3D Whole-Heart Coronary MR Angiography (MRA) with SSFP at 1.5 T: A Comparison with Coronary MRA using Gd-Enhanced FLASH Sequences

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3D Whole-Heart Coronary MR Angiography (MRA) with SSFP at 1.5 T: A Comparison with Coronary MRA using Gd-Enhanced FLASH Sequences

Directed by Professor Tae Hoon Kim

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ABSTRACT

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Purpose: To determine the optimal cardiac phase and appropriate acquisition window for 3D whole-heart coronary magnetic resonance angiography (MRA) with a steady-state free precession (SSFP) sequence, and to compare image quality and detection rates between SSFP and Gd-enhanced fast low-angle shot (FLASH) MR techniques at 1.5T.

Methods: Thirty healthy volunteers (25 men and 5 women; mean age, 35 years, range, 24-54 years) underwent coronary MRA at 1.5T. 3D whole-heart coronary MRA with an SSFP was performed three times: 1) at end-systole with a narrow (120 msec) acquisition window (ESN), 2) mid-diastole with narrow acquisition (MDN); and 3) mid-diastole with wide (170 msec) acquisition (MDW). Gd-enhanced coronary MRA with FLASH was performed during MDN. Visibility of the coronary artery and image quality were evaluated for 11 segments, as suggested by the American Heart Association (AHA). Image quality was scored by a five-point scale (1 = not visible to

5 = excellent). The signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) were evaluated at the proximal coronary arteries.

Results: The SSFP sequence gave higher detection rates in coronary artery segments, higher SNR and CNR, and higher image quality than the Gd-enhanced FLASH technique at 1.5T ($p < 0.05$). The narrow acquisition window at mid-diastole with SSFP gave a relatively high image quality and excellent SNR, although it required more scan time. Imaging with an SSFP at end-systole showed results similar to those at mid-diastole for coronary artery detection rates and image quality.

Conclusion: The use of contrast material did not improve the detection rate, SNR, CNR or image quality on the 3D whole-heart coronary MRA at 1.5T. The optimal cardiac phase, either at mid-diastole or at end-systole, may be determined from the patient's heart rate.

Key words : cardiac magnetic resonance, coronary artery imaging, steady-state free precession, fast low-angle shot; contrast agent, 1.5T

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I. INTRODUCTION

Although coronary magnetic resonance angiography (MRA) has been in development for more than a decade, no consensus has been reached on the type of sequence to take or the need for contrast agent [1]. Major challenges for this technique include the motion artifacts produced in respiration and cardiac contraction. Respiratory motion can be minimized using the navigator-gated technique, in which a special navigator echo monitors motion of the diaphragm during free breathing. Based on the position of the diaphragm, a decision is made to either accept or reject the data [2-3]. To attenuate cardiac motion, the coronary MRA is usually set to acquire images during mid-diastole. Another relatively quiescent period occurs, however, at the end of ventricular systole. Heart rate (HR) variability affects the duration of systole to a lesser degree than the duration of diastole [4-7]. For this reason, end-systole imaging may alternatively be used to minimize the artifacts of HR variability.

The recent instruction of non-enhanced steady-state free precession (SSFP) MRA has met with wide acceptance for its accuracy in coronary MRA at 1.5T [2, 8-11]. This sequence has high blood signal-to-noise (SNR) and blood-myocardium contrast-to-noise ratios (CNR). Using SSFP with coronary MRA at 1.5T, Gerber et al. [12] reported sensitivity at 62%, specificity at 84% and accuracy at 80 %, even for distal segments of the coronary arteries.

Coronary MRA is conventionally performed by a thin-slab volume-targeted approach. Only a few studies have reported on whole-heart coronary MRA at 1.5T, but these have shown significantly greater resolution of coronary artery length, higher SNR, and easier setup compared with the volume-targeted approach [13-15]. Therefore, the purposes of our study were to determine the optimal cardiac phase and proper acquisition window for three-dimensional (3D) whole-heart coronary MRA with SSFP at 1.5T, and to compare the image quality using SSFP with that obtained using fast low-angle shot (FLASH) MRI.

II. MATERIALS AND METHODS

1. Patients

Thirty healthy volunteers (25 men and 5 women, mean age, 35 years, range, 24-54 years) underwent coronary MRA. Volunteers with contraindications to MR imaging (automatic implantable defibrillators, pacemakers, and intracranial aneurysm clip) were excluded from this study. No beta-blocker or nitroglycerine was administered to any patient. The institutional review boards approved this study, and all volunteers gave their written informed consent to participate.

