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3-T Navigator Parallel-Imaging Coronary MR Angiography: Targeted-Volume Versus Whole-Heart Acquisition

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Abstract

Objective—The purpose of this study was to compare whole-heart acquisition with targeted-volume acquisition in 3-T navigator coronary MR angiography with parallel imaging.

Subjects and Methods—The right and left coronary arteries of 20 subjects were imaged with axial wholeheart acquisition and two oblique targeted-volume acquisitions.

Results—Both whole-heart and targeted-volume acquisitions were completed with similar navigator efficiencies ($\approx 50\%$) and depicted similar coronary artery diameters (≈ 3 mm) ($p = 0.06$). The lengths of the coronary arteries were not significantly different ($p = 0.07$ – 0.45) for the whole-heart and targeted-volume approaches. Depiction of the sharper coronary arteries ($p = 0.04$) and overall image quality ($p = 0.02$) were better with the targeted-volume approach.

Conclusions—For current 3-T navigator parallel-imaging coronary MR angiography, targeted-volume acquisition yields sharper coronary images than does whole-heart acquisition.

Keywords

3 T; coronary MR angiography; navigator; targeted volume; whole heart

Introduction

Coronary artery disease is the leading cause of death among both men and women in the United States and throughout the Western world [1]. Conventional x-ray coronary angiography is the reference standard for identification of clinically significant coronary artery disease. This technique, however, is invasive, expensive, and associated with morbidity—as many as 40% of patients undergoing the procedure have no significant coronary artery stenosis [2]. Noninvasive imaging of the coronary arteries has been pursued to compensate for the limitations of x-ray angiography.

Coronary MR angiography (MRA) can be used for noninvasive imaging of the major coronary arteries. Unlike other noninvasive imaging techniques, such as cardiac CT angiography, coronary MRA is not performed with ionizing radiation or potentially nephrotoxic contrast medium and is not affected by CT-specific calcium blooming artifacts, which can reduce diagnostic accuracy. Since the late 1990s, use of ECG- and respiration-gated coronary MRA techniques have allowed patients to breathe freely during the

examination while high-resolution data are acquired within a large volume [3]. In a large multicenter study [4], coronary MRA at 1.5 T was found accurate in the detection of disease of the proximal and middle segments of the coronary arteries, reliably ruling out left main coronary artery and three-vessel disease. However, the low signal-to-noise ratio (SNR) at 1.5 T limits the use of coronary MRA in the distal segments and small branch vessels of the coronary arteries. With the higher field strength of a 3-T magnet, the SNR can be improved considerably for parallel imaging, such as sensitivity encoding, to reduce imaging duration [5, 6].

Coronary MRA is conventionally performed with thin-slab volumes targeting specific coronary arteries. Whole-heart coronary MRA with a single large volume that encompasses the entire heart and all coronary arteries has been developed [7]. Initial data acquired with whole-heart coronary MRA at 1.5 T have consistently shown significant improvement in visible coronary artery length, higher SNR, and easier setup in comparison with the conventional targeted-volume approach [8–12]. Some investigators [11, 12], however, have observed a reduction in image quality with the whole-heart approach, reporting a significant degradation in image sharpness, possibly due to the long duration of whole-heart acquisition.

The purpose of this study was to compare the image quality of targeted-volume acquisition with that of whole-heart acquisition with a 3-T system. The higher SNR afforded by a 3-T magnet may improve the visibility of distal coronary artery segments and small branch vessels, which may be poorly visualized at 1.5 T. In addition, the higher SNR at 3 T coupled with parallel imaging of a modest reduction factor can halve imaging time, further improving not only image sharpness and quality but also patient comfort.

Subjects and Methods

Subjects

We enrolled a total of 20 subjects (five women, 15 men; mean age, 44.9 ± 16.6 [SD] years; range, 22–71 years). Of these 20 subjects, nine 22- to 41-year-old men were consecutively recruited healthy volunteers and 11 were patients (five women, six men; age range, 49–71 years) who consecutively presented with a history of chest pain. Seven of these 11 patients had ST-T depression on ECG. All 20 subjects provided informed consent to the study protocol, which was approved by our institutional review board. This study was completed in October and November 2006.

