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Research article

Comparison between multi-shot gradient echo EPI and balanced SSFP in unenhanced 3T MRA of thoracic aorta in healthy volunteers

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ABSTRACT

Purpose: The purpose of this study was to compare scan time and image quality between magnetic resonance angiography (MRA) of the thoracic aorta using a multi-shot gradient echo planar imaging (MSG-EPI) and MRA using balanced steady-state free precession (b-SSFP).

Materials and methods: Healthy volunteers (n = 17) underwent unenhanced thoracic aorta MRA using balanced steady-state free precession (b-SSFP) and MSG-EPI sequences on a 3T MRI. The acquisition time, total scan time, signal-to-noise ratio (SNR) of the thoracic aorta, and the coefficient of variation (CV) of thoracic aorta were compared with paired *t*-tests. Two radiologists independently recorded the images' contrast, noise, sharpness, artifacts, and overall quality on a 4-point scale.

Results: The acquisition time was 36.2% shorter for MSG-EPI than b-SSFP (115.5 ± 14.4 vs 181.0 ± 14.9 s, $p < 0.01$). The total scan time was 40.4% shorter for MSG-EPI than b-SSFP (272 ± 78 vs 456 ± 144 s, $p < 0.01$). There was no significant difference in mean SNR between MSG-EPI and b-SSFP scans (17.3 ± 3.6 vs 15.2 ± 4.3, $p = 0.08$). The CV was significantly lower for MSG-EPI than b-SSFP (0.2 ± 0.1 vs. 0.5 ± 0.2, $p < 0.01$). All qualitative scores except for image noise were significantly higher in MSG-EPI than b-SSFP scans ($p < 0.05$).

Conclusion: The MSG-EPI sequence is a promising technique for shortening scan time and yielding more homogenous image quality in MRA of thoracic aorta on 3T scanners compared with the b-SSFP.

1. Introduction

Unenhanced magnetic resonance angiography (MRA) is a non-invasive modality for evaluation of a variety of aortic diseases, including aortic aneurysm, acute aortic syndrome, and congenital abnormalities [1–4]. Previous reports suggested the usefulness of the steady-state free precession (SSFP) technique for obtaining high diagnostic accuracy in 1.5T MRA of thoracic aorta [5–7]. However, in 3T MRI scanner, this sequence is highly sensitivity to B0 inhomogeneity [8] and image quality may be degraded as compared with 1.5T MRI scanner. Therefore, in 3T MRI, there have been no established standard three-dimensional (3D) unenhanced MRA sequences for thoracic aorta.

Single-shot echo planar imaging (EPI) is the fastest acquisition method in MRI (100 ms/slice), but it has limited spatial resolution and is sensitive to off-resonance artifacts [9]. Multi-shot gradient echo (MSG)-EPI is the combination of EPI scanning and SSFP [10], and it has fewer off-resonance artifacts than single-shot EPI. However, this technique has a relatively low signal-to-noise ratio (SNR) and temporal resolution without contrast media, limiting its clinical use [11,12]. A previous report suggested the usefulness of multi-source RF

Abbreviations: MRA, magnetic resonance angiography; EPI, echo planar imaging; MSG-EPI, multi-shot gradient echo EPI; RF, radiofrequency; SNR, signal-to-noise ratio; 3D, three-dimensional; SSFP, steady-state free precession; ROI, region of interest; SI, signal intensity; SD, standard deviation

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transmission for optimization of RF shimming at 3T cardiac MRI to each patient's anatomy [13]. This technique can overcome the B1 inhomogeneity without additional scanning time and increase the image contrast because its T2-pre pulse has high-power refocusing pulses [14].

To our knowledge, there are no reports on unenhanced MRA of thoracic aorta with MSG-EPI in 3T MRI. We hypothesize that MSG-EPI with 3T-MRI can improve image quality in unenhanced thoracic aorta MRA.

The purpose of this study was to compare scan time and image quality between magnetic resonance angiography (MRA) of the thoracic aorta using a multi-shot gradient echo planar imaging (MSG-EPI) and MRA using balanced steady-state free precession (b-SSFP).

2. Material and methods

2.1. Subjects

This prospective study received institutional review board approval; prior informed consent to participate was obtained from 18 healthy volunteers. All underwent imaging consecutively in November–December 2015. One volunteer's data were subsequently excluded because of a severe motion artifact. The age of the 17 volunteers (16 men and 1 woman) ranged 25–44 years (mean 32.5 ± 7.0), their heart rate 53–77 beats (mean 65.0 ± 7.8) per minute, and their body weight 51–88 kg (mean 64.2 ± 8.7).

2.2. MR angiography acquisition

All subjects underwent imaging on a 3T MRI scanner (Ingenia-CX, Philips Medical Systems) using a 16-element phased-array direct digital RF receiver coil and vector electrocardiographic gating [15]. A multislice gradient echo (TR = 2.6 ms, TE = 1.27 ms, α = 20°) 3D scout scan was acquired in three orthogonal orientations to determine the volume for thoracic aorta imaging.

