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Comparison of Radiation Dose and Image Quality: 320-MDCT Versus 64-MDCT Coronary Angiography

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Abstract

OBJECTIVE—The purpose of this study was to compare radiation dose and image quality of 320- and 64-MDCT angiography using prospective gating.

MATERIALS AND METHODS—One hundred seventy-four patients underwent 320-MDCT, and 95 patients underwent 64-MDCT. The scan parameters for 320-MDCT were 120 kVp, 400 mA, and gantry rotation of 350 milliseconds; the parameters for 64-MDCT were 120 kVp, 600 mA, and gantry rotation of 350 milliseconds. Effective dose (ED) was calculated from the dose-length product and a conversion factor ($k = 0.014 \text{ mSv} / \text{mGy} \times \text{cm}$). Two observers independently assessed image quality using a 3-point scale, where 3 denotes excellent quality and 1 denotes nondiagnostic quality, using a 16-segment model. Discrepancies were settled by consensus.

RESULTS—The ED was significantly lower in patients undergoing 320-MDCT angiography, with a median ED of 4.4 mSv (interquartile range [IQR], 3.4–6.2 mSv), compared with 64-MDCT angiography, with a median ED of 6.2 mSv (IQR, 5.5–6.9 mSv) ($p = 0.0001$). In patients with a heart rate of 65 beats/min or less (92%), the median radiation dose using 320-MDCT was 4.1 mSv (IQR, 3.2–6.1 mSv), and that for 64-MDCT angiography was 6.2 mSv (IQR, 5.8–6.9 mSv) ($p = 0.0001$). In patients with heart rate greater than 65 beats/min (8%), the median dose was higher with 320-MDCT (8.7 mSv; IQR, 5.9–14.3 mSv) than with 64-MDCT (5.8 mSv; IQR, 5.3–6.7 mSv) ($p = 0.02$). Segmental image quality was significantly better for 320-MDCT (excellent or good quality, 96.66%; nondiagnostic quality, 0.1%) than for 64-MDCT angiography (excellent or good quality, 86%; nondiagnostic quality, 3.33%) (all $p < 0.0001$).

CONCLUSION—Image quality was good for both 320- and 64-MDCT angiography. Overall radiation dose was significantly lower in 320-MDCT angiography when the heart rate was 65 beats/min or less. Every effort should be made to control heart rate to minimize radiation dose.

Keywords

64-MDCT; 320-MDCT; coronary artery disease; image quality; radiation dose

With the introduction of 64- and 320-MDCT, coronary CT angiography (CTA) has become a reliable diagnostic imaging modality for the assessment of coronary artery disease (CAD) because of its noninvasive nature. However, radiation dose and image quality are the two major concerns in MDCT angiography [1]. The clinical use must therefore be weighted

against radiation exposure and potential risks of developing cancer [2, 3]. Advances in MDCT technology have addressed these concerns with continuous improvement in temporal resolution and prospective gating [4, 5]. The specificity and sensitivity of CTA for the diagnosis of significant stenosis in coronary segments have increased along with the increasing number of detectors per scanner. Two large multicenter research studies have found high sensitivities (85% and 95%) and specificities (83–90%) for the detection of coronary artery stenosis [6, 7]. The development of wide-area-detector CT has enabled greater coverage per gantry rotation and also has enabled whole heart coverage in a single heartbeat, eliminating the stair-step artifact that is common in 64-row technology [4, 5, 8–11]. However, it remains to be seen whether this improved technology can reduce the radiation dose and improve image quality. The purpose of our study was to retrospectively compare the radiation doses and image quality of 64- versus 320-MDCT angiography for the assessment of CAD.