Imaging

Imaging was performed with a 3-T MRI system (Achieva, Philips Healthcare) equipped with a gradient of 80 mT/m maximum strength, 200 mT/m/ms slew rate, and a six-channel cardiac coil. A 40-mm-thick volume was acquired for targeted-volume imaging and a 140-mm-thick volume for whole-heart imaging. The targeted-volume images were obtained from three points in the right coronary artery (RCA) or the left main (LM) and left anterior descending (LAD) coronary artery as a unit. The whole-heart images were axial. The left circumflex artery (LCX) was not specifically targeted but was expected to be imaged in the RCA targeted volume.

Whole-heart coronary MRA was performed at 3 T with a 3D turbo field-echo sequence [5] during free breathing with the following parameters: TR/TE, 7.0/1.59; flip angle, 25°; number of signals averaged, 1; sensitivity-encoding factor, 2; band-width per pixel, 206.8 Hz; field of view, 320 × 320 mm; slice reconstruction, 140 mm; acquisition voxel size, 0.8 × 1.04 × 1.5 mm; reconstruction voxel, 0.55 × 0.55 × 0.75 mm; fractional k space, 76.2% ky 62.5% kz; total acquired views, NyNz, 380; number of echoes per heartbeat, 20. The flip

angle of the T2-prepared sequence was 180°, and the flip angle for fat-suppression pulses was 135°. The T2 preparation time was 57 milliseconds, and the fat saturation preparation time was 17 milliseconds. The imaging parameters for targeted-volume coronary MRA were identical to those for whole-heart coronary MRA except that the slab thickness was 40 mm with reduced Nz at the same slice thickness. The trigger delay time was selected from a scout cine image. The motion of the heart and particularly of the RCA easily visible on cine images was visually inspected to identify mid-diastole as the trigger delay. The same delay time was used for all whole-heart and targeted-volume acquisitions.

For all images, magnetization preparation was performed by application of a T2-weighted preparation pulse and a frequency-selective fat-saturation pulse followed by a spoiler gradient. An automated shim procedure was applied to the imaging volume. All 3D coronary MRA images were acquired with real-time navigator gating for respiratory artifact suppression. For real-time respiratory gating, a navigator echo was acquired from a cylindric volume generated by a 2D excitation pulse perpendicular to the right hemi diaphragm with a gating window of 5 mm with real-time slab monitoring of respiratory drift with a 0.6 scaling factor between diaphragmatic motion and coronary motion [13]. To prevent long imaging times due to respiratory drift out of the gating window, the gating window was updated to the most likely position of the diaphragm when there was no data acceptance in 15 consecutive heartbeats.

Image Interpretation

All image data were evaluated on a workstation (SoapBubble Tool, Philips Healthcare). Image data were analyzed objectively by measurement of coronary artery length in millimeters, coronary artery diameter in millimeters, and coronary artery sharpness. An average of vessel intensity profile slopes at vessel edges was used for objective measurement of vessel sharpness [14]. A sharpness of 100% implied maximum sharpness, and a sharpness of zero indicated lack of an edge. Coronary images from both targeted-volume and whole-heart acquisitions were presented in a randomized manner to two blinded experienced readers for scoring of overall image quality. The readers evaluated the delineation of vessels, the extent of interfering noise, and the presence of motion artifacts, and subjective scores were generated in consensus. Image quality was scored on a 4-point scale as follows: 4, excellent, no visible artifacts; 3, good, few artifacts; 2, fair, moderate artifacts; 1, poor, substantial artifacts.

Statistical Analysis

All values were expressed as mean $\pm$ SD. The statistical significance of differences in the length, diameter, and sharpness of coronary arteries were evaluated with a paired one-tailed Student's t test. The image quality score differences for the reformatted coronary images of targeted-volume and whole-heart acquisitions were assessed with the Wilcoxon's signed rank test. For all evaluations, $p < 0.05$ was considered to indicate a statistically significant difference.

