

Superior CT coronary angiography image quality at lower radiation exposure with second generation 320-detector row CT in patients with elevated heart rate: a comparison with first generation 320-detector row CT

Dennis T. L. Wong¹, Siang Y. Soh^{1*}, Brian S. H. Ko^{1*}, James D. Cameron¹, Marcus Crossett², Arthur Nasis¹, John Troupis^{1,2}, Ian T. Meredith¹, Sujith K. Seneviratne¹

¹Monash Heart, Monash Cardiovascular Research Centre & Monash University, Clayton, Victoria, Australia; ²Department of Diagnostic Imaging, MMC, Southern Health, Melbourne, Australia

*These authors contributed equally to this work.

Correspondence to: Dennis T. L. Wong, MBBS, PhD. Monash Heart, Monash Cardiovascular Research Centre & Monash University, Clayton, Victoria, Australia. Email: drdenniswong@yahoo.com.au.

Background: This study aims to compare the image quality of second generation versus first generation 320-computed tomography coronary angiography (CTCA) in patients with heart rate ≥ 65 bpm as it has not been specifically reported.

Methods: Consecutive patients who underwent CTCA using second-generation-320-detector-row-CT were prospectively enrolled. A total of 50 patients with elevated (≥ 65 bpm) heart rate and 50 patients with controlled (< 65 bpm) heart rate were included. Age and gender matched patients who were scanned with the first-generation-320-detector-row-CT were retrospectively identified. Image quality in each coronary artery segment was assessed by two blinded CT angiographers using the five-point Likert scale.

Results: In the elevated heart rate cohorts, while there was no significant difference in heart rate during scan-acquisition (66 vs. 69 bpm, $P=0.308$), or body mass index (28.5 vs. 29.6, $P=0.464$), the second generation scanner was associated with better image quality (3.94 ± 0.6 vs. 3.45 ± 0.8 , $P=0.001$), and with lower radiation (2.8 vs. 4.3 mSv, $P=0.009$). There was no difference in scan image quality for the controlled heart rate cohorts.

Conclusions: The second generation CT scanner provides better image quality at lower radiation dose in patients with elevated heart rate (≥ 65 bpm) compared to first generation CT scanner.

Keywords: Image quality; computed tomography (CT); likert scale; 320-detector row; radiation dose

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Introduction

Computed tomography coronary angiography (CTCA) is an established non-invasive imaging tool in assessing coronary artery disease (1). It is particularly useful for the exclusion of coronary artery disease because of its established high sensitivity and negative predictive value (2,3). Recently it has been shown to be a useful modality to assess patients with low to intermediate risk of suspected acute coronary syndromes presenting to the emergency

department (4,5). To minimize radiation exposure, recent advances include the advent use of wide-detector scanners such as the 320 detector row scanner which has a 16 cm cranial-caudal coverage (6) and allows for acquisition of the whole coronary artery tree in one gantry rotation over less than one heartbeat (3,7).

The patients' heart rate during image acquisition remains a critical determinant of radiation dose and image quality (8-10). Administration of beta blockers reduces heart rate and heart rate variability and results in better image

quality (11). However, heart rate acceleration during image acquisition in response to intravenous contrast injection, anxiety and breath holding remains problematic (11-13). The ability to scan patients at higher heart rate with lower radiation exposure will significantly improve CTCA safety, applicability and may improve clinical efficiency. Compared to first generation 320 detector row scanner which has a gantry rotation time of 350 ms and a temporal resolution of 175 ms, the second generation detector row scanner has faster gantry rotation time of 275 ms and an improved temporal resolution of 137.5 ms. The image quality using second generation 320 detector-row CT scanner in patients with high heart rates during image acquisition when compared with the first generation 320 detector-row CT has not been specifically reported.

We hypothesize that the second generation 320-MDCT scanner with a combination of a faster gantry rotation, wide volume coverage, iterative reconstruction, automated exposure control and larger power generator provides better image quality with lower radiation exposure in patients with increased heart rate (≥ 65 bpm) compared to the first generation 320-MDCT scanner.

