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3D non-contrast whole-heart coronary MR angiography at 3 T with compressed sensing in elderly patients: Optimization of the acceleration factor

Yue Jiang [a], Qiuju Hu [a], Yane Zhao [a], Dongsheng Jin [a], Guangming Lu [a], Tong Chen [b], Yong Yuan [a,*], Wenjing Liu [a,*]

[a] Department of Radiology, Geriatric Hospital of Nanjing Medical University, Nanjing, China
[b] Philips (China) Investment Co., Ltd., Hangzhou, China

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ABSTRACT

Background: Coronary magnetic resonance angiography (CMRA) is increasingly used in clinical practice, but lengthy scan times can be challenging for elderly patients. This study evaluates the impact of compressed sensing (CS) technology on image quality and diagnostic performance of 3 T CMRA in elderly patients, aiming to identify the optimal acceleration factor.

Methods: We prospectively enrolled elderly individuals who underwent coronary computed tomography angiography (CCTA) from June to November 2023 for non-contrast whole-heart CMRA with CS acceleration factors of 4, 6, or 8. Elderly volunteers rated their experiences with the optimal acceleration factor. Image quality and diagnostic performance were analyzed using a general linear model and the area under the receiver operating characteristic curves (AUC), with CCTA as the reference standard.

Results: Sixty-seven individuals (34 men, mean age 74.3 ± 7.2 years) were enrolled. Scan times significantly decreased from 578.6 ± 131.4 s to 366.1 ± 91.2 s and 261.1 ± 76.5 s for acceleration factors 4, 6, and 8, respectively. Subjective image quality scores, signal-to-noise ratio, and contrast-to-noise ratio were significantly better with CS4 and CS6 than with CS8. Diagnostic performance declined with increasing acceleration, with sensitivities of 92.2 %, 88.0 %, and 72.5 %, and specificities of 94.1 %, 92.6 %, and 85.3 % for CS4, CS6, and CS8, respectively. CS6 was determined to be the optimal acceleration factor. Volunteers reported that CS6 was more acceptable than CS4.

Conclusions: CMRA with CS6 provides rapid scanning while maintaining adequate diagnostic performance, making it a reliable alternative to CCTA for diagnosing coronary artery disease in elderly patients.

1. Introduction

Coronary artery disease (CAD) is one of the most prevalent types of cardiovascular disease worldwide and is responsible for over 62 % of heart failure cases [1]. Invasive coronary angiography remains the gold standard for confirming CAD diagnosis; however, it is an invasive procedure typically reserved for severe cases [2]. Increasing evidence supports the use of coronary computed tomography angiography (CCTA) as the first-line imaging modality for ruling out CAD [3,4]. While CCTA is non-invasive or minimally invasive, it involves ionizing radiation and nephrotoxic iodine contrast agents, which can pose significant risks for elderly patients, many of whom have compromised kidney function [5,6].

An alternative diagnostic method that circumvents these drawbacks is coronary magnetic resonance angiography (CMRA), although it is associated with long scan times. Extended scan durations are critical not only for the success of CMRA but also limit the number of patients that can be examined in a day, making widespread application challenging. This issue is exacerbated by the fact that CAD predominantly affects the elderly, who may struggle to tolerate lengthy scans and are at an

Abbreviations: CCTA, coronary computed tomography angiography; CMRA, coronary magnetic resonance angiography; CS, compressed sensing; BSSFP, balanced steady-state free precession; SNR, signal-to-noise ratios; CNR, contrast-to-noise ratio; TR, repetition time; TE, echo time.

* Correspondence to: Geriatric Hospital of Nanjing Medical University, 65 Jiangsu Road, Nanjing, Jiangsu 210024, China.
E-mail addresses: 53615238@qq.com (Y. Yuan), 914123851@qq.com (W. Liu).

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increased risk of image quality degradation due to body motion or altered breathing patterns [7].

To address the challenge of prolonged scanning, compressed sensing (CS) technology has been integrated into CMRA. This technology allows for reduced scan times by selecting an appropriate acceleration factor that balances scanning speed with diagnostic performance: higher acceleration factors lead to faster scans but lower signal-to-noise ratios (SNR) [8,9]. Research indicates that CS acceleration factors typically range from 3 to 9 [10,11]. A study using CS technology demonstrated that while a CS factor 9 can significantly reduce scan time, it results in relatively low image quality scores [12]. Conversely, CS factors 2 and 3 do not offer any advantages in terms of scan duration [13]. Currently, the most commonly used CS settings are 4 or 5 [8,9]. However, many elderly patients undergoing CMRA with CS4 have reported that the scan time is excessively long and intolerable. This raises the question of whether CS4 is indeed suitable for elderly patients. If the CS factor is increased, will it enhance the acceptability of CMRA among the elderly without significantly compromising image quality and diagnostic efficacy?