All subjects underwent pulse- and respiratory-gated non-contrast-enhanced MRA using a balanced SSFP (b-SSFP) sequence and MSG-EPI in the same session. 3D imaging was performed in the oblique sagittal plane. Image acquisition was set to occur during the mid-to-late diastole of the cardiac cycle. Using the visually identified trigger delay, we performed 3D MRA of thoracic aorta with MSG-EPI and b-SSFP. No contrast agents were injected. We used a T2-pre pulse (TE = 50 ms) constructed with four refocusing pulses to increase the natural T2 contrast between blood and myocardium. Spectrally selective fat saturation enhanced the endogenous image contrast between thoracic aorta blood and the surrounding fat.

The schematics of the 3D b-SSFP and MSG-EPI sequences are shown in Fig. 1. The MSG-EPI sequence is similar to single-shot gradient-type EPI, except that rather than sampling the k-space completely with one shot, several acquisitions are used. In the MSG-EPI sequence, many signals can be obtained with one RF excitation; however, the signal acquisition time is limited by T2* relaxation. The acquisition of many k-space lines increases TE and TR and lowers the SNR, resulting in blurring. Therefore, we used an EPI factor of seven, which can yield seven echoes per excitation. The detailed scanning parameters are shown in Table 1.

We recorded the acquisition time and the total scan time (acquisition time, respiratory gating and ECG gating time) of all subjects for 3D b-SSFP and MSG-EPI sequences.

2.3. Quantitative analysis

A board-certified radiologist with 7 years of cardiac and great vessel MRI experience performed quantitative image analysis on the oblique images. To minimize bias from single measurements, we placed three circular regions of interest (ROIs) on three sequential slices and calculated their means. The mean signal intensity (SI) of the ascending aorta and descending thoracic aorta were measured in an ROI whose origin was placed at the level of the left main trunk. In addition, we measured the mean SI of the aortic arch. We attempted to select an ROI of 400 mm^2 to measure the SI of the ascending aorta, aortic arch, thoracic descending aorta (ROI_{Ao}) without affecting per-pixel variability and excluding the vessel walls or perivascular fat. We measured the mean SI of the aortic arch and thoracic descending aorta and the

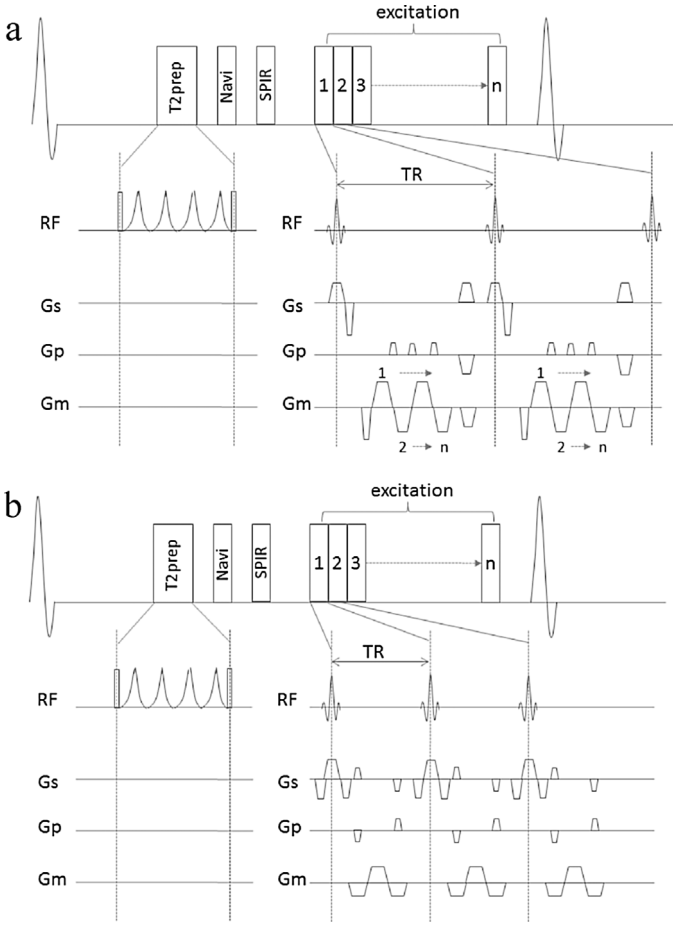

Fig. 1. Pulse sequence scheme. A T2-prepared (T2prep) pulse, fat saturated (SPIR), and respiratory and pulse navigator (Navi)-gated 3D multi-shot EPI (a) and b-SSFP (b) sequences were used for thoracic aorta MRA. This sequence acquired several n (=EPI factors) echoes per RF excitation and yielded N (=TFE factors) RF excitations per heartbeat. As a result, N × n echoes per heartbeat are acquired.

Table 1
Magnetic resonance imaging sequences and parameters.

	b-SSFP	MSG-EPI
TR/TE [ms]	5.2/2.3	14.0/7.5
FOV [mm x mm]	300	300
Matrix	256 * 256	256 * 256
Slice thickness [mm]	1.8 (overcontiguous)	1.8 (overcontiguous)
Spatial resolution [mm3]	1.17 * 1.31 * 1.8	1.17 * 1.39 * 1.8
Number slices	70	70
TFE factor	42	15
EPI factor	–	7
Shot duration (msec)	317.9	346.5
Acquision time[min] (Heart Rate 60 beats/min)	2:52	2:08
Flip angle	60	20
Fat suppresion	SPIR	Proset
Half scan	Non	Yes
Averages	2	3
SENSE factor	2.0*1.0	2.0*1.0