale 3) and 58% as good image quality with artifacts (Likert scale 2) in the PVs. Obs1 rated 89% of the PSIR MTC images as good image quality with artifacts in the PVs and 11% as excellent image quality without artifacts, while Obs2 rated 51% of the PSIR MTC images as good image quality with artifacts in the PVs and

49% as excellent image quality without artifacts. Table 1. summarize the results of qualitative evaluation.

An image quality analysis analysis was performed with respect to heart rate and presence of sinus rhythm during the measurement. In the case of sinus rhythm based on an ECG obtained within one hour before or after the CMR examination, the Observers gave a higher proportion of 3 points compared to atrial tachyarrhythmia cases (Table 1). A tendency of lower heart rates was found for cases rated with 3 points (Table 2), nevertheless we didn't find significant differences except for magnitude images with Observer 1.

Table 1: Qualitative assessment of image quality and heart rhythm

		Obs1		Obs2	
	Likert scale	sinus rhythm	atrial tachyarrhythmia	sinus rhythm	atrial tachyarrhythmia
Magnitude	2 points	14	12	13	13
	3 points	16	3	17	2
		p<0.05		p<0.01	
PSIR	2 points	25	15	12	11
	3 points	5	0	18	4
		p=0.10		p<0.05	

Number of cases classified by the two Observers on the Likert scale in case of sinus rhythm and atrial arrhythmia.

Table 2: Qualitative assessment of image quality and heart rate

Heart rate (bpm)				
		2 points	3 points	p
Obs1	Magnitude	82 ± 29	64 ± 14	<0.05
	PSIR	77 ± 26	59 ± 8	0.08

Obs2	Magnitude	81 ± 30	66 ± 14	0.15
	PSIR	81 ± 31	68 ± 15	0.10

Heart rate of patients divided by the rating on Likert scale.

3.3 Quantitative assessment of image quality of MTC BOOST

The results of quantitative assessments of image quality showed that the SNR and CNR values of the magnitude images were higher if patients had sinus rhythm in the majority of measurements. For some measurements the difference was not statistically significant, but the trend was similar (Table 3).

Table 3. SNR and CNR values of magnitude images according to heart rhythm

		Sinus rhythm	Atrial tachyarrhythmia	p
SNR				
Obs1	LIPV	27 ± 10	21 ± 5	<0.05
	LSPV	25 ± 7	22 ± 4	0.10
	RIPV	26 ± 8	23 ± 7	0.10
	RSPV	25 ± 7	21 ± 4	<0.05
Obs2	LIPV	26 ± 8	20 ± 4	<0.01
	LSPV	26 ± 8	21 ± 4	<0.01
	RIPV	28 ± 10	21 ± 5	<0.05
	RSPV	25 ± 8	20 ± 5	<0.01
CNR				
Obs1	LIPV	25 ± 10	19 ± 5	<0.05
	LSPV	22 ± 7	19 ± 4	0.17
	RIPV	24 ± 8	21 ± 6	0.19
	RSPV	22 ± 7	18 ± 4	0.07
Obs2	LIPV	24 ± 8	18 ± 4	<0.01
	LSPV	24 ± 8	18 ± 4	<0.01
	RIPV	25 ± 10	19 ± 5	<0.05

	RSPV	23 ± 8	17 ± 5	<0.01
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Abbreviations: LIPV – left inferior pulmonary vein, LSPV – left superior pulmonary vein, RIPV – right inferior pulmonary vein, RSPV – right superior pulmonary vein

We did not find a significant difference in SNR and CNR values between patients with sinus rhythm and atrial tachyarrhythmia on the PSIR images (Table 4).

Table 4. SNR and CNR values of PSIR images according to heart rhythm

		Sinus rhythm	Atrial tachyarrhythmia	p
SNR				
Obs1	LIPV	18 ± 5	18 ± 4	0.89
	LSPV	19 ± 6	18 ± 5	0.70
	RIPV	18 ± 5	18 ± 5	0.80
	RSPV	19 ± 6	19 ± 5	0.71
Obs2	LIPV	18 ± 5	18 ± 4	0.89
	LSPV	19 ± 5	19 ± 5	0.99
	RIPV	18 ± 5	18 ± 5	0.85
	RSPV	19 ± 6	19 ± 5	0.85
CNR				
Obs1	LIPV	4.9 ± 1.8	5.3 ± 1.9	0.48
	LSPV	3.5 ± 1.2	3.9 ± 1.4	0.36
	RIPV	4.3 ± 1.5	4.4 ± 1.4	0.78
	RSPV	3.5 ± 1.1	3.8 ± 1.4	0.36
Obs2	LIPV	5.1 ± 1.6	5.3 ± 2.1	0.82
	LSPV	4.2 ± 1.6	3.9 ± 1.0	0.56
	RIPV	4.6 ± 1.6	4.7 ± 1.5	0.89
	RSPV	4.0 ± 1.2	4.1 ± 1.1	0.81

Abbreviations: LIPV – left inferior pulmonary vein, LSPV – left superior pulmonary vein, RIPV – right inferior pulmonary vein, RSPV – right superior pulmonary vein

We found a significant or nearly significant negative correlation between heart rate and the SNR and CNR values of magnitude images. The SNR and CNR values of PSIR images did not correlate with the heart rate (Table 5).