Results

Imaging was performed successfully for all subjects. Table 1 summarizes the imaging comparison results. For all of the evaluated coronary arteries, the navigator efficiency of targeted-volume images did not differ significantly from that of whole-heart images. Coronary artery diameters were significantly greater on the whole-heart images of the LCX artery, and there was no significant difference between targeted-volume and whole-heart images for the other coronary arteries. For all evaluated coronary arteries, coronary artery length on targeted-volume images did not differ significantly from that on whole-heart

images. The targeted-volume approach yielded significantly sharper images and significantly higher subjective image quality than did the whole-heart approach. The overall quality of targeted-volume images of the RCA was superior to that of targeted-volume images of the LCX, but whole-heart images of the LM and LAD, RCA, and LCX arteries had similar overall quality.

Figures 1 and 2 are examples of LM and LAD, RCA, and LCX images of two subjects. The targeted-volume–whole-heart comparison scores ranged from moderately better to markedly better. Figure 1 shows targeted-volume acquisition was markedly better than whole-heart acquisition in quality of images of the LM and LAD arteries and moderately better in quality of images of the RCA. The two methods of acquisition yielded similar-quality images of the LCX artery. Figure 2 shows targeted-volume acquisition was moderately better than whole-heart acquisition in quality of images of all four main coronary arteries.

Discussion

Our preliminary data obtained at 3 T show that the targeted-volume approach yields significantly sharper images and overall better image quality than does the whole-heart approach in imaging of the LM and LAD, the RCA, and the LCX coronary arteries. This observation of improved sharpness with targeted-volume acquisition is consistent with findings in preliminary reports of evaluations of the whole-heart approach at 1.5 T [11, 12]. Although the whole-heart approach is easy to perform, the targeted-volume approach may be advantageous in terms of image quality.

One cause of degradation of coronary sharpness in whole-heart acquisition compared with the targeted-volume approach is drifting of the respiratory gating window used to shorten imaging time in the case of respiratory drift. Gating drift increases with imaging time. (We confirmed this point after our data analysis but were not able to extract the record of gating drifts from our data.) Consequently, the amount of residual motion artifact, such as blurring, increases with imaging time. Other possible causes include irregular motion and shimming. The amount of irregular motion not measured with navigator echo, such as the range of respiratory drift in the transverse plane, also can increase with imaging time. In addition, the quality of shimming over a large volume of the whole heart is likely to be poorer than that over a small targeted volume. Because the gating window was fixed in the previous study [12], gating drift may not be the main cause of the observed degradation in sharpness in the whole-heart approach. The asynchronous cardiac motion of the left and right coronary arteries can be excluded because both the targeted-volume and whole-heart approaches are performed with the same trigger delay and the same cardiac acquisition window.

Although we had the impression of improvement in SNR with the whole-heart approach over the targeted-volume approach, the two approaches were not significantly different in depicting the lengths of any of the coronary arteries. This observation differs from the finding at 1.5 T [12] of greater coronary artery length visualized with the whole-heart approach. We do not have an explanation for the discrepancy between the findings at 1.5 T, which were made without parallel imaging, and our findings at 3 T with parallel imaging ($R = 2$), because the two methods had similar SNRs. The patient sample size in our study was twice as large as that in the previous study, and there might have been differences in implementation of the navigator method. Further study is required to resolve the discrepancy.

With rapid real-time localization imaging, which has become commercially available from some manufacturers of MRI systems, the targeted-volume approach can be easily and rapidly applied [15]. The time to image a thin volume with the targeted-volume approach ($\approx$

3 minutes) is a fraction of the imaging time of a thick volume with the whole-heart approach (≈ 11 minutes) because the navigator efficiency is the same for both approaches. For thorough evaluation of the coronary tree, acquisition of dedicated images of each coronary artery leads to a total imaging time close to that of whole-heart imaging but with sharper image quality. In our study, the thin volume targeted to the RCA facilitated visualization of the proximal LCX (≈ 53 mm), but the overall quality of images of the LCX was poorer than that of images of the RCA ($p < 0.04$). The cause of the poor image quality might have been the greater distance between the LCX and the reception coils than between the RCA and the coils. It remains to be investigated whether LCX image quality can be improved with better volume targeting, which would likely increase the length of LCX segments visualized.