There is a scarcity of studies addressing CMRA specifically in elderly populations, as most existing research has focused on middle-aged individuals [8,9]. However, the application of CMRA in the elderly is urgently needed and holds significant potential, particularly in an aging society, given that CAD prevalence increases with age [1]. In this study, we performed CMRA on the same patient using three different CS acceleration factors 4, 6, and 8 to identify the optimal CS factor for elderly patients.

2. Materials and methods

2.1. Study population and design

This prospective observational study was approved by the Ethics Committee of our hospital, and all participants provided written informed consent prior to enrollment. The study was conducted in accordance with the principles outlined in the Declaration of Helsinki. Technical support for the study was provided by Philips Healthcare (China). The authors, who are not employees of Philips Healthcare, maintained complete control over data collection and analysis.

We prospectively enrolled elderly individuals who underwent CCTA at our hospital from June to November 2023 for suspected coronary artery disease. All participants underwent CMRA using compressed sensing (CS) with acceleration factors of 4, 6, or 8 to determine the most appropriate CS acceleration factor. In addition, we planned to recruit 80 elderly volunteers who met inclusion and exclusion criteria, regardless of whether they underwent CCTA or not. Following the identification of the optimal CS acceleration factor, 40 volunteers were selected to undergo CMRA with a CS factor of 4. Subsequently, another group of 40 volunteers underwent CMRA using the newly confirmed CS acceleration factor. After the CMRA procedure, participants rated their experience using the following scale: 1) completely acceptable, willing to undergo a CMRA review if needed; 2) acceptable, willing to undergo a CMRA review; 3) neutral, neither good nor bad; 4) barely tolerable, reluctant to undergo a CMRA review; 5) unbearable, unwilling to undergo a CMRA review.

Inclusion standard: 1) age $\geq$ 65 years old (defined as elderly); 2) body mass index < 28 kg/m^2; 3) no arrhythmia except for occasional ventricular premature beats; 4) no claustrophobia; 5) no histories of any heart surgery, including percutaneous coronary intervention, coronary artery bypass grafting, pacemaker implantation, or valve replacement. Individuals were excluded from the study if they experienced any arrhythmia (other than occasional ventricular premature beats) during scanning or if they were unable to understand and comply with the steady-breathing requirements.

2.2. CCTA protocol

All participants were examined using a dual-source computed tomography system (SOMATOM FORCE, Siemens, Berlin, Germany) equipped with retrospective electrocardiographic gating. The scanning parameters included a tube voltage of 110 kV, a slice thickness of 0.75 mm, a slice interval of 0.5 mm, a matrix size of 512 $\times$ 512, and a tube current that was automatically adjusted using the manufacturer-specified CARE DOSE algorithm. Image reconstruction was performed during the diastolic phase. The entire heart was scanned in a head-to-foot direction, starting 2 cm below the tracheal bifurcation and extending down to the apex of the heart. Bolus tracking was initiated in the ascending aorta, positioned 1.5 cm below the tracheal bifurcation, with a threshold set at 100 Hounsfield Units (HU). Each subject received an injection of 45–55 mL of the contrast agent iodixanol, tailored to the patient's body weight (350 mg/mL, Yangzijiang Pharmaceuticals, Jiangsu, China)., followed by a flush of 20 mL of normal saline (Sichuan Kelun Pharmaceutical, Sichuan, China). A high-pressure dual-barrel injector was used to administer the contrast agent at a rate of 4.0–4.5 mL/s.

2.3. CMRA protocol

All participants underwent CMRA using a 3 T magnetic resonance scanner (Ingenia, Elition, Philips, Netherlands) with a 32-channel phased-array body coil. Participants were instructed to refrain from taking nitroglycerin or any other medications for 24 hours prior to the scan. If a subject's heart rate exceeds 80 beats per minute, a beta-blocker will be administered to reduce it to 80 beats per minute. Fasting was mandatory before the CMRA procedure. During the scan, individuals were positioned supine, breathing calmly with their legs resting on a wedge pad. We acquired transverse, coronal, and sagittal images. Participants were then instructed to hold their breath while cine sequences of the four-chamber view were obtained, allowing for visualization of the right coronary artery to identify the relatively quiescent phase (Fig. 1). Cine sequences were also utilized to assess diaphragmatic motion amplitude, with a diaphragm navigator placed on the right side of the diaphragm at the end of inspiration. Finally, a 3D balanced steady-state free precession (bSSFP) sequence was employed to image the entire heart at acceleration factors of 4, 6, or 8. Imaging parameters were as follows: field of view, 280 $\times$ 280 mm^2; size of the original voxel, 1.5 $\times$ 1.5 $\times$ 1.5 mm^3; size of reconstructed voxel, 0.73 $\times$ 0.73 $\times$ 0.75 mm^3; matrix, 188 $\times$ 228; number of slices, 320–350; gating window, 5; repetition time (TR), 2.6 ms; echo time (TE), 1.28 ms; and flip angle, 70° (Table 1). Patient-level subjective scores, SNRs, and CNRs were calculated based on the average of each segment.