Methods

Study design

This study was carried out at a tertiary institution cardiac CT centre (Monash Medical Centre, Clayton, Australia). Consecutive patients who underwent CTCA with the second generation 320-MDCT (Aquilion ONE ViSION) scanner between November-December 2012 were included in this study. A total of 50 patients who had heart rate of ≥ 65 bpm at time of imaging were identified between 12 November 2012 and 18 December 2012 and were categorised into cohort 1. Another 50 patients who had heart rate of < 65 bpm at time of imaging were identified between 12 November, 2012 and 3 December, 2012 and were categorised into cohort 3. We then retrospectively selected a cohort of patients with similar age and gender who were scanned with the first generation 320-MDCT (Aquilion ONE) scanner between September 2008 and October 2012. These patients were categorized as cohort 2 (heart rate ≥ 65 bpm) and cohort 4 (heart rate < 65 bpm).

Study cohort

All patients who were clinically referred for CTCA at

the institution during the study period were eligible for inclusion. Patients would be excluded if they were pregnant, less than 18 years of age, had estimated glomerular filtration less than 30 mL/min/1.73 m² and had known contrast allergy. No patients met exclusion criteria.

Computed tomography protocol

Cardiovascular medications were ceased 48 hours prior to CTCA apart from beta-blockers. On arrival, an 18-gauge intravenous line was inserted in the right antecubital vein for administration of contrast. Oral and/or intravenous metoprolol was given if the resting heart rate was > 60 bpm. If beta blocker was contraindicated, oral and/or intravenous ivabradine was given if the resting heart rate was > 60 bpm. Cohort 1 and 3 patients were scanned on 320-detector row CT scanner (Aquilion ONE ViSION, Toshiba Medical Systems, Japan). Cohort 2 and 4 patients were scanned on the 320-detector-row CT scanner (Aquilion ONE, Toshiba Medical systems, Japan). The scan was acquired during injection of 75 mL of 100% Iohexal (Omnipaque 350) at 6 mL/s, followed by 50 mL of saline at 6 mL/s. Scanning was triggered manually when peak enhancement in the left ventricular cavity is achieved and no enhancement in the right ventricle is observed.

The scanning parameters on the Aquilion ONE ViSION scanner were: detector collimation 320 mm \times 0.5 mm. The tube current was determined with use of automatic exposure control (^{SURE}Exposure3D, Toshiba Medical Systems) on the basis of X-ray attenuation on anterior-posterior and lateral scout images and the reconstruction kernel. Tube potential is manually set by the operator with the default set at 100 kVp, and is manually adjusted to 120 or 135 kVp when the automatic tube current selected is the maximum. The gantry rotation time was 275 ms and temporal resolution 137.5 ms. Prospective electrocardiogram gating was used covering 70-80% of the R-R interval. Images were reconstructed with a 512 \times 512 matrix, 0.5 mm thick sections, and 0.25 mm increments by using kernel FC43, iterative reconstruction with adaptive iterative dose reduction 3D (AIDR3D, Toshiba Medical Systems) standard, and asymmetric cone beam reconstruction (14).

On the Aquilion ONE scanner the scanning parameters were: detector collimation 320 mm \times 0.5 mm; tube current 300-500 mA [depending on body mass index (BMI)]; tube voltage 120 kV if BMI ≥ 25 (100 kV if BMI < 25); gantry rotation time 350 ms; and temporal resolution 175 ms. Prospective electrocardiogram gating was used covering