Materials and Methods

Informed consent for this retrospective HIPAA-compliant study was waived, and the study was approved by our institution's institutional review board. Data analysis included radiation dose, image quality, patient demographics, clinical details, heart rate, and age and sex of 268 patients scanned for suspected CAD. The pretest probability of significant CAD was calculated using the previously validated Duke Clinical Score model integrating the type of chest pain, together with clinical variables of age, sex, history of myocardial infarction, smoking, hyperlipidemia, and diabetes [12–14]. From the calculated pretest probability of significant CAD, each patient was then categorized as having low risk (< 30%), intermediate risk (30–70%), or high risk (> 70%) of having CAD. Of our study population, 14% of patients were categorized as low risk, 22% were intermediate risk, and 74% were high risk. One hundred seventy-four patients were imaged with a 320-MDCT scanner (Aquilion One, Toshiba), and 95 patients were imaged with a 64-MDCT system (LightSpeed VCT, GE Healthcare); patients were referred for coronary CTA for a variety of clinical symptoms, including atypical chest pain, suspected CAD, abnormal or equivocal stress test or ECG findings, dyspnea, evaluation of stents and grafts, and other cardiac risk factors. Clinical exclusion criteria for cardiac CT included nonsinus rhythm, severe allergy to iodine-containing contrast material, history of renal disease (calculated from creatinine levels > 1.7 mg/dL), pregnancy, hemodynamic instability, asthma, and severe respiratory or cardiac failure. For evaluation purposes, patients were divided into two groups: 320-MDCT angiography and 64-MDCT angiography.

Patients were connected to ECG leads placed in standard position to enable CT synchronization with ECG. Beta-blocker medication (oral metoprolol) was administered to patients with heart rates greater than 65 beats/min unless contraindicated according to the fixed protocol (Table 1). IV metoprolol was administered, if necessary, in the CT scanner in 5-mg doses every 5 minutes for a maximum of 20 mg. The target heart rate for scanning was below 65 beats/min and preferably 60 beats/min. Sublingual nitroglycerine (0.4 mg) was administered to all patients just before the calcium score or localization unless contraindicated before imaging. There were no patients with contraindication to beta-blockers or nitroglycerine in our study. The image acquisition and reconstruction parameters for prospective ECG-gated acquisition using both 64- and 320-MDCT are shown in Table 2 and Table 3.

64-MDCT Angiography

This technique requires approximately five to eight heartbeats to capture the entire heart with a “step-and-shoot” method. Data acquisition occurs during every alternate heartbeat, with incremental table motion of 3.5 cm in the intervening heartbeat. A 64-MDCT system

provides 41 mm of coverage, with a gantry rotation of 0.33–0.4 s/rotation [15]. Usually, radiation exposure and data scanning are targeted toward the middiastolic phase (75% of the R-R interval is selected as the midpoint for the data acquisition). However, two cardiac cycles may not be completely identical, and banding artifacts cannot be completely avoided. This step-and-shoot acquisition technique was proposed to reduce the radiation dose by up to 20% when compared with the more traditional retrospective techniques [15, 16].

320-MDCT angiography

The number of detectors (detector row) in the z-axis has increased with each new scanner generation. The 320-MDCT system we used has a detector element consisting of 320×0.5 mm detector and provides 160 mm of coverage in the z direction. However scanning can also be performed using 120-, 128-, and 140-mm coverage in the z direction. Gantry rotation is 0.35 second. The heart can therefore be imaged in a single heartbeat, which allows comprehensive anatomic imaging of the whole heart and coronary vessels. However, if the heart rate increases above 65 beats/min, the scanner automatically changes from single-segment to multisegment reconstruction, capturing the heart in two beats and thereby doubling the radiation exposure [4].

Assessment of Image Quality

Analysis was performed for all patients by using standard axial and multiplanar reformatted images. After the examination results were blinded, the image quality of the coronary vessels was assessed subjectively by two independent level 3 certified observers using the 16-segment model of vessel disease proposed by the American Heart Association [17]. All patients were analyzed in randomized manner and all segments were evaluated using a scale from 1 to 3—where 3 is excellent, 2 is good, and 1 is nondiagnostic—by two experienced cardiovascular imaging radiologists using axial images, maximum intensity projections, and curved multiplanar reformatted images. Segments assigned a score of 1 were nondiagnostic because of marked motion artifacts, structural discontinuity, image noise–related blurring, and poor vessel opacification [1, 18].