Although our findings show several advantages to the targeted-volume approach at 3 T, the whole-heart approach has important advantages as well. Established clinical evaluation of cardiac structure and function requires the whole-heart approach. The learning curve for applying the whole-heart approach to the coronary tree is shorter than that for the targeted-volume approach, which may allow MRI technologists with minimal cardiac experience to successfully perform coronary MR angiography. In addition, the technology for cardiac MRI, particularly on 3-T systems, is rapidly evolving. Image quality with the whole-heart approach at 3 T will probably continue to improve as more accurate navigators, higher-order shimming, and more sensitive discrimination of cardiac motion are developed.

Field inhomogeneity and related image artifacts have been described as potential concerns in cardiac imaging at 3 T. These artifacts include susceptibility artifacts, reduced T2*, increased T1, radiofrequency field distortion, altered tissue dielectric constants, and amplified magnetohydrodynamic effects [16–21]. Our data did not allow us to deduce the direct effects of these artifacts on coronary artery imaging. Parallel imaging was used in this study, making it difficult to measure SNR because of spatially varying noise, though visually whole-heart images have higher SNR than targeted-volume images [22]. It was not always possible to blind readers to image acquisition techniques because the source images and reformatted images for the targeted-volume images were clearly different from the whole-heart images in orientation and bordering. Additional weaknesses of this study included lack of a reference standard for vessel diameter measurements and lack of a direct comparison with 1.5-T imaging. These weaknesses did not affect our observation that the targeted-volume approach at 3 T generates coronary image quality superior to that of the whole-heart approach, as found in the objective image sharpness measurements. There is a need for an effective means of overcoming the image degradation currently associated with the whole-heart approach, which has the advantages of higher SNR and easier imaging setup.

Our preliminary data show that for 3-T navigator parallel-imaging coronary MR angiography, targeted-volume acquisition yields better image quality than whole-heart acquisition.

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Fig. 1A

Fig. 1B

Fig. 1C

Fig. 1D

Fig. 1E

Fig. 1F

Figure 1.

Fig. 1A —52-year-old woman with ST-T depression on ECG who had consecutively presented with history of chest pain. Targeted-volume acquisition (A–C) and whole-heart acquisition (D–F). Targeted-volume acquisition showed markedly better image quality in left main and left anterior arteries (scored 4 for A vs 2 for D), moderately better in right coronary artery (scored 4 for B vs 3 for E), and similar quality in left circumflex artery (scored 3 for both C and F).

Fig. 1B —52-year-old woman with ST-T depression on ECG who had consecutively presented with history of chest pain. Targeted-volume acquisition (A–C) and whole-heart acquisition (D–F). Targeted-volume acquisition showed markedly better image quality in left main and left anterior arteries (scored 4 for A vs 2 for D), moderately better in right coronary artery (scored 4 for B vs 3 for E), and similar quality in left circumflex artery (scored 3 for both C and F).

Fig. 1C —52-year-old woman with ST-T depression on ECG who had consecutively presented with history of chest pain. Targeted-volume acquisition (A–C) and whole-heart acquisition (D–F). Targeted-volume acquisition showed markedly better image quality in left main and left anterior arteries (scored 4 for A vs 2 for D), moderately better in right coronary artery (scored 4 for B vs 3 for E), and similar quality in left circumflex artery (scored 3 for both C and F).

Fig. 1D —52-year-old woman with ST-T depression on ECG who had consecutively presented with history of chest pain. Targeted-volume acquisition (A–C) and whole-heart acquisition (D–F). Targeted-volume acquisition showed markedly better image quality in left main and left anterior arteries (scored 4 for A vs 2 for D), moderately better in right coronary artery (scored 4 for B vs 3 for E), and similar quality in left circumflex artery (scored 3 for both C and F).

Fig. 1E —52-year-old woman with ST-T depression on ECG who had consecutively presented with history of chest pain. Targeted-volume acquisition (A–C) and whole-heart acquisition (D–F). Targeted-volume acquisition showed markedly better image quality in left main and left anterior arteries (scored 4 for A vs 2 for D), moderately better in right coronary artery (scored 4 for B vs 3 for E), and similar quality in left circumflex artery (scored 3 for both C and F).

Fig. 1F —52-year-old woman with ST-T depression on ECG who had consecutively presented with history of chest pain. Targeted-volume acquisition (A–C) and whole-heart acquisition (D–F). Targeted-volume acquisition showed markedly better image quality in left main and left anterior arteries (scored 4 for A vs 2 for D), moderately better in right coronary artery (scored 4 for B vs 3 for E), and similar quality in left circumflex artery (scored 3 for both C and F).