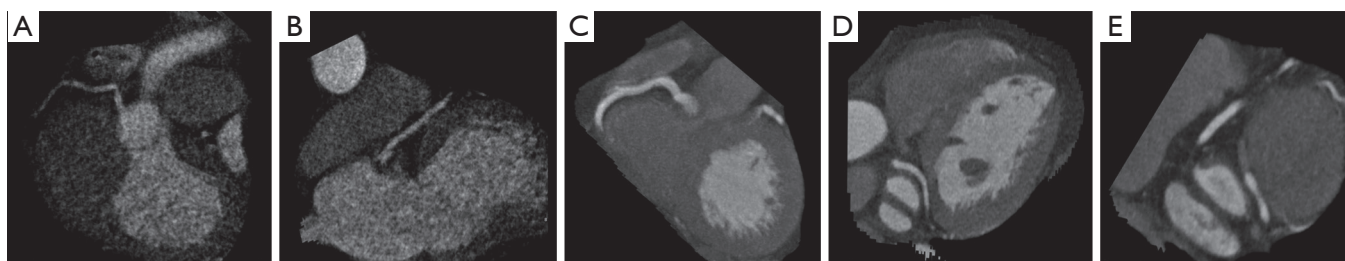


Figure 1 Examples of image quality according to Likert score (A-E).

70-80% of the R-R interval. Images scanned before August 2012 was reconstructed using the filtered back-projection technique with FCO4 algorithm while images scanned after August 2012 were reconstructed using AIDR 3D reconstruction.

For the first generation scanner, images acquired at heart rates ≤ 65 bpm, scanning was completed within a single R-R interval utilizing a 180° segment. In patients with a heart rate >65 bpm, data segments from two consecutive beats were used for multi-segment reconstruction. For the second generation scanner, if the heart rate was <70 bpm, scanning was completed within a single R-R interval utilizing a 180° segment. If the heart rate was ≥ 70 bpm, scanning was completed still within a single R-R interval utilizing a 180° segment but instead the window was widened to include systole and diastole (35-80%).

Analysis of image quality

Two experienced CT angiographers (DW and BK) evaluated the image quality on a per-segment basis using the 16 segment AHA model and each segment was rated by consensus agreement using a five point Likert scale. The Likert scale was defined as 1= poor, impaired image quality limited by excessive noise or poor vessel wall definition; 2= adequate, reduced image quality with poor vessel wall definition or excessive image noise, limitations in low contrast resolution remain evident; 3= good, impact of image noise, limitations of low contrast resolution and vessel margin definition are minimal; 4= very good, good attenuation of vessel lumen and delineation of vessel walls, relative image noise is minimal, coronary wall definition and low contrast resolution well maintained and 5= excellent, excellent attenuation of the vessel lumen and clear delineation of the vessel walls, limited perceived image noise (Figure 1) (15). Segments with diameter <1.5 mm or missing were not evaluated and were excluded from analysis.

Radiation dose estimation

The volume CT dose index (CTDI) and dose length product (DLP) were automatically generated by the machine and recorded for each patient during examination. Effective dose (ED, in units of mSv) was calculated using the formula $ED = DLP \times k$, where k is the conversion factor ($k = 0.014 \text{ mSv} \cdot \text{mGy}^{-1} \cdot \text{cm}^{-1}$) (8).

Statistical analysis

Continuous variables are expressed as mean \pm SD or median (interquartile range) as appropriate, whereas categorical variables are expressed as percentage. Continuous and categorical variables were compared using t -test, Mann-Whitney or chi-square as appropriate. Interobserver variability was performed by calculating intraclass coefficient. Statistical analysis was performed with SPSS 20.0 (SPSS Inc, Chicago, IL, USA). A P value <0.05 was considered statistically significant.

Results

Clinical characteristics

Two hundred subjects were studied (50 patients in group 1, 2, 3 and 4 respectively). The mean age was 58.1 ± 1.8 years in cohort 1; 58.3 ± 1.8 years in cohort 2; 60.5 ± 1.6 years in cohort 3; and 60.5 ± 1.6 in cohort 4. There were 92 (46%) males. The patient characteristics are summarized in Table 1. A total of 2831 coronary segments were evaluated after exclusion of missing segments or if the size was too small (<1.5 mm in diameter).