2.4. Assessment of image quality and diagnostic performance

CMRA images of nine segments were analyzed in all individuals, as defined in previous CCTA [14] and CMRA studies [15,16]. These segments included the proximal, middle, and distal segments of the left anterior descending artery and the right coronary artery; the proximal and distal segments of the left circumflex artery; and the left main coronary artery. The image quality of each segment, as well as each patient's diagnostic performance, was assessed using a clinical workstation (IntelliSpace Portal version 12.0, Philips Healthcare).

The subjective assessment of CMRA image quality was conducted independently by two investigators: one with eight years of CMRA experience (Y.Y.) and the other with six years of experience (H.Q.), both of whom were blinded to the results of CCTA. Each investigator assigned a quality score to each segment of CMRA from 1 to 5 as follows: 5, excellent quality with precise vessel contours and without motion artifacts; 4, good quality with minor artifacts and slight blurring of vessel contours; 3, fair quality with moderate artifacts that should not affect clinical interpretation; 2, poor quality with severe artifacts that affect

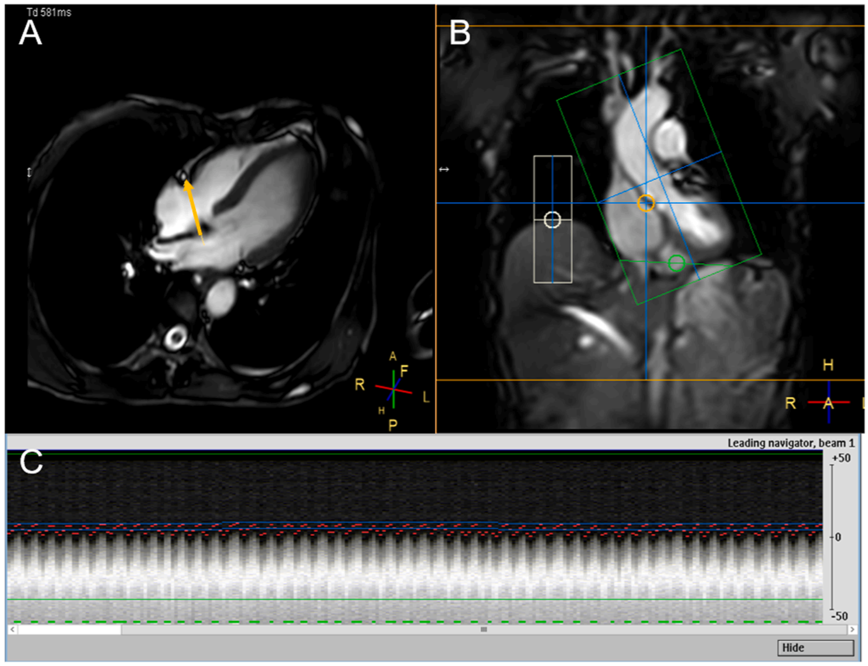

Fig. 1. Representative examples of magnetic resonance coronary angiography imaging. (A) Cardiac four-chamber cine sequence from one individual. (B) Diaphragmatic cine sequence from the same individual. (C) A diaphragmatic navigation diagram was derived from the data in panel B.

Table 1
Imaging parameters.

Sequence type	**CS 4** Balanced turbo fast echo	**CS 6** Balanced turbo fast echo	**CS8** Balanced turbo fast echo	*P* value
Magnetic field intensity	3 T	3 T	3 T	
TR/TE (ms)	3.1/1.56	3.1/1.56	3.1/1.56	
Matrix	200 × 271	200 × 271	200 × 271	
FOV (mm^3)	380 × 280 × 217	380 × 280 × 217	380 × 280 × 217	
Flip angle (degree)	70	70	70	
Fat suppression	SPIR	SPIR	SPIR	
3D	Yes	Yes	Yes	
Acquisition periods	Mid-diastole	Mid-diastole	Mid-diastole	
Acquire window (ms)	70–110	70–110	70–100	
Acquired factor	5	5	5	
Acquisition orientation	Coronal	Coronal	Coronal	
Acceptance window (mm)	5	5	5	
ECG gated navigation	Yes	Yes	Yes	
Navigator Gating efficiency	41.2 % ± 7.6 %	43.8 ± 8.9 %	42.3 ± 8.1 %	0.482
Glyceryl trinitrates	No	No	No	
Acquisition time (s)	578.6 ± 131.4	366.1 ± 91.2	261.1 ± 76.5	< 0.001

Values are n (%), means ± standard deviations, CS = compressed sensing.

clinical interpretation; or 1, inferior quality such that one or more segments could not be evaluated [17]. In cases of disagreement between the two primary investigators, the matter was discussed with a third experienced investigator (J.D.), who has 12 years of CMRA experience and was also blinded to the CCTA results. A consensus was reached to finalize the quality assessment.