2. True FISP Coronary MRA Protocol

Cardiac MR imaging was performed with a 1.5T scanner (Magnetom Avanto;

Siemens Medical Solutions, Erlangen, Germany) equipped with 16 channels body array and maximum strength of 45mT/m gradient system and maximum slew rate of 200 mT/m/s. Scout images of the heart were first obtained with true fast imaging with steady-state precession (FISP), and then multi-phase true FISP images, showing a transverse section of the middle right coronary artery (RCA), to determine the rest periods at end-systole and mid-diastole of the cardiac cycle (i.e., the periods of least motion for the RCA). 3D whole-heart coronary MRA (specifically, a true FISP respiratory-gated, ECG-triggered, fat saturated, and segmented technique) was then performed three times: 1) at end-systole with a narrow (120 msec) acquisition window (ESN); 2) mid-diastole with narrow window acquisition (MDN); and 3) mid-diastole with a wide (170 msec) acquisition window (MDW) (Fig 1).

The imaging parameters for the segmented 3D true FISP sequence were as follows: TR/TE = 373.3/1.6 milliseconds, flip angle = 90°, bandwidth = 590 Hz/pixel, field of view = 384 x 512 mm, matrix = 256 x 256, slice thickness = 0.8 mm, and voxel size = 1.4 x 1.3 x 0.8 mm^3. To improve blood-to-myocardium contrast, a T_2 preparation (40 msec) was applied. A parallel imaging factor of 2 was applied in the phase-encoding direction to accelerate data acquisition.

3. Contrast Enhanced Coronary MRA Protocol

Contrast enhanced coronary MRA was performed with a respiratory-gated, ECG-triggered, fat-saturated, segmented 3D fast low angle shot (FLASH) sequence without T_2 preparation. The imaging parameters were as follows: minimum TR/TE, flip angle = 20°, bandwidth = 200 Hz/pixel, field of view = 256 x 256 mm, matrix =

256 x 256, slice thickness = 1.0 mm, and voxel size = 1.0 x 1.0 x 1.0 mm^3. To minimize HR variability, acquisition window were adjusted to mid-diastole with a narrow window (Gd-MDN), which was comparable to the MDN condition in a true FISP sequence. Gadobutrol (Gadovist; Schering, Berlin, Germany) at 0.1 mmol/kg was injected slowly (1 mL/s) using a power injector (Nemoto; Nemoto Kyorindo, Tokyo, Japan), followed with 20 mL of normal saline given at the same rate.

4. Data Analysis

The average acquisition time and trigger delay time were evaluated for each acquisition method. The image sets were transferred to a postprocessing workstation (Aquarius Workstation V3.6; TeraRecon, San Mateo, CA, USA). Curved multiplanar reconstructions (MPR) and maximum intensity projections (MIP) were obtained along the coronary artery courses. The number of the visualized segments and signal-to-noise ratio (SNR) of the coronary arteries, and the contrast-to-noise ratio (CNR) between the coronary artery and the surrounding myocardium were evaluated for the four different methods.

Images of the coronary artery were evaluated for the following 11 segments, as defined in the AHA guidelines [16]: the left main (LM) coronary artery, proximal left anterior descending (LAD) artery , middle LAD artery, distal LAD artery, proximal left circumflex (LCx) artery, middle LCx artery, distal LCx artery, proximal RCA, middle RCA, distal RCA and posterior descending artery (PDA). The SNR and CNR were calculated from the original images. The region of interest (ROI) for measuring the blood signal intensity was placed centrally in the lumen of the proximal (within 3 cm from the origin) areas of the LAD, LCx and right coronary arteries. The electronic cursor was set to be as large as possible in the vessel lumen. Myocardial signal intensity was measured from the myocardium immediately next to each coronary artery. We determined mean values for each signal intensity measured at the proximal area of a coronary artery and at the surrounding myocardium. Noise measurements in parallel imaging techniques with inhomogeneous noise distributions cannot be directly compared. Hence for the background signal intensity value in the noise assessment, we used the mean of the signal intensity values obtained for two large air RIOs outside the chest wall. The SNR and CNR were defined according to the following equations:

$SNR = Mean\ (SI_{coronary\ artery})/SD_{air}$ and $CNR = SI_{coronary\ artery} - SI_{myocardium} / SD_{air}$,

in which SI is the signal intensity and SD is the standard deviation of the signal intensity of air outside the chest wall.

Two readers independently evaluated image quality and achieved a consensus for the 11 coronary artery segments. The readers scored image quality by a 5-point scale: 1, not visible; 2, poor (severe motion artifacts or poor fat saturation); 3, fair (delineated vessel lumen with moderate artifacts); 4, good (vessel delineation with minor artifacts); 5, excellent (clear vessel delineation without artifacts) (Fig 2).