Overall, hypertension, hypercholesterolemia and family history were the most common associated risk factors and majority of patients were overweight with a mean BMI of 28-29 across all groups. At baseline, 120 of the 200 patients (60%) were given oral beta-blockers.

Table 1 Baseline characteristics

	Cohort 1 (n=50), 2 nd generation scanner, HR ≥65 bpm	Cohort 2 (n=50), 1 st generation scanner, HR ≥65 bpm	Cohort 3 (n=50), 2 nd generation scanner, HR <65 bpm	Cohort 4 (n=50), 1 st generation scanner, HR <65 bpm	P value
Mean age ± SD	58.1±1.8	58.3±1.8	60.5±1.6	60.5±1.6	0.61
Male	20 (40%)	22 (44%)	25 (50%)	25 (50%)	0.57
BMI ± SD	28.5±1.1	29.6±1.0	28.3±0.8	28.6±1.0	0.80
Hypertension	29 (58%)	22 (44%)	30 (60%)	27 (54%)	0.34
Hypercholesterolemia	28 (56%)	20 (40%)	22 (44%)	30 (60%)	0.31
Diabetes mellitus	13 (26%)	5 (10%)	7 (14%)	12 (24%)	0.27
Smoking	22 (44%)	12 (24%)	19 (38%)	16 (32%)	0.31
Family history of ischaemic heart disease	33 (66%)	14 (28%)	25 (50%)	24 (48%)	0.004
Coronary stent	1 (2%)	0 (0%)	1 (2%)	0 (0%)	0.57
Previous coronary artery bypass surgery	0 (0%)	0 (0%)	2 (4%)	0 (0%)	0.11
Oral metoprolol	32 (64%)	40 (80%)	22 (44%)	21 (42%)	0.04
Intravenous metoprolol	5 (10%)	15 (30%)	1 (2%)	2 (4%)	<0.001
Oral ivabradine	11 (22%)	10 (20%)	4 (8%)	3 (6%)	0.046
Number of segments with >50% stenosis	0.9±1.5	0.5±1.1	0.8±1.2	0.7±1.0	0.452

More patients in the elevated heart rate cohorts (1 and 2) were given intravenous metoprolol ($P<0.001$) and oral ivabradine ($P=0.046$).

CT parameters

As shown in *Table 2*, there were no statistically significant difference in heart rate during acquisition between cohort 1 and 2 (66 ± 14.7 vs. 69 ± 14.4 bpm, $P=0.308$) and between cohort 3 and 4 (56 ± 6.3 vs. 55 ± 6.4 bpm, $P=0.6$). Majority of patients in the elevated heart rate cohorts, had heart rate between 65–75 bpm, with only 4 patients in cohort 1 and 5 patients in cohort 2 having heart rate of >75 bpm. Compared to first generation scanner, a significantly higher proportion of patients was scanned using lower tube potential of 100 kV using the second generation scanner. Overall, majority of scans were completed with one gantry rotation, with more patients requiring greater than one rotation in the higher heart rate groups.

Radiation dose

Patients scanned using the second generation scanner received significantly lower radiation dose (*Table 2*). When compared with the first generation scanner, the median

estimated effective dose with the second-generation scanner was 35% less in the higher heart rate group (2.8 vs. 4.3 mSv, $P=0.009$) and 34% less in the controlled heart rate group (2.1 vs. 3.2 mSv, $P=0.04$).

Image quality

The scan image quality was better on the second generation scanner in patients with higher rate (≥ 65 bpm) compared to the first generation scanner (3.94 ± 0.6 vs. 3.45 ± 0.8 , $P=0.001$) (*Table 3*). Otherwise there was no statistically significant difference in scan image quality between second and first generation scanner in patients with heart rate <65 bpm (4.11 ± 1.5 vs. 3.73 ± 0.4 , $P=0.091$). Patients scanned with the second generation scanner had less median number of poor segments (Likert score of 1 or 2) per patient in the higher heart rate cohorts (0 vs. 1, $P=0.016$) but not in the controlled heart rate cohorts (0 vs. 0, $P=0.581$).

