ORIGINAL ARTICLE

Feasibility and Accuracy of 64-Row MDCT Coronary Imaging from a Centre with Early Experience: A Review and Comparison with Established Centres

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Summary

The accuracy of multi-detector computed tomographic (MDCT) coronary angiography (CTA) is dependant on image quality as well as the experience of the operator. Established centers have reported negative predictive values of over 95%. The aim of our study was to investigate the accuracy and feasibility of CTA for the assessment of haemodynamically significant coronary stenosis in a center with very early experience (<6 months) utilizing the improved spatial and temporal resolutions of the latest generation 64-row MDCT scanner. One hundred and twenty eight patients (93 male, 35 female; mean age 56.2 ± 9.5 years) with suspected or known coronary artery disease underwent both CTA and conventional coronary angiography (CCA). The sensitivity, specificity, positive (PPV) and negative (NPV) predictive values for stenoses ≥50% by CTA compared to CCA were 70%, 97%, 70% and 97% respectively. Evaluation of main and proximal segments in patients with good quality images (78% of patients) produced values of 94%, 95%, 74% and 99% respectively. The improved spatial and temporal resolutions of 64-row MDCT provided a high negative predictive value in assessing significant coronary artery stenosis even in a centre with very early experience. However, new centers embarking on CTA might not be able to reproduce the results reported by more experienced centers.

Key Words: Multi-detector computed tomography (MDCT), Training, Angiography, Coronary artery disease

Introduction

Several approaches have been made to establish a non-invasive alternative to conventional coronary angiography (CCA) for the detection of coronary stenoses. Initial experiences using the 4-row multi-detector computed tomography (MDCT) as a non-invasive technique to visualize the coronary arteries were generally inconsistent and less reliable for the detection of coronary stenoses[1-6]. Next-generation 16-row MDCT provided improved image quality by reducing partial volume effects and motion artifacts. However, reported accuracy rates were highly variable with sensitivity ranging from 49-95%, specificity from 82-93%, positive predictive value from 53-97% and negative predictive value from 79-81% when comparing detection of coronary stenosis by computed tomographic angiography (CTA) to CCA[7-9]. It was apparent that experienced centers reported higher accuracy rates and were more confident in evaluating small-caliber vessels as well as those with calcification[10-12].

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With further advancement in CT technology and introduction of the latest 64-row MDCT scanners, these centers were able to overcome some of the earlier limitations of CTA such as high heart rates. This together with the ability to do the scan with ashorter breath-hold has improved the accuracy and feasibility of CTA[13-15]. In fact, the negative predictive value of CTA approaches 100% for patients with suspected coronary artery disease[16]. Determining whether such confidence is the result of improving CT technology or merely due to the increasing experience of the operators is of great interest to patients as well as clinicians[17]. The purpose of our study was to investigate the accuracy of the latest 64-row MDCT in detecting significant coronary disease in a centre with very early CTA experience, and comparing our results to those of established centers.

Materials and Methods

Study Population

Our hospital was the first public hospital in South East Asia, Australia and New Zealand to secure a 64-row MDCT. It was installed in early January 2005 and started functioning on 14th January 2005. Between 14th January and 10th May 2005, 293 patients underwent coronary CTA at our centre, out of which 173 (93 males, mean age 56.6 ± 9.3 years) had or were suspected to have coronary artery disease. Coronary imaging by CTA and CCA (less than 6 months apart) were available for comparison in 128 patients. Exclusion criteria included previous coronary bypass graft surgery, presence of tachyarrhythmias, atrial fibrillation and other irregular heart rhythm, known allergy to iodine contrast media, inability to hold breath for at least 15s, and documented renal insufficiency (serum creatinine >140 µmol/L). The study protocol was approved by the local institutional ethics committee, and all patients gave written informed consent to undergo both CTA and CCA.

Multi-detector CT scan

Patient preparation

In the absence of contra-indications, all patients with a resting heart rate of >60 bpm received 100 mg atenolol (AstraZeneca, UK) the night before the scan, and another 100 mg 1-2 hours before the scan. Patients who were intolerant of beta-blockade received 80mg of verapamil (Pharmaniaga, Malaysia). If the prescan heart rate remained >70 bpm, an additional 5 mg dose of intravenous metoprolol (AstraZeneca, UK) was given before the scan to further reduce the heart rate. Patients with resting heart rates >75 bpm after treatment were given new appointments for CTA.

