In-Plane bSSFP Phase-Contrast (PC-SSFP) for All-in-One Diastolic Function Evaluation

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Abstract

Purpose: Diastolic function evaluation requires estimates of early and late diastolic mitral filling velocities (E and A), and mitral annulus tissue velocity (e'), which are typically obtained by several separate MRI acquisitions. We aimed to develop a Cardiac MRI method with improved flow measurements, for simultaneous all-in-one diastolic dysfunction evaluation, providing all parameters in a single scan.

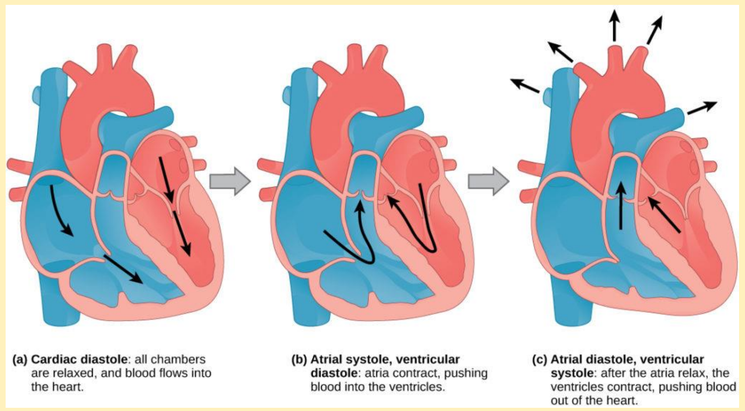
Methods: We proposed a phase-contrast (PC) sequence with bSSFP contrast (PC-SSFP). E and A could be measured with PC, and e' estimated by valve tracking on the magnitude images, using an established deep learning framework. K-t PCA acceleration, low field strength (0.55T), 4D flow extension has been also explored.

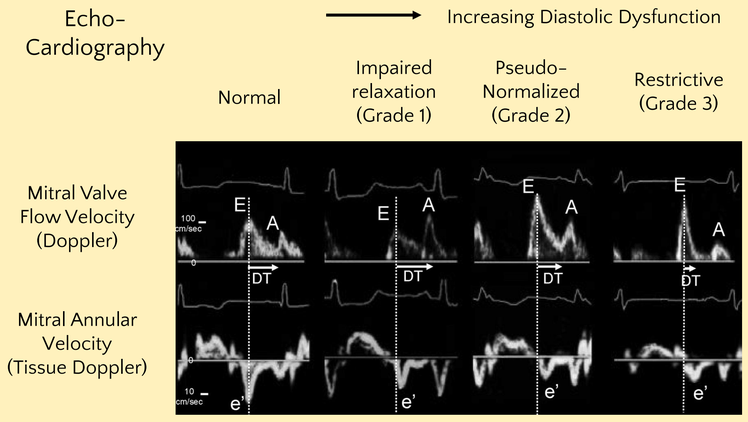
Results: Phantom experiments showed that PC-SSFP measured accurate velocities compared to PC-GRE (r = 0.98 for a range of pixel-wise velocities -80cm/s to 80cm/s). In subjects, PC-SSFP generated high SNR and myocardium-blood contrast, and excellent agreement for E (limits of agreement (LOA) 0.8±2.4 cm/s, r = 0.98), A (LOA 2.5±4.1 cm/s, r = 0.97), and e' (LOA 0.3±2.6 cm/s, r = 1.00), vs. the standard methods. The best k-t PCA approach processed the complex difference data and substituted in raw k-space data, which achieved higher frame rates yielding a 13% higher e'.

Conclusion: The proposed accelerated PC-SSFP method achieved all-in-one diastolic dysfunction evaluation, showing potential for application in low field MRI and extension to 4D flow method.

Key words: MRI; improved Cardiac flow; diastolic dysfunction

Introduction





In-plane PC-SSFP for E, A, e'

Conventional methods – separate MRI acquisitions:

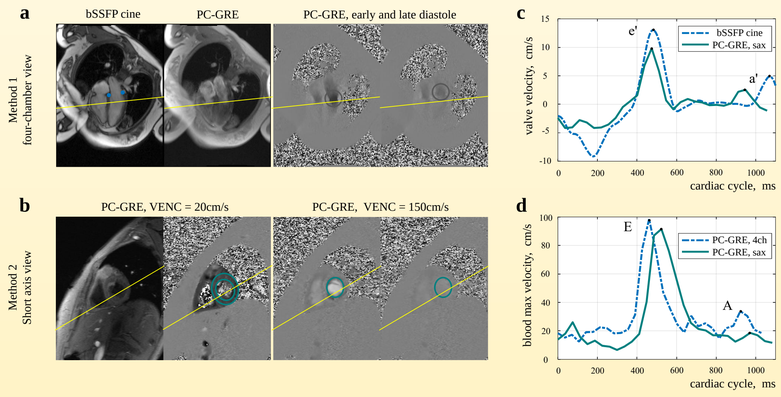
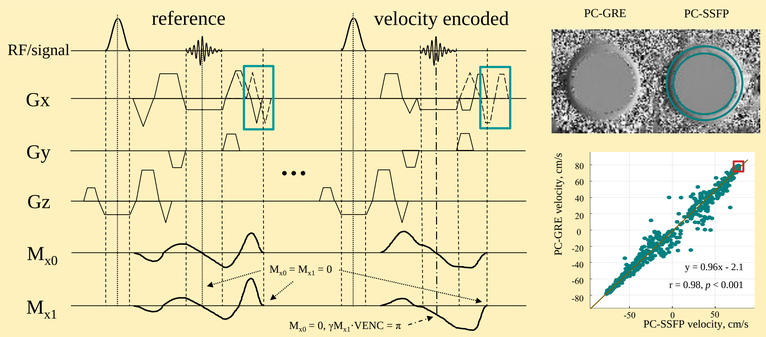
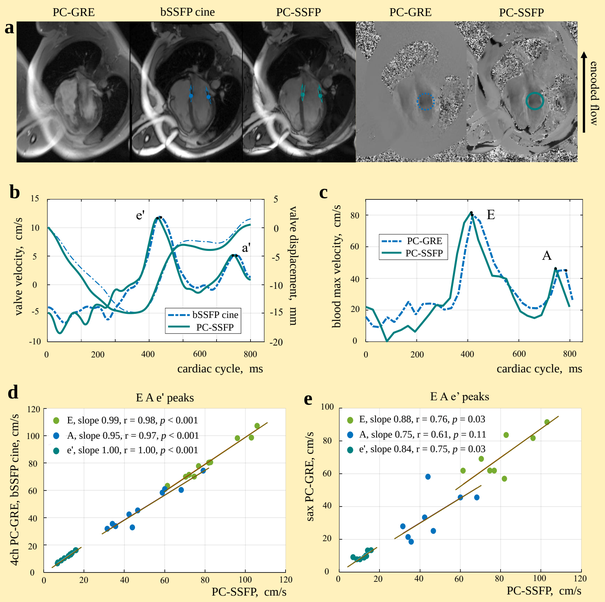


Diagram of our proposed in-plane PC-SSFP sequence:



Example study
(a) PC-SSFP images exhibited similar contrast as bSSFP cine. PC images also show agreement.
(b) e' (11.9 cm/s vs. 11.7 cm/s) and a' (5.2 cm/s vs. 5.1 cm/s)
(c) E peak (80.2 cm/s vs. 81.9 cm/s) and A peak (45.3 cm/s vs. 46.6 cm/s)



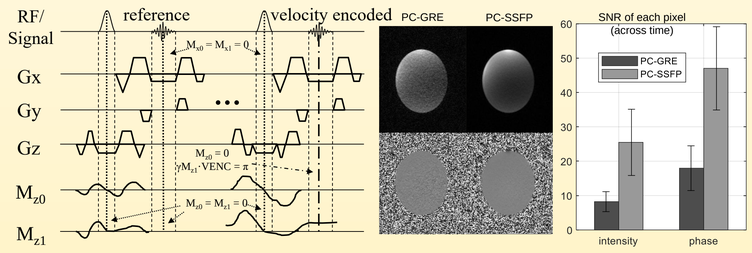
Ten healthy subjects imaged
PC-SSFP showed great agreement with four-chamber PC-GRE and bSSFP cine (d), as well as short axis PC-GRE (e), in terms of E, A, e'.

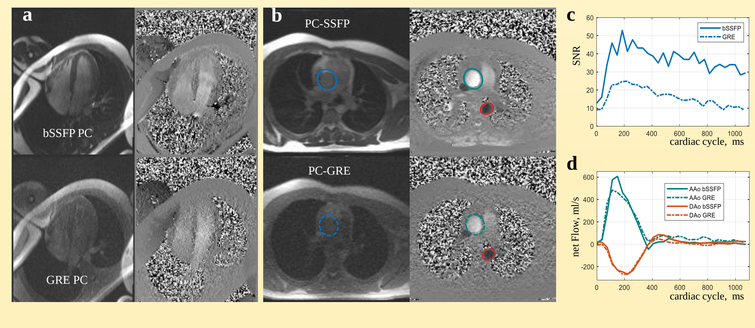
Stress Test – rapid pressure estimation using E/e', during or after exercise such as bicycle and handgrip. In Heart Failure with preserved Ejection Fraction (HFpEF), normal LV filling is achieved only at the expense of elevated LV filling pressure at rest or during exercise – and this may lead to dyspnea.

Studies reported linear correlation between E/e' ratio and heart pressure. Our PC-SSFP, by simultaneously providing E and e', may lead to a rapid pressure estimation or even monitoring.

Low field MRI application (0.55T)

Renewed interest in lower field MRI systems for cardiovascular MRI for their promise of increased patient access. However, the challenge of reduced SNR at lower field is especially problematic for phase-contrast.





Example study In-plane flow in four-chamber view is impossible with conventional GRE based phase contrast methods. Our proposed PC-SSFP provided much improved image quality and reasonable flow measurements in both four-chamber in-plane flow, and Ascending (AAo) / Descending (DAo) Aortic through-plane flow. – still in progress

Extension: bSSFP 4D flow

4D flow, is a promising tool for providing both structure and flow information in a single acquisition, by imaging a 3-dimentional time-resolved volume and encoding velocities in 3 dimensions.

Strong limitations remain with 4D flow - long acquisition time, low spatial and temporal resolution, limited contrast. Post-contrast 4D flow is typically for minimum signal loss and improved image quality, but a contrast-free approach is still important.

American Heart Association (AHA) predoctoral fellowship recently submitted a proposal as principal investigator. – to do