Interobserver variability

The interobserver variability for Likert score analysis was highly reproducible between observers in 100 randomly selected segments. The intraclass correlation coefficient was 0.9 ($P<0.001$).

Table 2 CT scanning parameters

	Cohort 1 (n=50), 2 nd generation scanner, HR ≥65 bpm	Cohort 2 (n=50), 1 st generation scanner, HR ≥65 bpm	Comparison of cohort 1 vs. cohort 2, (P value)	Cohort 3 (n=50), 2 nd generation scanner, HR <65 bpm	Cohort 4 (n=50), 1 st generation scanner, HR <65 bpm	Comparison of cohort 3 vs. cohort 4, (P value)
Heart rate at acquisition	66±14.7	69±14.4	0.308	56±6.3	55±6.4	0.6
Heart rate 65-75 bpm	46 (92%)	45 (90%)	0.9	0 (0%)	0 (0%)	1
Tube potential (100 kV)	34 (68%)	14 (28%)	0.003	35 (70%)	17 (34%)	0.001
Tube potential (120 kV)	14 (28%)	28 (46%)		14 (28%)	25 (50%)	
Average tube potential	107±10.7	117±13	<0.001	106±9.8	116±13	0.001
Average tube current	630 (312)	149 (491)	<0.001	580 (170)	130 (216)	<0.001
One beat scan (one gantry rotation)	46 (92%)	43 (86%)	0.63	49 (98%)	48 (96%)	1
Radiation dose (mSv)	2.8 (2.7)	4.5 (6)	0.009	2.1 (1.3)	3.4 (3.7)	0.04
AIR3D reconstruction	50 (100%)	38 (76%)	<0.001	50 (100%)	44 (88%)	0.027

Table 3 Comparison of image quality between groups

	Likert scale	P value	Median (IQR) number of poor segments	P value
Group 1 (2 nd generation scanner, HR ≥65 bpm)	3.94±0.6	0.001	0 [1]	0.016
Group 2 (1 st generation scanner, HR ≥65 bpm)	3.45±0.8		1 [2]	
Group 3 (2 nd generation scanner, HR <65 bpm)	4.11±1.5	0.091	0 [0]	0.581
Group 4 (1 st generation scanner, HR <65 bpm)	3.73±0.4		0 [0]	

Discussion

This study demonstrated that the second generation 320-CT scanner has the ability to provide better image quality at lower radiation dose compared to the first generation 320-MDCT scanner in patients with elevated heart rate (≥65 bpm). In addition, we showed that there was no statistical difference in image quality between the second generation and first generation 320-CT scanner in patients with controlled heart rate (<65 bpm). Recently Chen and colleagues demonstrated that the newer generation 320-MDCT scanner provided excellent image quality at lower radiation exposure across a wide range of body habitus and heart rate compared to the first generation 320-MDCT scanner. The majority of patients (78.5%) had heart rate <65 bpm in that study (16). Similarly, a retrospective study by Tomizawa demonstrated that the second generation 320-MDCT scanner tended to have superior image quality with reduced radiation exposure in the higher heart rate [66-75] group compared to the first generation 320-MDCT scanner, but it did not reach statistical significance (17). To

the best of our knowledge, no other study has specifically explored whether the new generation scanner could provide better image quality at lower radiation dose in patients with elevated heart rate (≥65 bpm).

Image quality of CTCA depends on multiple key aspects of the imaging process (1). There are CT related parameters, including temporal resolution, tube potential, tube current and scan reconstruction methods. On the other hand patient related factors such as heart rate during acquisition and BMI also affect image quality. In this study, despite using low tube potential in cohorts of patients whom heart rate and BMI did not differ, the second generation 320 detector-row CT produced better image quality than the first generation scanner. We therefore postulate that the improvement in image quality is due to a combination of improved temporal resolution and scan reconstruction methods used in the second generation 320 detector-row CT.