5. Statistical Analysis

All parameters were determined as the mean ± standard deviation. One-way ANOVA and Kruskal-Wallis ANOVA were used to compare scan times for the acquisition methods, SNR, CNR, the number of visualized segments of the coronary artery, and image quality. A p value less than 0.05 was considered to be significant. Calculations were performed with SPSS (version 12.0.1, Statistical Package for the

Social Sciences, Chicago, IL, USA).

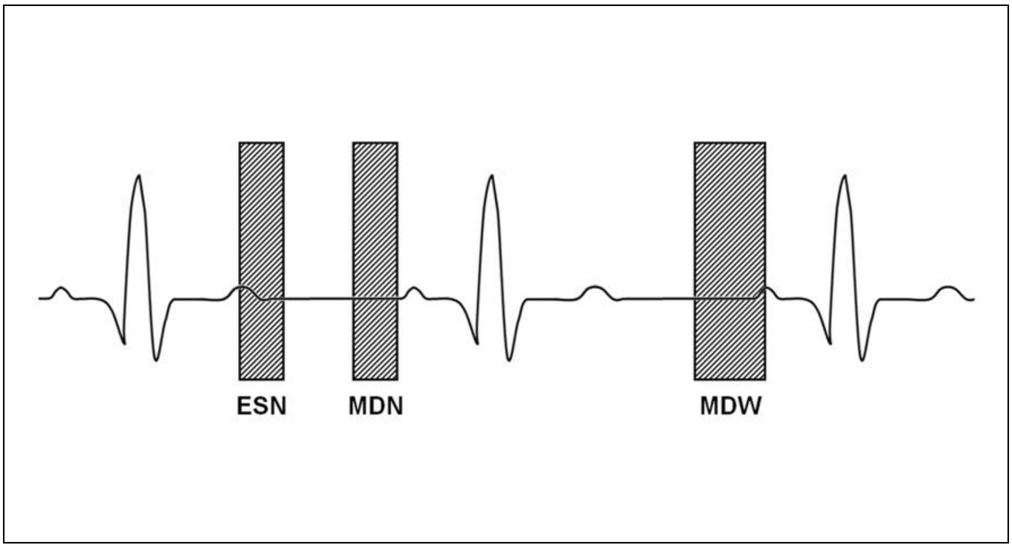

Fig 1. Schematic diagram of cardiac phase and acquisition window optimization for 3D whole-heart coronary magnetic resonance angiography (MRA) with a steady-state free precession (SSFP) sequence: end-systole with a narrow (120 msec) acquisition window (ESN); mid-diastole with narrow acquisition (MDN); and mid-diastole with a wide (170 msec) acquisition window (MDW). The Gd-enhanced coronary MRA with a fast low-angle shot (FLASH) technique was performed in the MDN condition.