Objective assessment of CMRA image quality was measured by two investigators independently, one with six years of CMRA experience (L. W.) and the other with five years of experience (J.Y.), both of whom were blinded to the results of CCTA. An at least 2 mm^2 region of interest was placed on the coronary artery segments, sized according to the lumen diameters, and signal intensity was recorded. The image noise of CMRA was set to the standard deviation of a 25 mm^2 region of interest placed at the septum. The SNR was calculated using the formula: SNR = coronary artery signal intensity/noise. The contrast-to-noise ratio (CNR) was calculated using the formula: CNR = (coronary artery signal intensity – ventricular septal myocardial signal intensity) /noise. The average of the two investigators' measurements is taken as the final value.

As outlined in the subjective image quality assessment, the same three investigators visually evaluated each patient for significant stenosis in the CMRA images. Significant stenosis was defined as a 50 % reduction in lumen diameter, with CCTA serving as the reference standard for diagnosis. In cases of multiple stenoses, the most severe stenosis was documented. CCTA analyses were conducted on a workstation (syngo.via, version VB60; Siemens Healthineers) by two experienced investigators, each with ten years of CCTA experience and blinded to the CMRA results. A consensus was reached regarding the findings.

2.5. Statistical analysis

Data were analyzed statistically using SPSS (version 26.0) and GraphPad Prism (version 8.0.2), with significance of $P < 0.05$. Continuous data were assessed for normal distribution using the Shapiro-Wilk test. Normally distributed data were reported as mean ± standard deviation, while non-normally distributed data were reported as median (interquartile range). Categorical data were expressed as n (%).

The general linear model was employed to evaluate the statistical differences in scan time, subjective image quality scores, SNR, and CNR across CMRA with three different CS of 4, 6, and 8, using the least significant difference (LSD) for post hoc pairwise comparisons. The area under the receiver operating characteristic curve (AUC) was utilized to assess the diagnostic performance of CMRA with a paired-sample design for post hoc comparisons (DeLong's test), using CCTA as the reference standard.

The Mann-Whitney test was conducted to analyze volunteers' perceptions between the CS4 and CS6 groups after the completion of CMRAs. Inter- and intra-observer agreements were evaluated using Bland-Altman analysis.

3. Results

Of the 73 individuals who underwent CCTA with suspected coronary artery disease initially enrolled in the study, 67 (33 men) with an average age of 74.3 ± 7.2 years were included in the final analysis (Fig. 2, Table 2).

Scan time decreased significantly with different accelerations, falling from 578.6 ± 131.4 s at CS4 to 366.1 ± 91.2 s at CS6, then 261.1 ± 76.5 s at CS8 (all post hoc pairwise $P < 0.001$). Subjective image quality scores at the patient level were equally high for CS4 and CS6 (pairwise $P = 0.426$). These two sets of scores were significantly higher than those for CS8 (both pairwise $P < 0.001$), with a higher proportion of excellent and good ratings (Table 3, Figs. 3–5). The SNR and CNR at the patient level were equally high for CS4 and CS6 ($P = 0.217$ and $P = 0.165$, pairwise, respectively), and these two sets of indices were significantly higher than those for CS8 (both pairwise $P < 0.05$), as shown in Table 3, Figs. 3 and 4.

Sensitivity at the patient level decreased from 92.2 % at CS4 to 88.0 % at CS6 and 72.5 % at CS8; Specificity decreased from 94.1 % to 92.6 % and 85.3 %; positive predictive value, from 85.2 % to 81.5 % and 64.3 %; negative predictive value, from 97.0 % to 95.5 % and 89.2 %; and AUC, from 0.931 to 0.903 and 0.786, $P < 0.001$, with post hoc CS4 vs. CS6 $P = 0.483$, CS4 vs. CS8 $P < 0.001$, CS6 vs. CS8 $P = 0.013$, as shown in Fig. 6.

The optimal acceleration factor for elderly patients was initially determined to be CS6. Volunteers reported that CS6 was more acceptable than CS4, with a higher proportion feeling acceptable and willing to undergo a CMRA review if needed, with the Mann-Whitney test $P = 0.007$, as shown in Fig. 7.

Regardless of the acceleration factors, there was a good agreement between the two designated independent researchers regarding the objective measurements of CMRA SNR (Fig. 8).

Table 2
Characteristics of study participants.

Characteristic	Value
Age (years)	74.3 ± 7.2
Women / Men	33 / 34 (49.3 %/50.7 %)
Body mass index (kg/m^2)	23.4 ± 2.8
Heart rate (bpm)	69.8 ± 8.53
Risk factors of coronary artery disease	
Hypertension	21 (31.3 %)
Diabetes mellitus	8 (11.9 %)
Dyslipidemia	23 (34.3 %)
Smoking	11 (16.4 %)
History of alcohol consumption	18 (26.9 %)
Family history of coronary artery disease	18 (26.9 %)

Values are n (%), means ± standard deviations.

Table 3
Scan time and patient-level CMRA image quality analysis.