The faster gantry rotation time of 275 ms in combination with up to 16 cm cranial-caudal volume coverage per rotation on the second generation 320 detector-row CT

scanner enables single heart beat acquisitions in patients with heart rates of up to 75 beats per minute (16), as compared to up to 65 beats per minute from the first generation 320-MDCT scanner with a gantry rotation time of 350 ms (18). Also, the second generation scanner could produce a high tube current when low tube potential was used, thus images with similar contrast to noise ratios could be reconstructed with lower radiation dose. This allows better temporal uniformity of the image including more uniform contrast enhancement and the absence of misalignment artefacts in the z-direction (19). The second generation 320 detector-row scanner by permitting higher proportion of patients (46/50) with elevated heart rate to be imaged with one heart-beat acquisitions improved the overall image quality while maintaining low radiation in our study. It is however still prudent to emphasize that faster heart rate still resulted in inferior image quality and higher radiation dose despite advancement with wider volume scanners with 320-detector rows compared to patients with low heart rate (20,21). Therefore good heart rate control with beta-blockers remains an important strategy in achieving good image quality and low radiation dose (22). We advocate adherence to the current guidelines of employing appropriate rate lowering strategies prior to scanning. However, in cases where lower heart rate could not be achieved due to symptoms or hypotension, or unexpected acceleration of heart rate during acquisitions, the second generation 320 detector-row CT scanner would still likely to produce good quality images.

Patients with elevated heart rate (≥ 65 bpm) scanned with second generation 320-MDCT scanner had 35% reduction in median radiation dose while patients with heart rate < 65 bpm had 34% reduction compared to the first generation 320-MDCT scanner. Despite having similar patient related factors (BMI, heart rate at acquisition) and CT related factors (prospective ECG gated imaging, one beat scan), the second generation scanner achieved lower radiation exposure compared to first generation scanner because of the following three factors: (I) lower tube potential (II) more third generation iterative reconstruction (AIDR3D) and (III) improved temporal resolution.

Tube potential determines the energy of the x-ray beam, which affects its penetrability and noise (8). A reduction in tube potential from 120 to 100 kV results in a 31% reduction in radiation dose (23) but a 20% increase in noise (8), if all other parameters are unchanged. In practice, to counter the negative effect of image noise by using lower tube potential, an increase in tube current maybe necessary.

Around 70% of patients scanned with the second generation 320-MDCT scanner used a tube potential of 100 kV as compared to around 30% using the first generation scanner owing to the availability of a larger x-ray generator (100 kW) that can produce up to 900 mA (16). This reduction in tube potential resulted in reduced radiation exposure while maintaining image quality in our study.

One strategy to decrease radiation exposure is to employ noise-reducing iterative reconstruction algorithms (24). Iterative reconstructions can produce higher resolution images and reduced imaging artefacts and were adopted by CTCA in recent years (25). The use of adaptive iterative dose reduction in three-dimensions (AIDR3D) reconstruction is capable of achieving up to 50% radiation reduction while maintaining comparable image quality compared to filtered back projection techniques (26). The combination of AIDR3D and automated exposure control markedly reduced radiation exposure by utilisation of low tube potential while decreasing the associated noise problem. In our study, all patients scanned with second generation scanner had AIDR3D reconstruction as compared to 82% of those scanned with the first generation scanner.

Limitations

This is an observational single centre experience with limited number of patients in each cohorts. The image quality tested was limited to patients with a heart rate between 65-75 bpm, and the effect of higher heart rate remains to be studied. The diagnostic accuracy of the second generation 320-detector row CT compared to invasive angiography will need further evaluation but studies from first generation scanner showed highly comparable results (3,7,21).

Conclusions

Based on the results of the study, the CTCA images performed using the second generation 320-CT scanner were superior in quality and required a lower radiation dose in patients with elevated heart rate (≥ 65 bpm) when compared with the first generation 320-CT scanner.

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