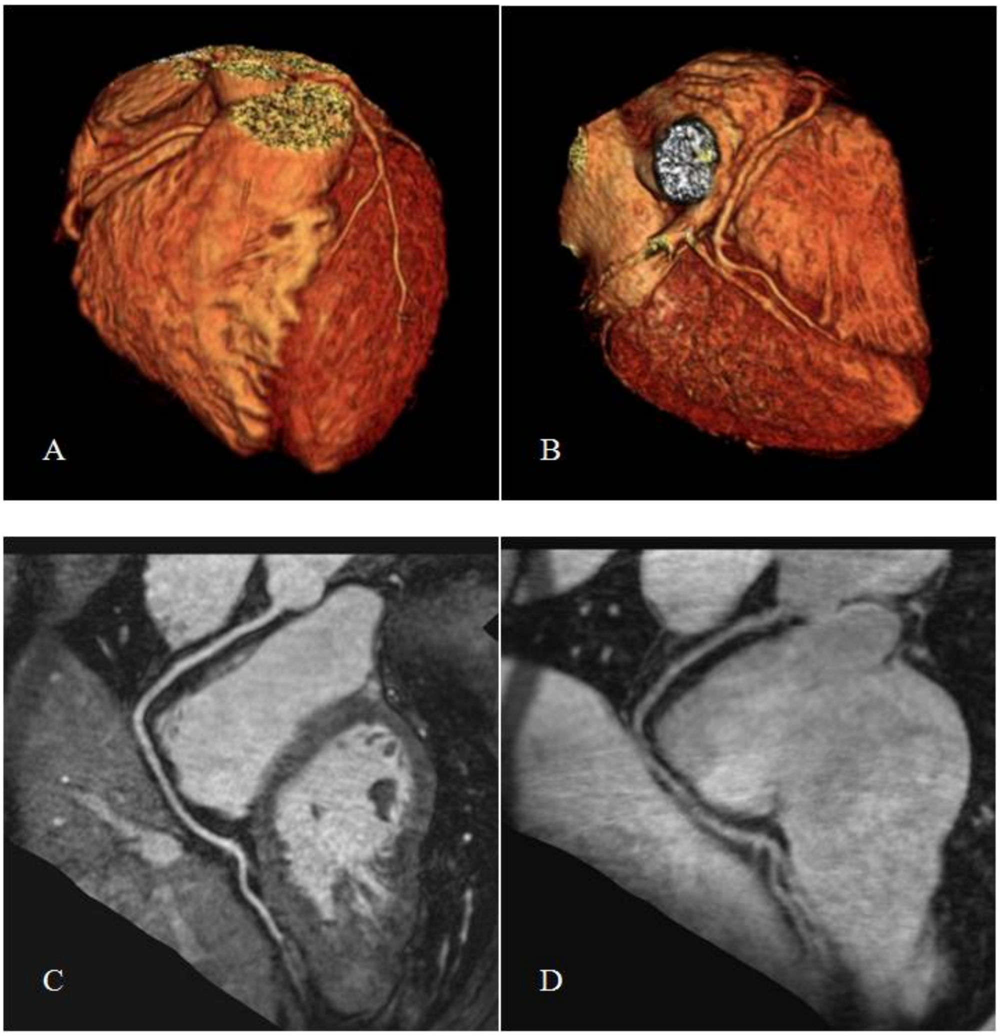

Fig 2. Volume rendering images and curved multiplannar reformatted images of the right coronary artery from the 3D whole-heart coronary magnetic resonance angiography (MRA) at 1.5T. The right coronary artery (RCA) and posterior descending artery (PDA) were well-defined on the images obtained at end-systole with narrow acquisition (A), at mid-diastole with narrow acquisition (MDN) (B), and at mid-diastole with wide acquisition (C). However, the PDA was not visible on the image obtained using Gd-enhanced MRA at MDN (D).

III. RESULTS

All 30 volunteers completed coronary MRA without complications. The mean total MR scanning time (including scout imaging) was 56.2±8.7 minutes: 12.1±3.4 minutes in the ESN, 12.0±2.0 minutes in the MDN, 8.9±2.4 minutes in the MDW and 22.2±3.5 minutes in the Gd-MDN. Mean scan time was significantly shorter in the MDW than in the ESN and MDN with an SSFP ($p < 0.01$). The acquisition time was significantly longer in the Gd-MDN than in the three methods with an SSFP sequence ($p < 0.01$). The mean trigger delay time determined by the RCA imaging with a multi-phase SSFP sequence was 273.3±27.5 msec (range, 220-330) for the ESN imaging, 621.0±72.1 msec (range, 450-760) for the MDN imaging, and 594.7±73.4 msec (range, 430-740) for the MDW imaging (Table 1).

Of 330 coronary artery segments in 30 volunteers, 316 segments (95.8%) were visualized in the ESN; 317 (96.1%), in the MDN; 310 (93.9%), in the MDW; and 283 (85.8%), in the Gd-MDN. The coronary artery segment detection rate was significantly lower in the Gd-MDN imaging technique than in the other three methods with an SSFP sequence ($p < 0.01$). However, the other three methods did not differ significantly in detection rates ($p > 0.05$).

The SNR and CNR are summarized in Table 2. Mean SNR in the coronary arteries was 65.1±6.5 in the ESN, 64.1±2.0 in the MDN, 52.9±3.5 in the MDW and 48.1±13.8 in the Gd-MDN. Although the mean SNR was a little lower in the MDW than in the ESN or MDN, these values did not differ significantly. The SNR was significantly lower, however, in the Gd-MDN than in the other three methods with an SSFP ($p < 0.05$). Mean CNR was 36.7±6.5 in the ESN, 36.1±2.0 in the MDN, 30.3±3.5 in the MDW and 8.9±13.8 in the Gd-MDN. While CNR in the ESN, MDN and MDW did not differ significantly, the Gd-MDN showed a significantly lower CNR than any of the other three methods ($p < 0.05$).

Mean image quality scores were 3.6±0.7 in the ESN, 3.7±0.7 in the MDN, 3.6±0.9 in the MDW and 2.8±1.2 in the Gd-MDN. The image quality scores for the ESN, MDN and MDW did not differ significantly, but the Gd-MDN sequence produced a lower quality image of the coronary arteries than did any of the other three methods with an SSFP ($p < 0.01$) (Fig 3).