Table 5. Correlations between heart rate and the SNR and CNR values of Magnitude and PSIR images

		Magnitude				PSIR			
		SNR		CNR		SNR		CNR	
		r	p	r	p	r	p	r	p
Obs1	LIPV	-0.22	0.14	-0.19	0.22	0.02	0.90	-0.12	0.48
	LSPV	-0.37	<0.05	-0.36	<0.05	0.18	0.24	-0.18	0.25
	RIPV	-0.24	0.11	-0.23	0.13	0.18	0.25	-0.19	0.21
	RSPV	-0.45	<0.01	-0.44	<0.01	0.17	0.27	-0.24	0.12
Obs2	LIPV	-0.30	<0.05	-0.30	<0.05	0.10	0.53	-0.17	0.31
	LSPV	-0.38	<0.01	-0.37	<0.05	0.27	0.08	-0.15	0.32
	RIPV	-0.31	<0.05	-0.30	<0.05	0.24	0.11	-0.23	0.13
	RSPV	-0.46	<0.01	-0.45	<0.01	0.25	0.11	-0.22	0.16

Abbreviations: LIPV – left inferior pulmonary vein, LSPV – left superior pulmonary vein, RIPV – right inferior pulmonary vein, RSPV – right superior pulmonary vein, r – correlation coefficient

3.4 Interobserver agreement

We found excellent or good agreement between the two observers in the signal intensity assessments. (Table 6).

Table 6. Interobserver agreement examined with the intraclass correlation coefficient

	ICC – Magnitude	ICC – PSIR
LIPV	0.89	0.97
LSPV	0.94	0.78
RIPV	0.95	0.94
RSPV	0.99	0.89
Background mean	0.95	0.72
Background SD	0.83	0.97

4. Discussion

Previously, BOOST sequence was successfully applied to identify the coronary lumens, thrombi, congenital diseases, etc. MTC BOOST outperformed the standard T2-prep sequence in pulmonary vein isolations, nevertheless this study was based on only 11 healthy volunteers and 4 patients with atrial fibrillation (8). In our study we focus on the feasibility of MTC measurement in clinical practice and investigate the performance of the sequence in patients with sinus rhythm and atrial tachyarrhythmia. We applied both the T2-prep- and MTC sequence to compare them and determine their feasibility. Last, but not least we used the images during the EP planning.

The main finding of this study is that MTC BOOST is applicable for assessing pulmonary vein independently of the patients' heart rate and rhythm. In the study population 30 patients had sinus rhythm and 15 patients had atrial tachyarrhythmia at the time of the CMR examination, and none of them had images of poor quality in which the PVs could not be adequately assessed. These results are very promising, especially considering the use of a fixed diastolic acquisition window (100 ms). This setting is not optimal at higher heart rates, but our experience is that the

images are still well evaluated, and using this setting is comfortable and shortens the measurement time.

For MTC images, the image quality was affected by heart rate and rhythm. With subjective qualitative analysis, the Observers rated images as excellent image quality with higher proportion in case of sinus rhythm, moreover, a tendency of lower heart rate was found for cases rated as excellent image quality. The difference was significant only at Magnitude image analysis and only at Observer 1.

The SNR and CNR values of magnitude images were higher in case of sinus rhythm. However, for some measurements the difference was not statistically significant, but the trend was similar which can be explained by the relatively small sample size. A negative correlation was found between heart rate and the SNR and CNR values of magnitude images in the majority of the measurements. Based on these results, the image quality of magnitude images might be influenced by the heart rate and rhythm, and it is better if patients had sinus rhythm and lower heart rate. Analyzing the PSIR images, no differences were found in the SNR and CNR values between sinus rhythm and atrial tachyarrhythmia, and the SNR and CNR values showed no correlation with the heart rate. These results suggest that the image quality of PSIR images is less affected by heart rate and rhythm.

Surprisingly, T2-prep BOOST quality was under our expectation, and we found poor, non/diagnostic image quality at the large portion of the patients, independently from the heart rate. We found that T2prep BOOST is not suitable for visualizing the PVs (8). On the other hand, previously it was demonstrated that T2prep BOOST is applicable for thrombus visualization without contrast administration (9) which has a high clinical relevance as excluding LA appendage thrombus before an electro cardioversion or ablation therapy of AF is particularly important. However, for visualizing the LA appendage, there is no widely accepted CMR technique. With cine movies and late enhancement images there is a risk of overlooking

small but relevant LA appendage thrombi due to slice thickness and difficulties of proper angulation. Therefore, in the future, T2prep BOOST imaging may play a role in the exclusion of LA appendage thrombus.

5. Study limitations

One limitation of our study is that it was a single-center study, which might limit the generalizability of our conclusions. Another limitation is the relatively small sample size which can explain that some of our results were statistically not significant. Last, but not least we think that the quantitative image analysis would be more precise if we can segment the pulmonary veins and calculate the means and standard deviations from the entire vein. Taking into account that our main aim was to investigate the clinical feasibility of BOOST imaging, we dispense from that analysis.