Calculation of Radiation Dose Estimates

The radiation dose was calculated from the volume CT dose index (CTDI_{vol}) and the dose-length product (DLP) [15, 19]. The CTDI value is calculated as a mathematic integral under the radiation dose profile of a single rotation scan that would produce one tomographic image at a fixed table position [20]. CTDI_{vol} is the average radiation dose over a specific investigated volume. The DLP was calculated by multiplying CTDI_{vol} by the respective scan length (i.e., $\text{DLP} = \text{CTDI}_{\text{vol}} \times \text{scan volume length}$) [21].

The DLP is an estimation of the radiation exposure for the entire CT examination. This was the primary parameter used to calculate radiation dose in our study. The CTDI_{vol} and DLP were recorded as direct data output from prospective ECG-gated examinations. The CT scanner provides a protocol summary containing the DLP for each image series. The total dose includes the dose from the scanogram, calcium score, and coronary arteriogram. The effective radiation dose (ED) was calculated as the DLP multiplied by a previously published conversion coefficient ($k = 0.014 \text{ mSv} / \text{mGy} \times \text{cm}$) [3, 22–24].

Statistical Analysis

Continuous variables within the two patient groups were compared using Bartlett's test for equal variances. Median radiation doses were reported. The differences between median radiation doses were assessed using the Kruskal-Wallis equality-of-populations rank test. Then regression analysis was performed for median radiation dose for the two groups

adjusted for age, sex, body mass index (BMI), heart rate, tube voltage, and tube current. A *p* value of less than 0.05 was considered statistically significant. Image quality rankings were documented on an ordinal scale from 1 (nondiagnostic) to 3 (excellent). Wilcoxon signed rank test was used to compare the two groups with reference to vessel-based image quality (median and range) of the right coronary artery (segments 1–4), left main artery (segment 5), left anterior descending artery (segments 6–10), and left circumflex artery (segments 11–16). The statistical software packages used for data analysis were Stata and MP (version 10.0, both from StataCorp).

Results

In our study, prospectively gated axial coronary CTA was performed in 268 patients. The mean ($\pm$ SD) heart rate was 58 ± 6 beats/min for patients examined by 320-MDCT and 59 ± 6 beats/min for patients examined by 64-MDCT. Individuals were younger in the 64-MDCT group, whereas no difference in sex, BMI, and heart rate between the groups was noted.

The resulting mean *z*-coverage was 140–160 mm for the 64-MDCT group (depending on the number of rotations used for the scan) and 120–160 mm for the 320-MDCT group (depending on the heart length size). There was no difference in volume of contrast agent between the 64-MDCT group (80 mL of ioversol [Optiray 350, Mallinckrodt Imaging] at a flow rate of 5 mL/s) and the 320-MDCT group (70–80 mL of ioversol at a flow rate of 5 mL/s). The mean DLP was $317 \text{ mGy} \times \text{cm}$ (interquartile range [IQR], 246–444 $\text{mGy} \times \text{cm}$) for the 320-MDCT group and $440 \text{ mGy} \times \text{cm}$ (IQR, 396–491 $\text{mGy} \times \text{cm}$) for the 64-MDCT group ($p < 0.0001$). The resulting ED was significantly lower in patients undergoing respective 320-MDCT angiography, with a median ED of 4.4 mSv (IQR, 3.4–6.2 mSv), compared with patients undergoing prospective 64-MDCT angiography, with a median ED of 6.2 mSv (IQR, 5.5–6.9 mSv) ($p = 0.0001$).

In subanalyses of all 268 subjects, 246 patients (92%) had a heart rate of 65 beats/min or less; the median radiation dose for 320-MDCT angiography was 4.1 mSv (IQR, 3.2–6.1 mSv), and that for 64-MDCT angiography was 6.2 mSv (IQR, 5.8–6.9 mSv) ($p = 0.0001$). However, in 22 patients (8%) with a heart rate greater than 65 beats/min, the radiation dose was significantly greater with the 320-MDCT scanner (median, 8.7 mSv; IQR, 5.9–14.3 mSv) than for the 64-MDCT scanner (median, 5.8 mSv; IQR 5.3–6.7 mSv) ($p = 0.02$) (Fig. 1).