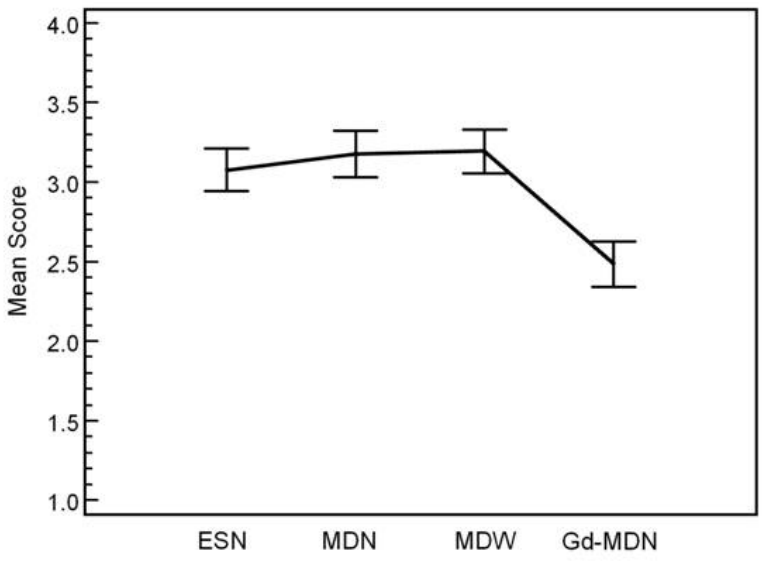

Fig 3. Graph represents mean image quality scores for the coronary artery segments based on a five-point scale: 1, not visible; 2, poor; 3, fair; 4, good; and 5, excellent. Images obtained at end-systole with narrow acquisition (ESN), mid-diastole with narrow acquisition (MDN) and mid-diastole with wide acquisition (MDW) did not differ significantly in quality. The Gd-enhanced MRA at MDN produced coronary artery images significantly lower in quality than those obtained by the other three methods with steady-state free precession (SSFP) ($p < 0.01$).

Table 1. Comparison of the mean scanning times and trigger delay times for four different acquisition methods in 3D whole-heart coronary MR angiography at 1.5 T.

	ESN	MDN	MDW	Gd-MDN
Scanning time (min)	12.1±3.4	12.0±2.0	8.9±2.4[a]	22.2±3.5[b]
Trigger delay time (msec)	273.3±27.5	621.0±72.1	594.7±73.4	621.0±72.1

a: Mean scanning time was significantly shorter in the MDW than in the ESN and MDN (p < 0.01). **b**: Mean scanning time was significantly longer in the Gd-MDN than in the other three methods with steady-state free precession (SSFP) (p < 0.01).

ESN = end-systole with a narrow acquisition window, MDN = mid-diastole with a narrow acquisition window, MDW = mid-diastole with a wide acquisition window, and Gd-MDN = Gd-enhanced MRA at mid-diastole with a narrow acquisition window.

Table 2. Comparison of signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) using four different acquisition methods with 3D whole-heart coronary MR angiography at 1.5 T.

	ESN	MDN	MDW	Gd-MDN
SNR	65.1±25.1	64.1±19.6	52.9±23.5	48.1±22.0[a]
RCA	57.9±20.0	61.9±20.4	49.0±17.8	61.4±16.0
LAD	67.3±228.	65.9±19.6	55.5±21.3	49.1±14.6
LCX	70.3±30.7	64.7±19.3	54.3±20.9	33.8±29.9
CNR	36.7±6.5	36.1±2.0	30.3±3.5	8.9±13.8[b]
RCA	29.4±13.2	33.8±16.8	26.4±11.6	4.4±17.1
LAD	38.8±15.8	37.8±15.3	32.7±14.2	7.9±14.6
LCX	41.9±22.4	36.6±14.5	31.7±13.4	23.2±38.2

a and b: Mean values of the SNR and CNR were significantly lower in the Gd-MDN than in the other three methods with steady-state free precession (SSFP) ($p < 0.05$).

ESN = end-systole with a narrow acquisition window, MDN = mid-diastole with a narrow acquisition window, MDW = mid-diastole with a wide acquisition window, Gd-MDN = Gd-enhanced MRA at mid-diastole with a narrow acquisition window, RCA = right coronary artery, LAD = left anterior descending artery, and LCx = left circumflex artery.

IV. DISCUSSION

This study demonstrates superior results overall for coronary MRA with SSFP, as compared to a Gd-enhanced FLASH, using a 1.5T scanner. The SSFP sequence produces high detection rates in coronary artery segments, good SNR and CNR, and high image quality. The narrow acquisition window at mid-diastole with an SSFP gives a relatively high image quality and excellent SNR, although the scan requires more time. Furthermore, imaging with SSFP at end-systole shows results similar to those at mid-diastole for coronary artery detection rates and image quality.