6. Conclusion

3D whole-heart MTC BOOST imaging is suitable for visualizing the PVs in patients with AF with excellent or good image quality and no cases in the current study in which the PVs could not be adequately assessed. However, the overall image quality of magnitude images can be influenced by the heart rate and rhythm, with slightly better image quality if patients are in sinus rhythm and have lower heart rate.

References

1. Osranek M, Bursi F, Bailey KR, Grossardt BR, Brown RD, Kopecky SL, et al. Left atrial volume predicts cardiovascular events in patients originally diagnosed with lone atrial fibrillation: Three-decade follow-up. *Eur Heart J*. 2005;26(23):2556–61.
2. Hindricks G, Potpara T, Dagres N, Bax JJ, Boriani G, Dan GA, et al. 2020 ESC Guidelines for the diagnosis and management of atrial fibrillation developed in collaboration with the European Association for Cardio-Thoracic Surgery (EACTS). *Eur Heart J*. 2021;42(5):373–498.
3. Donal E, Lip GYH, Galderisi M, Goette A, Shah D, Marwan M, et al. EACVI/EHRA Expert Consensus Document on the role of multi-modality imaging for the evaluation of patients with atrial fibrillation. *Eur Heart J Cardiovasc Imaging*. 2016;17(4):355–83.
4. Chyou JY, Biviano A, Magno P, Garan H, Einstein AJ. Applications of computed tomography and magnetic resonance imaging in percutaneous ablation therapy for atrial fibrillation. *J Interv Card Electrophysiol*. 2009;26(1):47–57.
5. Syed MA, Peters DC, Rashid H, Arai AE. Pulmonary vein imaging: comparison of 3D magnetic resonance angiography with 2D cine MRI for characterizing anatomy and size. *J Cardiovasc Magn Reson Off J Soc Cardiovasc Magn Reson*. 2005;7(2):355–60.
6. Mansour M, Holmvang G, Sosnovik D, Migrino R, Abbara S, Ruskin J, et al. Assessment of pulmonary vein anatomic variability by magnetic resonance imaging: implications for catheter ablation techniques for atrial fibrillation. *J Cardiovasc Electrophysiol*. 2004 Apr;15(4):387–93.
7. Groarke JD, Waller AH, Vita TS, Michaud GF, Di Carli MF, Blankstein R, et al. Feasibility study of electrocardiographic and respiratory gated, gadolinium enhanced

- magnetic resonance angiography of pulmonary veins and the impact of heart rate and rhythm on study quality. *J Cardiovasc Magn Reson*. 2014;16(1):1–11.
8. Ginami G, Lòpez K, Mukherjee RK, Neji R, Munoz C, Roujol S, et al. Non-contrast enhanced simultaneous 3D whole-heart bright-blood pulmonary veins visualization and black-blood quantification of atrial wall thickness. *Magn Reson Med*. 2019;81(2):1066–79.
 9. Ginami G, Neji R, Phinikaridou A, Whitaker J, Botnar RM, Prieto C. Simultaneous bright- and black-blood whole-heart MRI for noncontrast enhanced coronary lumen and thrombus visualization. *Magn Reson Med*. 2018;79(3):1460–72.
 10. Milotta G, Ginami G, Cruz G, Neji R, Prieto C, Botnar RM. Simultaneous 3D whole-heart bright-blood and black blood imaging for cardiovascular anatomy and wall assessment with interleaved T2prep-IR. *Magn Reson Med*. 2019;82(1):312–25.
 11. Ginami G, Neji R, Rashid I, Chiribiri A, Ismail TF, Botnar RM, et al. 3D whole-heart phase sensitive inversion recovery CMR for simultaneous black-blood late gadolinium enhancement and bright-blood coronary CMR angiography. *J Cardiovasc Magn Reson*. 2017;19(1):1–14.
 12. Fotaki A, Kunze K, Alam H, Emmanuel Y, Frigola A, Pushparajah K, et al. Gadolinium-free Bright and Black-Blood 3D whole-heart MRI for efficient anatomical assessment in patients with Congenital Heart Disease. In: *Proc Intl Soc Mag Reson Med* 30. 2022.
 13. Henningsson M, Koken P, Stehning C, Razavi R, Prieto C, Botnar RM. Whole-heart coronary MR angiography with 2D self-navigated image reconstruction. *Magn Reson Med*. 2012 Feb;67(2):437–45.

14. Yoon SS, Preuhs E, Schmidt M, Forman C, Chitiboi T, Fernandes JL, et al. Automated Cardiac Resting Phase Detection Targeted on the Right Coronary Artery.
arXiv:210902342.
15. Kellman P, Arai AE, McVeigh ER, Aletras AH. Phase-sensitive inversion recovery for detecting myocardial infarction using gadolinium-delayed hyperenhancement. *Magn Reson Med*. 2002 Feb;47(2):372–83.

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