Groups		Scan time (s)	Subjective score	SNR	CNR
A: CS 4		578.6 ± 131.4	4.5 ± 0.6	32.7 ± 6.3	16.0 ± 4.8
B: CS 6		366.1 ± 91.2	4.3 ± 0.7	32.1 ± 6.0	15.7 ± 5.3
C: CS 8		261.1 ± 76.5	3.2 ± 0.7	24.0 ± 5.8	9.8 ± 4.2
P value		< 0.001	< 0.001	< 0.001	< 0.001
LSD Pairwise comparisons: *P* value	A vs. B	< 0.001	0.426	0.217	0.165
	A vs. C	< 0.001	< 0.001	0.016	0.023
	B vs. C	< 0.001	< 0.001	0.004	0.021

SNR = signal-to-noise ratio; CNR = contrast-to-noise ratio; CMRA = coronary magnetic resonance angiography; CS = compressed sensing.

4. Discussion

This study focused on evaluating the image quality and diagnostic performance of CMRA using Compression Sensing (CS) with acceleration factors of 4, 6, and 8, particularly in elderly patients. Our findings demonstrate that an acceleration factor of CS6 significantly reduces scanning time while maintaining excellent image quality and diagnostic performance, making it highly suitable for clinical use in elderly

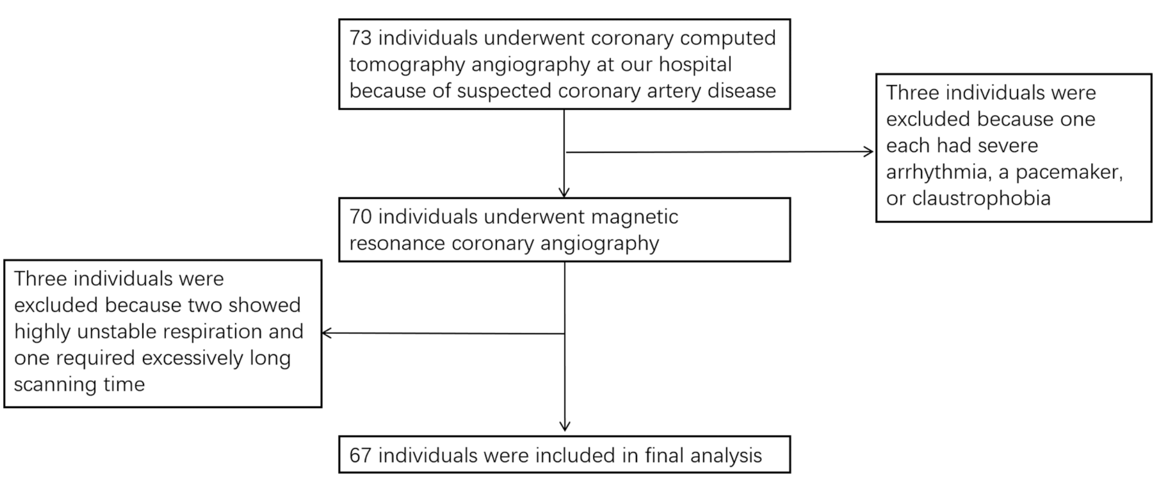

Fig. 2. Flowchart of participant inclusion and exclusion.

