



Clinical research

Accuracy of MSCT coronary angiography with 64-slice technology: first experience

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Aims The aim of our study was to investigate the accuracy of 64-slice computed tomography (CT) for assessing haemodynamically significant stenoses of coronary arteries.

Methods and results CT angiography was performed in 67 patients (50 male, 17 female; mean age 60.1 ± 10.5 years) with suspected coronary artery disease and compared with invasive coronary angiography. All vessels ≥ 1.5 mm were considered for the assessment of significant coronary artery stenosis (diameter reduction $>50\%$). Forty-seven patients were identified as having significant coronary stenoses on invasive angiography with 18% (176/1005) affected segments. None of the coronary segments needed to be excluded from analysis. CT correctly identified all 20 patients having no significant stenosis on invasive angiography. Overall sensitivity for classifying stenoses was 94%, specificity was 97%, positive predictive value was 87%, and negative predictive value was 99%.

Conclusion Sixty-four-slice CT provides a high diagnostic accuracy in assessing coronary artery stenoses.

Introduction

Invasive coronary angiography (ICA) is the accepted reference standard for the assessment of coronary artery stenoses because of its unprecedented temporal and spatial resolution and the ability to perform therapeutic interventions in the same session. Although the associated risk for serious complications is small,¹ the inconvenience for the patient and economic deliberations have strengthened the search for a non-invasive alternative. Current multi-slice computed tomography (MSCT) scanners provide promising results in the assessment of coronary artery disease (CAD), but some segments are not evaluable because of motion artifacts or severe vessel wall calcification.^{2–4} The recently developed 64-slice CT scanner

generation provides 0.4 mm nearly isotropic voxels in a rotation time of 0.37 s, thus increasing temporal and spatial resolution when compared with previous CT scanner types. This is accomplished by using periodic motion of the focal spot in the longitudinal direction resulting in two simultaneously acquired overlapping projections of 32 detectors (z-Sharp Technology).⁵

The aim of our study was to investigate the accuracy of 64-slice CT for assessing haemodynamically significant stenoses of the coronary arteries in comparison with ICA.

Methods

Study population

Seventy-three consecutive patients (54 male, 19 female; mean age 62.0 ± 10.8 years; range 34–82 years) were referred to

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our centre between October 2004 and January 2005 for suspected CAD or prior to coronary artery bypass surgery. Exclusion criteria for CT were as follows: previous allergic reactions to iodine contrast media, severe renal insufficiency (creatinine level, $>120 \mu\text{mol/L}$), haemodynamic instability, atrial fibrillation, inability to follow breath-hold commands, previous percutaneous transluminal coronary stent placement, and previous bypass surgery. Seven patients were excluded because of elevated creatinine levels ($n = 4$), previous stent placement ($n = 2$), or disclaimed to take part in the study ($n = 1$). The remaining 67 patients (50 male, 17 female; mean age 60.1 ± 10.5 years; range 34–82 years) underwent both ICA and CT coronary angiography and were included in this study. The mean interval time between ICA and CT was 14.1 ± 14.5 days (median 13; range 1–55 days). Twenty-four (36%) investigations were performed in patients presenting with signs of unstable angina pectoris, 43 (64%) patients were examined before undergoing coronary artery bypass surgery. From the 67 patients, 40 (60%) had taken β -receptor-blocking as part of their baseline medication at the time of the CT examination. The study was approved by our institutional ethics committee and all participating patients gave written informed consent.

Invasive coronary angiography

ICA was performed according to standard techniques and multiple views were stored on a CD-ROM. The angiograms were evaluated by an experienced observer who was blinded to the results from CT coronary angiography. The coronary arteries were segmented according to the guidelines of the American Heart Association⁶ and to a previous publication⁴ as follows: the right coronary artery (RCA) was subdivided in a proximal, middle, and distal parts; the posterior descending artery was considered as independent because of the variability of its origin; the left circumflex artery (LCX) was divided into proximal and distal parts; the left anterior descending artery (LAD) was divided into proximal, middle, and distal parts; the diagonal (DIA) branches, obtuse marginal (OM) branches, and posterolateral (PLA) branches were considered as being independent segments. Each vessel segment was scored as being significantly stenosed, defined as a diameter reduction of $>50\%$ or not. Coronary artery analysis was performed in all vessels with a diameter down to 1.5 mm, including those vessels distal to complete occlusions.