Patients were fasted for 4 hours prior to the scan and received instructions and exercises in breath-hold techniques. An 18-20G venous cannula was inserted into a large vein at the cubital fossa. All patients received 2.5 mg sublingual isosorbide dinitrate (Eisai, USA) immediately before the scan.

CTA Scan Protocol and Image Reconstruction

Coronary CTA was performed using a 64-row MDCT (Siemens Somatom Sensation 64 Cardiac, Germany). A volume data set was acquired covering the region from the pulmonary hilum to the diaphragmatic surface of the heart. CT gantry rotation time was 330msec. Tube voltage and effective tube current-time product were 120 kV and 500-900 mAseff.

ECG-controlled tube current modulation (ECG Pulsing) to reduce radiation dose was used if the patient had a steady heart rate of ≤60 bpm. Furthermore an implemented fully automated real-time anatomy-based dose regulation (CAREDose 4D) was utilized for all patients. 80-120 ml (mean 90 ml) of contrast (Ultravist 370®, Schering AG, Germany) was continuously injected into a large cubital vein at a rate of 4 ml/s, followed by a saline injection of 50 ml at a flow rate of 5ml/s. As soon as the signal density in the ascending aorta reached a predefined threshold of 100 Hounsfield units (HU), the patient was instructed to maintain an end-inspiratory breath hold during which the CT volume data set and ECG trace were acquired. All CT scans could be completed within a 12 second breath-hold (mean 9 ±1.1 sec).

For axial image reconstruction an effective row thickness of 0.75 mm and a reconstruction increment of 0.5 mm were applied, utilizing an ECG-gated half-scan reconstruction algorithm. Initial data set reconstruction was performed at 65% of the cardiac cycle. If motion artifacts were present, further reconstructions were done at different positions within the cardiac cycle. All data sets were reconstructed with a 512^2 reconstruction matrix and B25f convolution kernel resulting in a spatial resolution of equal to or better than 0.4x0.4x0.4 mm^3 as shown by Flohr et.al.[14]. If the vessel segment contained heavy calcification, additional reconstructions were performed using a row thickness of 0.6 mm with a reconstruction increment of 0.4 mm and B46f++ kernel. Stented segments were excluded from analysis in this study.

Image quality was graded by degree of motion artifacts and noise-to-contrast ratio based on previous published reports[14,18]. Images were considered to be of good quality if there were no or minor motion artifacts and allowed unrestricted evaluation. Moderate quality images included those with some artifacts but still allowed analysis of most segments while poor quality images had severe artifacts which prevented adequate interpretation.

Training and Reporting

The CTA images were analyzed by a total of 4 cardiologists using a combination of axial images, multiplanar reconstructions and thin-slab maximum intensity projections (3.0-9.0mm). Two of the four cardiologists had attended a 4-day workshop in Erlangen Germany prior to installation of the MDCT scanner. Further training was given by the Siemens product applications specialist in the initial 3 months following installation. All CTA were reported after 3 month's basic training. Cardiologists interpreting the CTA were blinded to the findings of the corresponding CCA and vice versa. CTA used for training purposes were excluded from analysis.

Sixteen segments were identified based on established AHA criteria that comprised the right coronary artery and distal branches (5 segments), left main stem (1), left anterior descending artery and branches (5) and circumflex artery and branches (5). Each segment was graded as diseased or normal. Diseased segments were graded as 1 = mild or no stenosis, 2 = greater than 50% stenosis (percentage luminal diameter narrowing compared to pre- and post-stenotic vessel lumen) by visual estimation. Stenoses ≥50% were regarded as significant. Segments that were absent or too small (less than 1.5mm diameter), heavily calcified or stented were scored 0 = non-evaluable.

Conventional Coronary Angiography

Conventional coronary angiography (CCA) was performed with a bi-plane digital fluoroscopy (Infinix, Toshiba Corp., Japan) via radial approach under local anesthesia with a Terumo radial 5F catheter and Omnipaque 350 (GE Healthcare, UK) contrast agent. A minimum of 6 orthogonal views were obtained. The CCA was interpreted by 2 cardiologists with at least 10 years intervention experience each, blinded to the CTA findings. Assessment of diameter stenosis was by visual estimation. The same segments and grading were used as for CTA. [Figure 1]

Statistical Analysis

All data were stored on Microsoft Access and transferred to SPSS 11.5. The specificity, sensitivity, positive predictive value (PPV) and negative predictive value (NPV) of detecting significant coronary stenoses on CTA was compared to CCA by cross-tabulation. The effects of image quality on correlations were also compared. Further analyses were performed on the main and proximal segments only, including the left main stem and proximal and mid segments of the left anterior descending artery, circumflex artery and the right coronary artery. For baseline characteristics and comparisons between groups of patients with good or moderate image quality, continuous variables were expressed as median [interquartile range] and compared by Mann-Whitney test, while discrete variables were expressed in absolute counts and percentages and compared by Chi square.