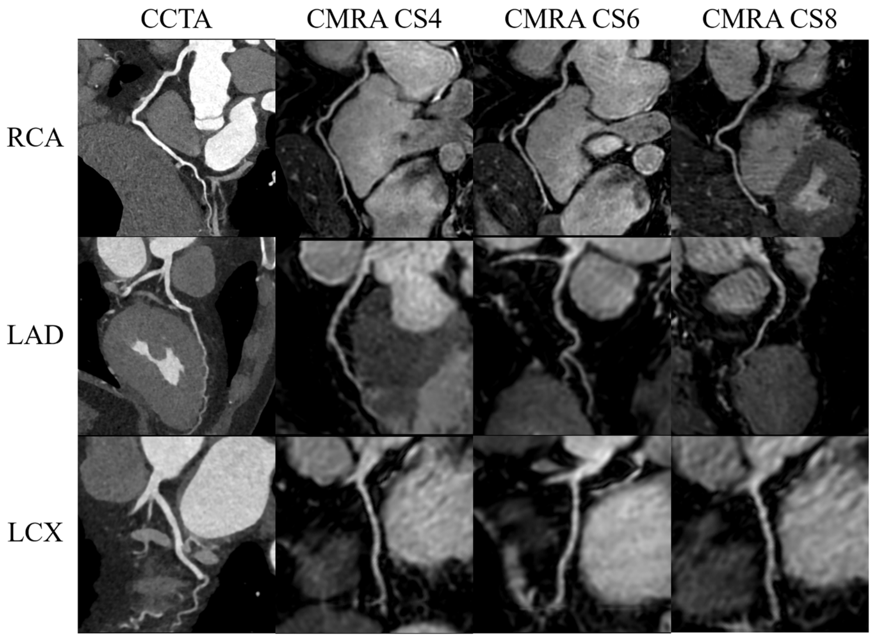

Fig. 3. Comparison of coronary artery imaging by CCTA and CMRA with CS4, 6, and 8. The images come from a 66-year-old man with angina pectoris. The upper row is RCA, the middle row is LAD, and the lower row is LCX. CCTA, CMRA CS4, CMRA CS6, and CMRA CS8 images are sequenced from left to right. The image quality of CS8 is inferior to that of CS4 and CS6, exhibiting more jagged artifacts and lower coronary signal intensity. There is a slight stenosis of the proximal segment of the LAD. Abbreviations: RCA = right coronary artery; LAD = left anterior descending artery; LCX = left circumflex; CMRA = coronary magnetic resonance angiography; CCTA = coronary computed tomography angiography; CS = compressed sensing.

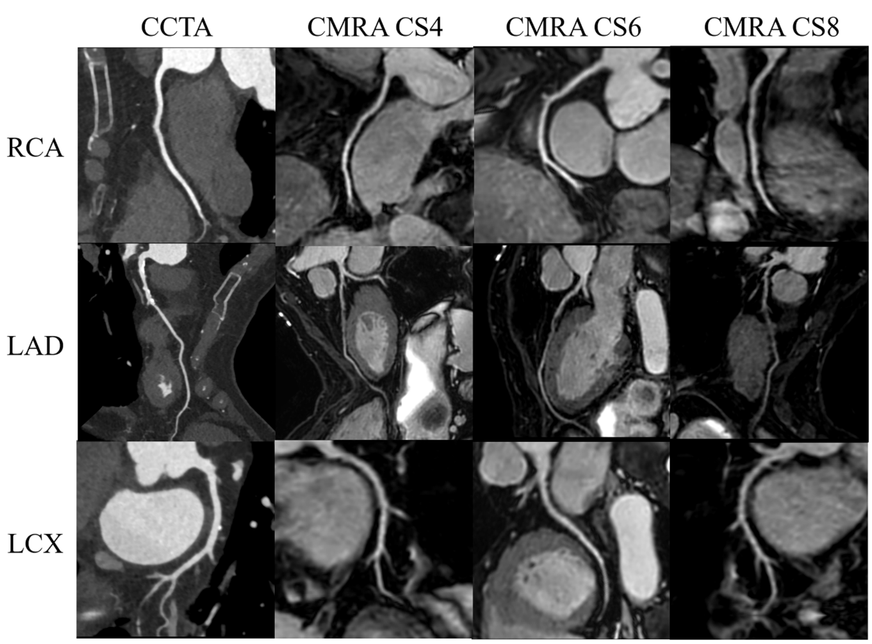

Fig. 4. Comparison of coronary artery imaging by CCTA and CMRA with CS 4, 6, and 8. The images come from a 75-year-old man with angina pectoris. The upper row is RCA, the middle row is LAD, and the lower row is LCX. CCTA, CMRA CS4, CMRA CS6, and CMRA CS8 images are sequenced from left to right. The image quality of CS8 is inferior to that of CS4 and CS6, exhibiting more jagged artifacts and lower coronary signal intensity. There is a severe stenosis of the middle segment of the LAD. Abbreviations as in Fig. 3.

populations.

In contrast to a prior study [9]by Zhang et al., which concluded that CS4 provided the best image quality, our results indicate that CS6 is more appropriate for elderly patients. This discrepancy may stem from differences in study populations: while Zhang et al. primarily examined middle-aged patients, our study focused on elderly individuals, who often face challenges such as poor tolerance for lengthy scans and irregular breathing patterns. The reduced scan time achieved with CS6 minimizes motion artifacts, coughing, and respiratory variability, which are common in elderly patients. This may explain why CS6 delivers image quality comparable to CS4, despite the higher acceleration factor.

CMRA with CS6 emerges as a reliable alternative to CCTA for elderly patients. The shortened scan time enhances patient acceptability, as evidenced by our survey results. This increased acceptability could encourage more elderly patients with precordial discomfort or suspected CAD to undergo CMRA. If severe stenosis is detected, these patients can