An SSFP sequence produces good results in coronary MRA at 1.5T using a volume-targeted approach because of its intrinsically high blood signal intensity and blood-myocardial contrast [2, 8]. Contrast medium is not required in this approach because it does not significantly improve the visibility of coronary segments, length of vessel visualized, or image quality [17]. Recently, however, Weber et al. [2] introduced 3D whole-heart coronary MRA that reveals the entire group of coronary arteries in a single acquisition. This technique permits subsequent reformations in arbitrary orientations and reformations for manifold imaging. These advantages, not shared with the conventional volume-targeted approach, simplify the planning and performance of coronary MRA. In this study, we found that 3D whole-heart coronary MRA using an SSFP sequence provided excellent image quality, and good CNR and SNR in the coronary artery images. In contrast, a 3D whole-heart FLASH sequence at 1.5T did not improve the coronary segment visibility, SNR, CNR or image quality.

The long acquisition time for 3D whole-heart coronary MRA presents a challenge because it may lead to motion artifacts, such as heart rate variations and respiratory drifts. Use of parallel imaging techniques may help to reduce acquisition times [13, 18]. Nehrke et al. [14] reported that a short scanning time of about four minutes with free breathing increases patient comfort and allows a whole-heart coronary MRA with sufficient SNR and spatial resolution to show the main trees and major branches of the coronary arteries. Sakuma et al. [13] also reported reliable 3D imaging of the coronary arteries, with 82% sensitivity and 91% specificity in detecting coronary artery stenosis.

Reducing cardiac motion artifacts may significantly improve image quality in the coronary MRA. Motion correction in the coronary computed tomographic (CT) angiography is generally performed by means of retrospective rearrangement of multi-section partial scan data relative to an electrocardiographic (ECG) signal that is recorded during image acquisition [19]. In contrast to coronary CTA, coronary MRA usually limits the data acquisition window to a portion of mid-diastole in which cardiac motion is expected to be minimal. To acquire the data sets at end-systole, the other low motion period in the cardiac cycle, we need to perform an additional scan. The low motion period at the completion of ventricular systole occurs at approximately 34% of the cardiac cycle, and lasts for approximately 118 msec (range 0-223 msec) [4]. The duration of systole is less affected by heart rate variability than the duration of diastole [20]. Gharib et al. [21] found no significant differences in image quality when comparing mid-diastole and end-systole, and from comparing vessel lengths, suggested that imaging during end-systole is least affected by heart rate variability. In our study, we found no significant differences between end-systole and mid-diastole images with respect to coronary segment visibility, SNR, CNR or image quality.

One advantage of coronary MRA is the ability to manipulate the scan window for image acquisition, and therefore, the acquisition time: the wider the acquisition window, the shorter the acquisition time. Although the acquisition time in our study did not differ significantly between the narrow window (120 msec) and the wide window (170 msec) at mid-diastole, the narrow window acquisition slightly increased acquisition time. However, the narrow window acquisition produced a much higher SNR (but not CNR) than the wide window acquisition. A higher SNR facilitate the evaluation of coronary artery disease and the 3D reformation of image data.

An MRA to evaluate the vascular system is most commonly performed with an intravenous administration of contrast material. Recent studies suggest, however, that an SSFP sequence gives better results for the abdominal and thoracic aorta with their branches than contrast-enhanced MRA [22-23]. Our study showed consistently better performance for an SSFP without contrast material than for the Gd-enhanced coronary MRA. The coronary MRA with SSFP gives better image quality, SNR and CNR than the Gd-enhanced coronary MRA and is also faster. The SSFP may therefore provide an excellent method for 3D whole-heart coronary MRA at 1.5T, although the contrast-enhanced coronary MRA with a FLASH sequence may be superior at 3.0T [24-26].

Our findings present several limitations. First, we performed our study in healthy volunteers. We did not evaluate the diagnostic accuracy of the 3D whole-heart coronary MRA as compared to coronary CTA or conventional coronary angiography. Second, we based the coronary rest period determination on cross-sectional RCA images only. On the average, the RCA moves more than twice as much as the LCA, and had a significantly shorter and later rest period [4, 6]. Furthermore, we did not evaluate the image quality or SNR for the coronary arteries (RCA, LAD or LCx) individually. Future studies may find differences between coronary arteries or coronary segments with respect to image quality, SNR, or other parameters.

V. CONCLUSION

In conclusion, the application of contrast material does not help to improve the detection rate, SNR, CNR or image quality in 3D whole-heart coronary MRA at 1.5T. The addition of an SSFP sequence provides an excellent method for the 3D whole-heart coronary MRA. Use of a narrow acquisition window improves the SNR, although this increases the acquisition time. Selection of the optimal cardiac phase, either at mid-diastole or at end-systole, may depend on the patient's heart rate.