Results

Feasibility

Out of 128 patients, 100 patients (78%) had good image quality while 28 had moderate image quality. Those with good quality images were younger (median 56 years [49,60] vs. 59 [49,65]; P 0.05) and had lower calcium scores (33[1,97] vs. 354[105,982]; P<0.001). 85.3% of total segments were evaluable in the 'good quality image' group compared to 64.1% in the 'moderate quality' group. Conversely, significant lesions were more frequent in the 'moderate quality image' group (10.0% vs. 21.6%). No significant variations were found between groups for heart rate, serum creatinine and contrast volume used. [Table I] Moderate image quality was mainly due to high calcium scores (17 patients), motion artifacts from poor breath-holds and frequent ectopics (8 patients) and low contrast-holds ratio (3 patients).

Correlation of all vessel segments

One hundred and ninety eight significantly diseased (≥ 50% stenosis) vessel segments (representing 12% of total evaluable segments) were identified on CCA. The specificity, sensitivity, PPV and NPV of CTA compared to CCA for all segments were 96.6%, 69.5%, 69.8% and 97.0% respectively. Table II. Analysis of CTA with satisfactory image quality only (number of diseased segments = 136) produced figures of 96.7%, 75.6%, 71.8% and 98.0% respectively. Table III

Correlation of main and proximal vessel segments

For main and proximal vessel segments (diseased segments 142), the values were 95.3%, 83.8%, 77.4% and 97.2% respectively. When we analyzed only patients with good CTA image quality within this subgroup (diseased segments 96), the specificity, sensitivity, PPV and NPV were 95.3%, 93.9%, 73.6% and 99.0% respectively. [Figure 2].

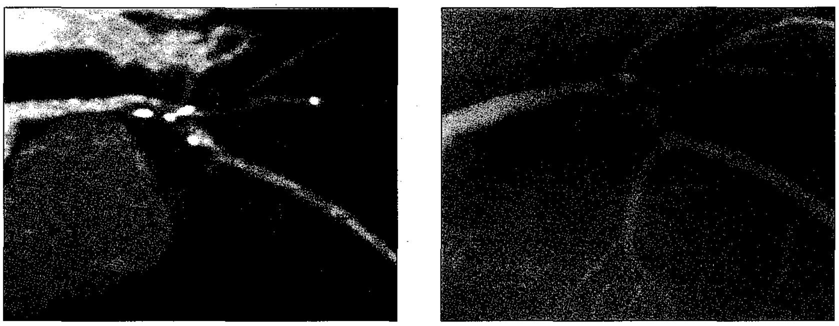

Fig. 1: CTA (top) and CCA (bottom - reversed contrast) of a 39-year gentleman presenting with angina post-infarction. Both images reveal a tight (up to 95%) stenosis in the proximal LAD segment involving the ostium of the 1st diagonal branch.

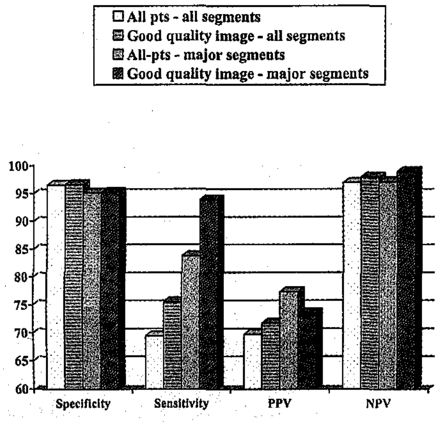

Fig. 2: Bar chart detailing the percentage specificity, sensitivity, positive predictive value (PPV), negative predictive value (NPV) and overall correlation of 64-row MDCT angiography in evaluation of significant coronary stenosis in all 128 patients, and in sub-group of 100 patients with good image quality, compared to conventional angiography. In both sets, analysis was performed on all coronary segments and on major/proximal segments only.