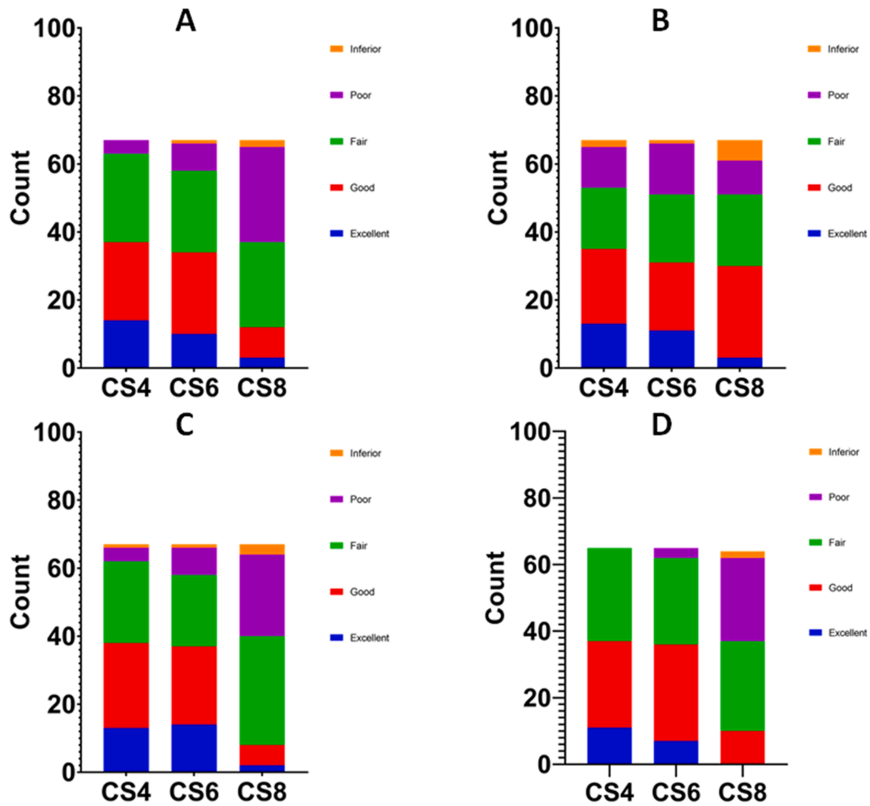

Fig. 5. Stacked graphs of subjective image quality scores of RCA (A), LAD (B), LCX, (C), and the three coronary arteries as a whole (D). There is a higher proportion of excellent and good ratings in the CS4 and CS6 groups compared to CS8, $P < 0.001$, with no significant difference between CS4 and CS6, $P = 0.426$. Abbreviations as in Fig. 3.

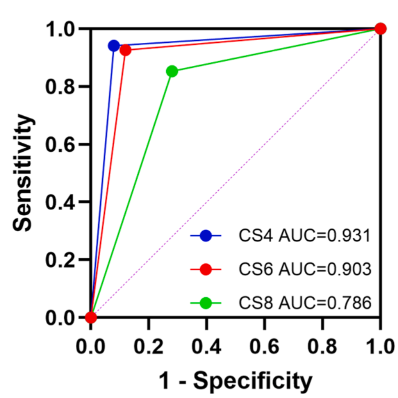

Fig. 6. Receiver operating characteristic curves for CMRA at CS4, CS6, and CS8. Aera under curves are 0.93, 0.90, and 0.79, respectively, $P < 0.001$. Post hoc analysis using DeLong's test revealed the following pairwise comparisons: CS4 vs. CS6 ($P = 0.483$), CS4 vs. CS8 ($P < 0.001$), and CS6 vs. CS8 ($P = 0.013$). Abbreviations as in Fig. 3.

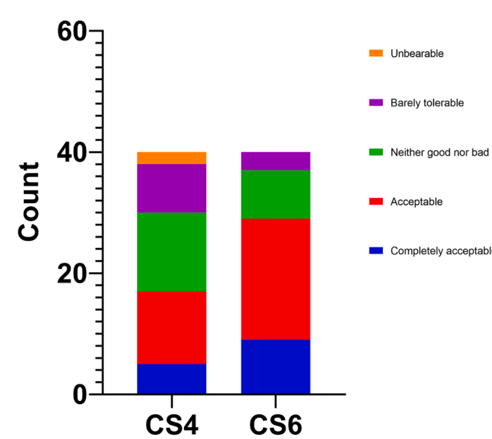

Fig. 7. A stacked graph illustrating volunteer perceptions after CMRA with CS4 and CS6. Volunteers indicated that CS6 was more acceptable than CS4, with a higher proportion reporting it as acceptable and expressing willingness to undergo a CMRA review if needed, $P = 0.007$. Abbreviations as in Fig. 3.

be directly referred for invasive coronary angiography, potentially eliminating the need for CCTA. This approach not only reduces healthcare costs but also avoids the risks associated with ionizing radiation and contrast-induced nephropathy, thereby influencing clinical decision-making in favor of CMRA over CCTA.

Traditional MRI methods require extensive raw data collection for image reconstruction. CS, however, exploits the sparsity or compressibility of MRI signals in specific domains, allowing for significant reductions in scan time without substantial loss of information [18,19]. While higher acceleration factors further reduce scan times, they come at the cost of image quality. Our study found that CS4 and CS6 provided significantly superior image quality compared to CS8, which proved inadequate for elderly patients. Prior studies [12] have also reported poor image quality with CS9, reinforcing our conclusion that CS8 and CS9 are unsuitable for this population. Future research could explore the potential of CS7 for elderly patients if needed.