REFERENCES

1 Manning WJ, Li W, Edelman RR. A preliminary report comparing magnetic resonance coronary angiography with conventional angiography. N Engl J Med 1993;328:828-32.

2 Weber OM, Martin AJ, Higgins CB. Whole-heart steady-state free precession coronary artery magnetic resonance angiography. Magn Reson Med 2003;50:1223-8.

3 Botnar RM, Stuber M, Danias PG, Kissinger KV, Manning WJ. Improved coronary artery definition with T2-weighted, free-breathing, three-dimensional coronary MRA. Circulation 1999;99:3139-48.

4 Johnson KR, Patel SJ, Whigham A, Hakim A, Pettigrew RI, Oshinski JN. Three-dimensional, time-resolved motion of the coronary arteries. J Cardiovasc Magn Reson 2004;6:663-73.

5 Wang Y, Watts R, Mitchell I, Nguyen TD, Bezanson JW, Bergman GW, et al. Coronary MR angiography: selection of acquisition window of minimal cardiac motion with electrocardiography triggered navigator cardiac motion prescanning--initial results. Radiology 2001;218:580-5.

6 Hofman MB, Wickline SA, Lorenz CH. Quantification of in-plane motion of the coronary arteries during the cardiac cycle: implications for acquisition window duration for MR flow quantification. J Magn Reson Imaging 1998;8:568-76.

7 Wang Y, Vidan E, Bergman GW. Cardiac motion of coronary arteries: variability in the rest period and implications for coronary MR angiography

Radiology 1999;213:751-8.

8 Finn JP, Nael K, Deshpande V, Ratib O, Laub G. Cardiac MR imaging: state of the technology. Radiology 2006;241:338-54.

9 Deshpande VS, Shea SM, Laub G, Simonetti OP, Finn JP, Li D. 3D magnetization prepared true-FISP: a new technique for imaging coronary arteries. Magn Reson Med 2001;46:494-502.

10 Giorgi B, Dymarkowski S, Maes F, Kouwenhoven M, Bogaert J. Improved visualization of coronary arteries using a new three-dimensional submillimeter MR coronary angiography sequence with balanced gradients. AJR Am J Roentgenol 2002; 179:901-10.

11 Spuentrup E, Buecker A, Stuber M, Botnar R, Nguyen TH, Börnert P, et al. Navigator-gated coronary magnetic resonance angiography using steady-state-free-precession: comparison to standard T2-prepared gradient-echo and spiral imaging. Invest Radiol 2003;38:263-8.

12 Gerber BL, Coche E, Pasquet A, Ketelslegers E, Vancraeynest D, Grandin C, et al. Coronary artery stenosis: direct comparison of four-section multi-detector row CT and 3D navigator MR imaging for detection--initial results. Radiology 2005;234:98-108.

13 Sakuma H, Ichikawa Y, Suzawa N, Hirano T, Makino K, Koyama N, et al. Assessment of coronary arteries with total study time of less than 30 minutes by using whole-heart coronary MR angiography. Radiology 2005;237:316-21.

14 Nehrke K, Bornert P, Mazurkewitz P, Winkelmann R, Grasslin I. Free-breathing whole-heart coronary MR angiography on a clinical scanner in four minutes. J Magn Reson Imaging 2006;23:752-6.

15 Stehning C, Bornert P, Nehrke K, Eggers H, Stuber M. Free-breathing whole-heart coronary MRA with 3D radial SSFP and self-navigated image reconstruction. Magn Reson Med 2005;54:476-80.

16 Scanlon PJ, Faxon DP, Audet AM, Carabello B, Dehmer GJ, Eagle KA, et al. ACC/AHA guidelines for coronary angiography. A report of the American College of Cardiology/American Heart Association Task Force on practice guidelines (Committee on Coronary Angiography). Developed in collaboration with the Society for Cardiac Angiography and Interventions. J Am Coll Cardiol 1999; 33:1756-824.

17 Zagrosek A, Noeske R, Abdel-Aty H, Friedrich MG, Dietz R, Schulz-Menger J. MR coronary angiography using 3D-SSFP with and without contrast application. J Cardiovasc Magn Reson 2005;7:809-14.

18 Niendorf T, Hardy CJ, Giaquinto RO, Gross P, Cline HE, Zhu Y, et al. Toward single breath-hold whole-heart coverage coronary MRA using highly accelerated parallel imaging with a 32-channel MR system. Magn Reson Med 2006; 56:167-76.

19 Ohnesorge B, Flohr T, Becker C, Kopp AF, Schoepf UJ, Baum U, et al. Cardiac imaging by means of electrocardiographically gated multisection spiral CT: initial experience. Radiology 2000; 217:564-71.

