Two-Dimensional Multi-Shot Echo-Planar Coronary MR Angiography

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Introduction

Two-dimensional (2D) breath-hold segmented gradient-echo imaging has proven to be an effective tool for visualizing the coronary arteries (1-3). Three-dimensional (3D) imaging (4-6) can offer the advantages of multi-planar reformating, higher SNR, and thinner slices. However, 3D methods either preclude breath-holding or sacrifice SNR to achieve breath-holding.

Whether in 2D or 3D mode, most breath-held segmented coronary MRA techniques require repetitive excitation of the same slice or slab within each cardiac cycle. This results in two fundamental limitations: (i) suboptimal intravascular blood signal caused by saturation effects due to the use of low flip angles and short TRs and (ii) long acquisition times (>100 msec) per cardiac cycle (T_{acq}) that may not adequately freeze the cardiac motion that is invariably present throughout diastole, thus resulting in image blurring. Three-dimensional sequences, which generally have longer T_{acq} values than 2D sequences, are likely to be particularly susceptible to motion-induced blurring. The purpose of this study was to use breath-hold 2D multi-shot EPI to address the aforementioned limitations of conventional segmented coronary MRA, including blood saturation and SNR, motion sensitivity, anatomic coverage, and acquisition time.

Methods

Two-dimensional multi-shot EPI was used for multi-slice imaging of the four primary coronary artery branches in axial, sagittal, and single- and double-oblique planes. For an echo train length of eight, 16 shots were used to collect a 128x128 matrix which was reconstructed as 256x256. With a 125 kHz bandwidth, the total readout duration per shot for oblique acquisitions was only 11 msec. Because only one echo train was played out per slice per cardiac cycle, T_{acq} was less than 16 msec per slice (Figure 1). Furthermore, the TR equaled the R-R interval, and a 90° excitation could be used to take full advantage of the available magnetization. The TE was 4.7 msec for oblique acquisitions and 4.0 msec otherwise. Despite the relatively small acquisition matrix, several steps were taken to improve the overall spatial resolution. In the frequency-encoding direction, a frequency-restricted (low-pass-filtered) rectangular FOV of 19 cm was used, irrespective of the FOV in the phase-encoding direction. This increased the resolution by 26-36% over that for a square FOV. In the phase-encoding direction, the TE was chosen to occur on the second gradient echo of the echo train, resulting in asymmetric sampling of $k_y$. This increased the nominal resolution by more than 60% over that attainable by symmetric sampling. Typical in-plane resolution was 1.5 x 1.1 mm (frequency x phase).

Imaging of 16 volunteers was performed during diastole using ECG triggering. Fat saturation was applied prior to the excitation of each slice. Ten- to 15-slice axial and sagittal scans were used as scout acquisitions, and 3- to 5-slice oblique scans were subsequently used for more complete in-plane vessel depiction. Each scan was performed in a 17-heartbeat breath-hold.

Results

Double-oblique images of the right coronary (RCA), left main (LM), and left anterior descending (LAD) arteries of four volunteers are shown in Figure 2. The RCA and LM/LAD were measured in 15 of the 16 volunteers (94%). The left circumflex (LCx) artery was measured in 4 of the 10 volunteers (40%) in which it was sought. The average lengths of the vessels were: 78±17 mm (RCA); 71±9 mm (LM+LAD); and 37±2 mm (LCx). While these averages compare favorably with those reported for other coronary MRA techniques (7), the standard deviations are significantly lower, suggesting more consistent results.

![Image](https://example.com/image.png)

Figure 2. (a, b) Double-oblique images of the RCAs and (c, d) single-oblique images of the LM/LADs of four volunteers. Note the diagonal branches of the LADs in (c) and (d).

Conclusions

We have demonstrated the ability of 2D multi-shot EPI to reliably and reproducibly acquire multi-slice images of the proximal coronary arteries in single breath-hold acquisitions. The images provide high intravascular signal, good in-plane resolution, reduced motion sensitivity, and excellent slice registration.

References