Fig. 2A

Fig. 2B

Fig. 2C

Fig. 2D

Fig. 2E

Fig. 2F

Figure 2.

Fig. 2A —51-year-old man with history of chest pain and palpitations who had ST-T depression on ECG. Targeted-volume acquisition (A–C) and whole-heart acquisition (D–F). Targeted-volume acquisition showed moderately better image quality in left main and left anterior descending arteries (scored 3 for A vs 2 for D), moderately better in right circumflex artery (scored 3 for B vs 2 for E), and moderately better in left circumflex artery (scored 3 for C vs 2 for F).

Fig. 2B —51-year-old man with history of chest pain and palpitations who had ST-T depression on ECG. Targeted-volume acquisition (A–C) and whole-heart acquisition (D–F). Targeted-volume acquisition showed moderately better image quality in left main and left anterior descending arteries (scored 3 for A vs 2 for D), moderately better in right circumflex artery (scored 3 for B vs 2 for E), and moderately better in left circumflex artery (scored 3 for C vs 2 for F).

Fig. 2C —51-year-old man with history of chest pain and palpitations who had ST-T depression on ECG. Targeted-volume acquisition (A–C) and whole-heart acquisition (D–F). Targeted-volume acquisition showed moderately better image quality in left main and left anterior descending arteries (scored 3 for A vs 2 for D), moderately better in right circumflex artery (scored 3 for B vs 2 for E), and moderately better in left circumflex artery (scored 3 for C vs 2 for F).

Fig. 2D —51-year-old man with history of chest pain and palpitations who had ST-T depression on ECG. Targeted-volume acquisition (A–C) and whole-heart acquisition (D–F). Targeted-volume acquisition showed moderately better image quality in left main and left anterior descending arteries (scored 3 for A vs 2 for D), moderately better in right circumflex artery (scored 3 for B vs 2 for E), and moderately better in left circumflex artery (scored 3 for C vs 2 for F).

Fig. 2E —51-year-old man with history of chest pain and palpitations who had ST-T depression on ECG. Targeted-volume acquisition (A–C) and whole-heart acquisition (D–F). Targeted-volume acquisition showed moderately better image quality in left main and left anterior descending arteries (scored 3 for A vs 2 for D), moderately better in right circumflex artery (scored 3 for B vs 2 for E), and moderately better in left circumflex artery (scored 3 for C vs 2 for F).

Fig. 2F —51-year-old man with history of chest pain and palpitations who had ST-T depression on ECG. Targeted-volume acquisition (A–C) and whole-heart acquisition (D–F). Targeted-volume acquisition showed moderately better image quality in left main and left anterior descending arteries (scored 3 for A vs 2 for D), moderately better in right circumflex artery (scored 3 for B vs 2 for E), and moderately better in left circumflex artery (scored 3 for C vs 2 for F).

TABLE 1

Summary of Targeted-Volume Versus Whole-Heart Coronary MR Angiography

Structure	Efficiency (%)	Length (mm)	Diameter (mm)	Sharpness (%)	Quality ^a
Left main and left anterior descending coronary arteries					
Targeted volume	53 ± 7	84 ± 14	2.9 ± 0.3	43 ± 15	3.2
Whole heart	50 ± 8	84 ± 15	3.0 ± 0.3	34 ± 13	2.5
<i>p</i>	0.05	0.45	0.13	0.009	<0.006
Right coronary artery					
Targeted volume	49 ± 12	111 ± 31	3.0 ± 0.4	44 ± 13	3.15
Whole heart	50 ± 8	104 ± 24	3.2 ± 0.3	36 ± 9	2.65
<i>p</i>	0.25	0.07	0.06	0.02	<0.002
Left circumflex coronary artery					
Targeted volume	49 ± 12	53 ± 19	2.7 ± 0.3	44 ± 9	2.75
Whole heart	50 ± 8	53 ± 20	3.0 ± 0.3	41 ± 5	2.4
<i>p</i>	0.15	0.15	0.0008	0.04	<0.02

^a Average subjective image quality score of targeted-volume over whole-heart imaging with corresponding *p* values determined by Wilcoxon's test.