20 Weissler AM, Harris WS, Schoenfeld CD. Systolic time intervals in heart

failure in man. Circulation 1968;37:149-59.

21 Gharib AM, Herzka DA, Ustun AO, Desai MY, Locklin J, Pettigrew RI, et al. Coronary MR angiography at 3T during diastole and systole. J Magn Reson Imaging 2007;26:921-6.

22 Iozzelli A, D'Orta G, Aliprandi A, Secchi F, Di Leo G, Sardanelli F. The value of true-FISP sequence added to conventional gadolinium-enhanced MRA of abdominal aorta and its major branches. Eur J Radiol 2009;72:489-93.

23 Pereles FS, McCarthy RM, Baskaran V, Carr JC, Kapoor V, Krupinski EA, et al. Thoracic aortic dissection and aneurysm: evaluation with nonenhanced true FISP MR angiography in less than 4 minutes. Radiology 2002; 223:270-4.

24 Bi X, Li D. Coronary arteries at 3.0 T: Contrast-enhanced magnetization prepared three-dimensional breathhold MR angiography. J Magn Reson Imaging 2005; 21:133-9.

25 Bi X, Carr JC, Li D. Whole-heart coronary magnetic resonance angiography at 3 Tesla in 5 minutes with slow infusion of Gd-BOPTA, a high-relaxivity clinical contrast agent. Magn Reson Med 2007; 58:1-7.

26 Sommer T, Hackenbroch M, Hofer U, Schmiedel A, Willinek WA, Flacke S, et al. Coronary MR angiography at 3.0 T versus that at 1.5 T: initial results in patients suspected of having coronary artery disease. Radiology 2005; 234:718-25.

ABSTRACT(IN KOREAN)

1.5T에서 항정상태자유세차를 이용한 3차원 전심장 관상동맥 자기공명혈관조영술: 가돌리늄 조영증강 고속저각영상획득 연쇄를 이용한 관상동맥 자기공명혈관조영술과의 비교

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목적: 1.5T에서 항정상태자유세차를 이용한 3차원 전심장 관상동맥 자기공명혈관조영술 에서의 최적의 심장기와 적합한 획득창을 결정하고, 항정상태자유세차와 가돌리늄 조영 증강 고속저각영상회득 연쇄를 이용한 자기공명혈관조영술 사이에서 관상동맥 영상 질과 발견률을 비교하기 위함이다.

방법: 총 30 명의 건강한 자원자를 대상으로 1.5T 관상동맥 자기공명혈관조영술을 시행하였다. 항정상태자유세차를 이용한 3 차원 전심장 관상동맥 자기공명혈관조영술은 각각 3 차례 시행하였다: 1)좁은 획득창 (120 msec)을 이용한 수축기말 영상 (ESN), 2)좁은 획득창을 이용한 이완중기 영상 (MDN), 3)넓은 획득창 (170 msec)을 이용한 이완중기 영상 (MDW). 가돌리늄 조영증강 고속저각영상획득을 이용한 관상동맥 자기공명혈관조영술은

MDN 으로 시행하였다. 관상동맥의 시감도와 영상 질은 American Heart Association 에서 제시한 11 분절을 이용하여 평가하였다. 영상 질은 5 점 척도로 측정하였다 (1=보이지 않음, 5=우수함). 신호대잡음비와 대조잡음비는 근위부 관상동맥에서 평가하였다.

결과: 1.5T 에서 항정상태자유세차 연쇄는 가돌리늄 조영증강 고속저각영상획득 기술에 비하여 더 높은 관상동맥 발견률, 더 좋은 신호대잡음비율과 대조잡음비 그리고 더 높은 영상 질을 보여주었다 ($p < 0.05$). 항정상태자유세차를 이용한 MDN 영상은 비록 스캔 시간은 길었지만, 높은 영상 질과 우수한 신호대잡음비를 보여주었다. 수축기말의 항정상태자유세차를 이용한 영상은 관상동맥 발견률과 영상 질에 있어서 이완중기 영상과 비슷한 결과를 보여주었다.

결론: 1.5T 3 차원 전심장 관상동맥 자기공명혈조영술에서 조영제를 이용한 영상은 발견률, 신호대잡음비, 대조잡음비 그리고 영상 질을 향상시키지 못했다. 최적의 영상을 얻기 위한 심장기는 이완중기나 수축기말에 큰 차이가 없어, 일괄적으로 적용하기 보다는 환자의 심박수에 따라 결정되어야 할 것이다.

핵심되는 말 : 심장자기공명영상, 관상동맥영상, 항정상태자유세차, 고속저각영상획득, 조영증강, 1.5T