Table I: A comparison of baseline characteristics between 100 patients with good image quality and 28 patients with moderate image quality on 64-row multi-detector CT coronary angiography in a centre with early learning experience.

	Good	Moderate	P value
Age	56 [49,60]	59 [49,65]	0.05
Serum creatinine (umol/l)	96 [86,105]	95 [85,104]	0.82
Heart rate (per min)	62 [56,68]	60 [55,65]	0.303
Contrast volume (ml)	80 [80,88]	82 [80,85]	0.991
Calcium scoring (HU)	33 [1,97]	354 [109,982]	<0.001
Total evaluable segments/Total possible (%)	1365/1600 (85.3)	277/432 (64.1)	0.01
Total number of lesions/Total evaluable (%)	10.0137/1365 (10)	60/277 (21.6)	0.01

Continuous variables expressed as Median [interquartile range] and compared by Mann-Whitney U-test. Discrete variables expressed as counts and percentages, and compared by Chi square test. P <0.05 is statistically significant.

Table II: 64-row MDCT correlations of coronary vessel segments in 128 patients compared to conventional coronary angiography.

Segment	No. of Evaluable segments	No. of lesions	Specificity (%)	Sensitivity (%)	PPV (%)	NPV (%)
Left main stem	122	3	100	100	100	100
Proximal LAD	118	31	93.1	87.1	81.1	95.3
Mid LAD	114	32	90.2	93.8	78.9	97.4
Distal LAD	104	4	98	100	66.7	100
1st diagonal branch	107	16	96.7	81.3	81.3	96.7
2nd diagonal branch	64	4	96.7	50	50	96.7
Proximal left circumflex	120	15	94.3	80	66.7	97.1
Mid left circumflex	116	10	95.3	60	54.5	96.2
Distal left circumflex	113	6	99.1	16.7	50	95.5
1st obtuse marginal	106	10	97.9	50	50	94.9
2nd obtuse marginal	50	3	100	100	100	100
Proximal RCA	116	24	97.8	95.8	92	98.9
Mid RCA	108	16	93.5	62.5	62.5	93.5
Distal RCA	106	11	97.9	90.9	83.2	98.9
PDA	106	9	100	44.4	100	94.6
PLV	92	4	95.5	0	0	95.5
Total	1662	198	96.6	69.5	69.8	97.0

LAD, left anterior descending artery; RCA, right coronary artery; PDA, posterior descending artery; PLV, posterior left ventricular artery. Segments denoted in italics are excluded in main and proximal segment analyses.

Table III: 64-row MDCT correlations of coronary vessel segments in 100 patients with good quality image acquisition compared to conventional coronary angiography.

Segment	No. of Evaluable segments	No. of Lesions	Specificity (%)	Sensitivity (%)	PPV (%)	NPV (%)
Left main stem	95	1	100	100	100	100
Proximal LAD	94	23	91.5	95.7	78.6	98.5
Mid LAD	93	27	91.6	92.6	83.3	96.8
Distal LAD	85	2	98.8	100	66.7	100
1st diagonal branch	87	13	95.9	76.9	76.9	95.9
2nd diagonal branch	53	3	98	66.7	66.7	98
Proximal left circumflex	97	8	94.4	87.5	58.3	98.8
Mid left circumflex	97	3	95.7	100	42.9	100
Distal left circumflex	93	4	100	25	100	96.7
1st obtuse marginal	88	5	97.6	40	50	96.4
2nd obtuse marginal	42	1	100	100	100	100
Proximal RCA	94	17	97.4	100	89.5	100
Mid RCA	91	8	94	75	54.5	97.5
Distal RCA	91	9	97.6	100	81.8	100
PDA	84	8	100	50	100	95
PLV	81	4	94.8	0	0	94.8
Total	1365	136	96.7	75.6	71.8	98.0

LAD, left anterior descending artery; RCA, right coronary artery; PDA, posterior descending artery; PLV, posterior left ventricular artery. *Segments denoted in italics are excluded in main and proximal segment analyses*

Table IV: Summary of recent reports of correlation studies between minimally-invasive multi-detector CT and and conventional coronary angiography by centres with established (first 4 reports) and early learning experience (last 3 reports).