While established studies [8,9,20,21] on CS acceleration factors have primarily focused on image quality, our research also assessed diagnostic performance. Using CCTA as a reference, we found that CS6 achieved high diagnostic sensitivity and specificity while shortening scan times. This enhances the clinical value of CS6, as image quality ultimately serves clinical needs. Among the nine arterial segments

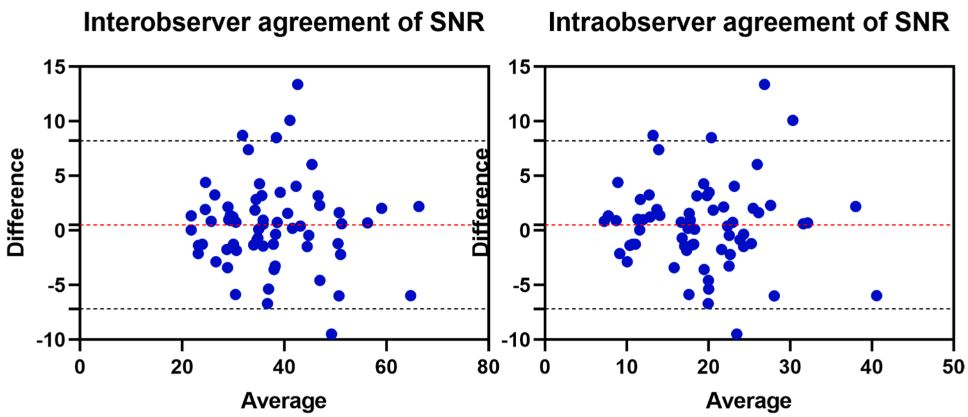

Fig. 8. Bland-Alterman plots of inter- and intra-observer agreements for objective measurements of CMRA SNR. The plots demonstrate good agreement between the two readers regarding the objective measurements of CMRA. Abbreviations as in Fig. 3.

analyzed, we successfully imaged all with sufficient diagnostic quality, even though distal segments typically exhibited lower signal-to-noise ratios compared to middle or proximal segments. This contrasts with another CMRA study, which reported decreased diagnostic performance in distal segments [22].

Our study has several limitations. First, the relatively small sample size from a single medical center, comprising patients clinically suspected of having CAD, necessitates a cautious interpretation of the results. Second, as all participants underwent serial CMRA scans at three acceleration factors, variations in heart rate and respiration during these scans could not be entirely ruled out. Third, the use of CCTA as the reference standard, rather than invasive coronary angiography, may introduce an "Imperfect Gold Standard Bias," potentially overestimating or underestimating CMRA's diagnostic accuracy. While invasive coronary angiography is considered the gold standard for coronary artery diagnosis, its invasive nature and high-cost limit its widespread use. Future studies should include a larger cohort of patients who have undergone invasive coronary angiography to validate our findings more robustly. Lastly, we did not perform further severity classifications of stenosis when assessing diagnostic performance, a gap that will be addressed in future research.

5. Conclusions

CMRA with CS6 represents an optimal balance between rapid scanning and adequate diagnostic performance, particularly for elderly patients. Non-contrast 3D whole-heart CMRA at 3 T using CS technology offers a reliable alternative to CCTA for diagnosing CAD in this population. Future studies should explore the utility of CMRA with compressed sensing for assessing stenosis severity, further solidifying its role in clinical practice.

Ethics approval and consent to participate

The Ethics Committee of Geriatric Hospital of Nanjing Medical University approved this prospective observational study. All participants provided written informed consent before enrollment. The study was performed under the principles of the Declaration of Helsinki.

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Author contributions

Guangming Lu, Dongsheng Jin, Yane Zhao, Tong Chen, and Yong Yuan designed the study protocol. Yong Yuan and Wenjing Liu performed the statistical analysis and drafted the manuscript. Yue Jiang, Wenjing Liu, performed data acquisition and measurements. Wenjing Liu, Yong Yuan, Qiuju Hu, and Song Luo revised the manuscript and participated in the scientific discussion during the study. All authors read and approved the final manuscript.

Consent for publication

Not applicable.

Clinical Trial Number

Not applicable.

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Ethical statement

The Ethics Committee of our hospital approved this prospective observational study. All participants provided written informed consent before enrollment. The study was performed under the principles of the Declaration of Helsinki.

CRediT authorship contribution statement

Tong Chen: Software, Methodology, Conceptualization. **Guangming Lu:** Supervision, Methodology, Conceptualization. **Wenjing Liu:** Writing – original draft, Software, Methodology, Conceptualization. **Dongsheng Jin:** Supervision, Conceptualization. **Yane Zhao:** Software, Methodology. **Qiuju Hu:** Software, Methodology. **Yue Jiang:** Writing – original draft, Software, Methodology, Formal analysis. **Yong Yuan:** Writing – review & editing, Supervision, Software, Methodology, Formal analysis, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Not applicable.

Data Availability

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request. The authors, who were not employees of Philips Healthcare, had complete control of data collection and analysis.

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