Table 4 shows the comparison of image quality between the two groups. For all vessels, we noted a significant ($p < 0.01$) improvement in subjective image quality in the 320-MDCT group, with median image quality rated as excellent in all segments, compared with the 64-MDCT group, with median image quality rated as good in all segments. When all segments were considered together, image quality assessed at segment levels was significantly ($p < 0.0001$) better for 320-MDCT angiography than for 64-MDCT angiography (excellent, 81.53% vs 32.86%; good, 18.33% vs 63.79%; and nondiagnostic, 0.12% vs 3.33%). In cases of nondiagnostic segments, one of three segments in the 320-MDCT angiography group and four of 45 segments in the 64-MDCT angiography group were not evaluated because of calcium-induced blooming artifact. Figures 2 and 3 show representative images from both groups for comparative image quality assessment.

Discussion

Radiation exposure to patients from coronary CTA and the associated risk of developing cancer is a major deterrent to wide application and acceptance of this technology [2, 3, 25, 26]. Various studies document that significant dose reduction is achievable with prospective

ECG triggering, and radiation doses of coronary CTA are comparable with or even lower than those of conventional coronary angiography [3, 15, 19, 27]. This fact was supported by a study showing a 78% decrease in ED when a prospective gating technique was used [3]. Although marked reduction in ED is possible by using this technique, current 64-MDCT and dual-source scanners have limitations (e.g., temporal and spatial resolution, cardiac coverage, heart rate, heart rate variability, BMI, and motion artifacts), resulting in a decrease in the image quality, which prevents the widespread clinical utility of this imaging modality [16, 18, 28, 29]. Previous literature has shown that heart rate greater than 70 beats/min, heart rate variation greater than 10 beats/min, and BMI greater than 30 are all factors that result in a compromise in image quality [29, 30]. New-generation MDCT scanners have improved temporal resolution of faster image acquisition in comparison with old MDCT [4]. New imaging techniques (prospective gating) also result in a marked decrease in radiation doses in comparison with retrospective gating. Baumuller et al. [31] and Rixe et al. [32] reported mean EDs of 10.4 ± 1.7 mSv and 8.6 ± 2.8 mSv, respectively, for patients scanned with prospective gating at 64-MDCT in comparison with the previously reported radiation range (11–22 mSv) for retrospective techniques [16].

The findings of our study show that prospective MDCT angiography using 320-MDCT is clinically feasible. The ED is lower and image quality is better than with 64-MDCT. However, it is vital to note that the advantage of radiation dose reduction is only noted in patients with a heart rate of 65 beats/min or less (92% of patients in this study). However, this advantage was reversed in a minority of patients (8%) with a heart rate greater than 65 beats/min who had the complete scan in more than one heartbeat. A 320-MDCT scanner acquires the heart rate during breath exercise, and then in patients whose heart rate changes above 65 beats/min at the instant of exposure, the heart is captured in more than one beat for improved temporal resolution [4]. This important feature is clearly apparent with our results, because there is a substantial increase in radiation dose with heart rate greater than 65 beats/min versus 65 beats/min or less (8.7 vs 5.7 mSv). The role of heart rate in radiation dose exposure and image quality has been well documented [31, 33]. All possible efforts were made to achieve heart rate below 65 beats/min with beta-blockers. Heart rate control is a vital step in cardiac imaging for low radiation exposure and excellent image quality.

Our study shows that the 320-MDCT results in significantly improved image quality compared with 64-MDCT. Improved temporal resolution with fast gantry rotation not only ensures improved image quality, but also improves edge depiction of coronary vessels when compared with retrospective gated MDCT [34]. MDCT angiography diagnostic accuracy is dependent on excellent-to-good image quality, and every effort should be made to achieve this goal in addition to reducing radiation exposure [18, 22, 35].

To the best of our knowledge, this is the first study comparing the image quality in cardiac MDCT angiography between 64-MDCT and 320-MDCT in a clinical setting. Shuman et al. [18] compared the image quality for prospective and retrospective ECG gating for 64-MDCT angiography and documented similar results for both groups of patients, although that study showed that the absence of table motion usually has a beneficial effect on image quality. Wang et al. [1] discussed the image quality comparison for single-source CT versus dual-source CT and found equivalent results for both scanners at lower heart rates, but dual-source CT documented superior image quality at high heart rates (70–79 beats/min). However, our study data showed significantly better image quality among those undergoing prospectively gated 320-MDCT angiography versus 64-MDCT.