Author (Reference)	Year	Detector rows	Patient Group	Patient No.	AHA Segments	Evaluable segments (%)	No. of Lesions (% of Evaluable segments)	Sens.	Spec	PPV	NPV
Nieman	2002	16	Suspected CAD	58	Artery-based	88%	86	95	86	80	97
Ropers	2003	16	Suspected CAD	77	Artery-based	82%	78	87	89	77	97
Hoffman	2004	16	Positive ETT	33	16	438 (82.6)	43 (10)	70	94	58	97
					7			82	93	68	97
Hoffman	2005	16	Suspected CAD	103	16	1549 (94)	157 (10)	95	98	87	99
Leber, Knez	2005	64	Chronic stable angina	55	15	798 (93)	75 (9)	77	94	74	95
Leschka+	2005	64	Suspected CAD & prior CABG	67	15	1005 (100)	176 (18)	94	97	87	99
Raff+	2005	64	Suspected CAD	70	15	773 (83)	130 (17)	86	95	66	98
Ong, Chin+		64	Known CAD + ACS	128	16	1662 (83)	198 (12)	66	97	71	97
					8	920	142 (15)	83	96	80	98

Discussion

The last few years have witnessed the emergence and establishment of MDCT as a minimally-invasive coronary imaging tool through the efforts of several pioneering centres[16,19]. Many of these centers started coronary imaging with electron-beam CT and 4-row MDCT technology and reported their initial experiences and accuracy at detecting coronary stenoses compared to conventional angiography. As technology improved, the same centers, utilizing 16-row MDCT, reported dramatically improved rates of accuracy[7,9,20,21]. [Table IV]

Through further advancement in technology, especially with the introduction of 64-row MDCT scanners in 2004, published accuracy rates are better than ever[22-24]. This has captured the attention of many diagnostic and imaging centers around the world. There is some concern that centers with little or no experience are quoting rates of accuracy from established centers when performing these scans, thinking that scan technology could compensate for inexperience when reporting CTA images; and the belief of some that CTA could replace CCA as the gold-standard for coronary imaging. It was on this basis that we decided to publish our initial experience with CTA.

Our results are interesting for several reasons. First, we achieved 97% specificity and negative predictive value for the exclusion of significant coronary stenosis. We feel this was possible because of the excellent image quality provided by the 64-row MDCT scanner. We attempted to evaluate all coronary segments. However, only 83% of all segments were deemed evaluable, comparable to figures quoted by Raff et al but much lower than those quoted by Leschka et al and Leber et al. Operator inexperience and initial lack of confidence likely led to lower rates of evaluable segments at our center. The main limiting factor to good image acquisition and accuracy remained heavy calcification. Patient factors such as poor breath-holds and ectopic heart beats were largely overcome by the 64-row MDCT technology and associated software.

Operator experience and learning is more difficult to qualify. The number of patients scanned during the 18-week period of our study was about eighty patients per cardiologist. This figure might vary quite considerably between different centers. Despite the relatively short time that we had with the 64-row scanner, the high volume of patients undergoing both CTA and CCA allowed us to learn quickly from the incorrect evaluations while preventing patients from being wrongly diagnosed or significant lesions missed. The 'missed' lesions were mostly in the distal segments and branches. When these segments were excluded from analysis, sensitivity improved to 83%. It is likely also that the sensitivity for the detection of significant coronary disease may improve further with a per-patient analysis[9,20,23,24].

Based on our experience and comparing it to other published reports, we believe that the new generation 64-row MDCT has improved the feasibility and accuracy of CTA. However, formal physician training is necessary and a learning curve has to be overcome before a new center can confidently evaluate difficult coronary segments such as those of small-caliber vessels and calcified plaques. A recent announcement by the joint taskforce of the American College of Cardiology and American Heart Association on proposed training guidelines for MDCT coronary imaging and analysis was most welcome[17].

Finally, as demonstrated in our study and other reports, the PPV obtained by CTA is generally lower than NPV. This suggests that CTA is a useful modality for exclusion of disease but limited in its capacity to confidently confirm CAD. Conventional coronary angiography should remain the 'gold standard' coronary imaging tool for patients with high-probability of the disease.

Study Limitations

We chose to determine the accuracy of CTA using a segment-by-segment instead of per-patient analysis as we felt the former will be more appropriate for a technical report on accuracy. Furthermore, this method was used in other recently published reports, making comparison of results easier.
centers.

Conclusion

The 64-row MDCT scanner is a valuable imaging modality for the detection of significant coronary stenosis. Centers embarking or intending to embark on CTA should consider the concurrent use of CCA during the initial learning curve. Centers with less than a year's experience must determine their own rates of accuracy and should not quote the accuracy rates reported by more experienced centers.

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