Limitations

The limitations of our study are those inherent in comparing two subject groups and two different scanners. Ours is a retrospective study of patients imaged on two different

scanners, rather than scanning the same patient on each scanner. This practice, however, would be prohibitive because of the accumulated radiation dose to a patient undergoing two sequential scans, but accuracy studies by Budoff et al. [7] for 64-MDCT angiography and Dewey et al. [36] for 320-MDCT angiography in comparison with the reference standard (i.e., invasive catheterization) showed 99% negative predictive value for both scanners. Another limitation is our use of subjective evaluation of image quality rather than quantitative evaluation by signal-to-noise ratio and contrast-to-noise ratio. However, our image quality scoring scales have been used successfully by other investigators for cardiac image quality [1, 16]. Further prospective studies are needed to corroborate the diagnostic accuracy between the two scanners.

Conclusion

In this study, we found that prospectively gated 320-MDCT angiography provides robust diagnostic image quality at lower radiation doses than those for 64-MDCT angiography. Regardless of the scanner, good heart rate control (< 65 beats/min) plays a vital role in radiation reduction; however, the ability of the 320-MDCT scanner to image in a single heartbeat will always result in a more beneficial reduction in dose. Therefore, the 320-MDCT scanner has the potential to be used routinely in patients with suspected CAD after a standard heart rate control protocol. This lowered radiation exposure, reduced scan time, and better image quality render 320-MDCT angiography as a viable noninvasive option for cardiac imaging.

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Fig. 1. Radiation dose with two different heart rates (subgroup analysis) among patients imaged with 64- and 320-MDCT.

Fig. 2.
47-year-old man who underwent 64-MDCT angiography. Images show motion artifact in left anterior descending artery.

Fig. 3. 69-year-old man who underwent 320-MDCT angiography. Images show excellent image quality and provide information about patency of coronary stent.

TABLE 1

Oral Beta-Blocker Protocol With Reference to Heart Rate

Heart Rate (Beats/Min)	Dose of Metoprolol Beta-Blocker (mg)
> 65	50
> 70	75
> 75	100
> 80	125

Note—If needed, IV metoprolol is administered at a dose of 5 mg every 5 minutes, up to a maximum of 20 mg.

TABLE 2

Typical Imaging Parameters for Prospectively Gated Axial Coronary CT Angiography: Comparison of 64- and 320-MDCT

Parameter	64-MDCT	320-MDCT
Typical collimation (mm)	64 × 0.65 (41.6)	320 × 0.5 (160)
Dynamic z focal spot	No	Yes
Rotation time (s)	0.35	0.35
Tube voltage (kVp)	120	120
Image duration (s)	5–7	0.35
Tube current–time product (mAs)	105	80–120
ECG synchronization	Prospective ECG gating (triggering)	Prospective ECG gating (triggering)

Note—Data in parentheses indicate area covered by single rotation (mm).

TABLE 3

Typical Reconstruction Parameters for 64- and 320-MDCT

Parameter	64-MDCT	320-MDCT
Reconstruction filter kernel	Standard FC 3	Standard FC 3
Reconstruction field of view (mm)	≤ 250	≤ 250
Matrix	512×512	512×512
Slice thickness (mm)	0.625	0.5
Reconstruction increment (mm)	0.625	0.3
Reconstruction ECG intervals (%)	75	75

Note—FC = reconstruction filter (FC03).

TABLE 4

Image Quality Scores for Left Main Artery, Left Anterior Artery, Left Circumflex Artery, and Right Coronary Artery for 64-Versus 320-MDCT Angiography

Artery	64-MDCT Angiography	320-MDCT Angiography
Left main	3 (1–3)	3 (1–3)
Left anterior descending	2 (1–3)	3 (1–3)
Left circumflex	2 (1–3)	3 (1–3)
Right coronary	2 (1–3)	3 (1–3)

Note—Data are median (range) score. The scoring system is as follows: 3 = excellent, 2 = diagnostic, and 1 = nondiagnostic. $p < 0.05$ for all comparisons.