CT coronary angiography

All CT scans were performed on a 64-slice scanner with a 0.37 s rotation time (Somatom Sensation 64, Siemens, Forchheim, Germany). A bolus of 80 mL iodixanol (Visipaque 320 mg/mL, Amersham Health, Buckinghamshire, UK) was injected into an antecubital vein at a flow rate of 5 mL/s, followed by a 50 mL saline chasing bolus. Start delay was defined by bolus tracking in the ascending aorta and scan start was automatically initiated 5 s after reaching the threshold [140 HU (HU, Hounsfield Units)]. After this, scanning was performed from the tracheal bifurcation to the diaphragm using the following parameters: X-ray tube potential 120 kV, effective tube current 680 mA, slice collimation $64 \times 0.6 \text{ mm}^2$, table feed 9.2 mm/rotation, and pitch 0.24. All CT scans were performed using an implemented fully automated real-time anatomy based dose regulation (CARE Dose 4D). The overall scan time was shorter than 12 s (median 11.2 s, range 10.7–11.9 s) and the mean total time for the examination was <15 min (median 12 min, range 8–14 min). We used retrospective electrocardiographic (ECG) gating for optimal heart phase selection.⁷

The implemented adaptive cardio volume approach was used for data reconstruction. Depending on the heart rate throughout the examination, axial slices were reconstructed synchronized to the ECG by a single sector ($\leq 65 \text{ b.p.m}$) or two sector algorithm ($>65 \text{ b.p.m}$) using data from one or two consecutive heartbeats.⁵ When necessary, R-wave indicators were manually repositioned to improve the quality of synchronization. Images were reconstructed at 10% intervals of the cardiac cycle to allow assessment of coronary arteries at that cardiac phase with minimal vessel motion. Slices with a thickness of 0.75 mm (increment 0.5 mm) and a medium soft-tissue reconstruction kernel (B30f) were used for evaluating coronary arteries.

CT data analysis

Coronary artery analysis was performed using the same guidelines⁶ as for ICA. Two independent and blinded observers without knowledge of the patients clinical history, the indication for the patients referral, and the results from ICA classified each vessel segment interactively on a post-processing workstation (Second Wizard, Siemens, Forchheim, Germany) for the presence of haemodynamically significant stenoses. Similar to ICA, significant stenosis was defined as narrowing of the coronary lumen exceeding 50% and all vessels with a diameter down to 1.5 mm including those vessels distal to complete occlusions were included in the analysis. The vessel diameters were measured on reconstructions perpendicularly oriented to the vessel course. Depending on the individual coronary anatomy and image quality, different visualization techniques such as multi-planar reformations (MPR), maximum intensity projections (MIP), and volume rendering (VR) were used. Each vessel was analysed on at least two planes, one parallel, and one perpendicular to the course of the vessel. In case of disagreement between the two observers, a final decision was obtained by consensus.

Image quality was classified for each segment as being excellent (no artifacts, unrestricted evaluation), good (minor artifacts, good diagnostic quality), adequate (moderate artifacts, acceptable for routine clinical diagnosis), and poor/not evaluative (severe artifacts impairing accurate evaluation). When image quality rating was not excellent, the reasons for impaired visualization were selected from the following list: low vessel opacification, calcium deposits or opacified adjacent structures (such as contrast-enhanced ventricle or cardiac vein), and motion artifacts. Motion artifacts were defined as any impairment of image quality caused by vessel movement resulting in blurred or doubled vessel contours. Arterial wall calcification was rated as either moderate (small isolated wall calcifications) or massive (extensive wall calcification with beam hardening artifacts impairing arterial lumen visualization).

Statistical analysis

Statistical analysis was performed using a commercially available statistical software (SPSS 11.5 for Windows, SPSS Incorporation, Chicago, IL, USA). Quantitative variables are expressed as mean \pm standard deviation. Inter-observer agreements were expressed as Cohen's kappa statistics⁸ and interpreted by the guidelines of Landis and Koch.⁹ Sensitivity, specificity, positive predictive value, and negative predictive value for 64-slice CT coronary angiography for detecting significant stenoses in all coronary arteries were calculated from χ^2 tests of contingency, and 95% confidence intervals (CI) were calculated from binomial expression. Because of the possible interdependencies between different vessel segments, the statistics

were calculated on a vessel-based analysis. ICA was regarded as the standard of reference.

Results

Using ICA, a total of 176 haemodynamically significant stenoses, 17% of them (30/176) being complete vessel occlusions, were identified in 70% (47/67) of the patients. One-vessel disease was present in 6% (4/67), two-vessel disease in 15% (10/67), and three-vessel disease in 49% (33/67). Significant coronary artery stenosis was absent in 30% (20/67).

No additional β -blockers were administered prior to the CT examination resulting in a mean heart rate of 66.3 ± 14.7 beats per minute (range 48–90). Regarding CT coronary angiography, kappa values for image quality, calcifications, and stenosis detection were 0.88, 0.87, and 0.95, respectively, indicating a good to excellent inter-observer agreement. Results for coronary artery stenosis detection, image quality, calcifications, reasons for impaired image quality, and diagnostic accuracy in each segment and the results regarding proximal, middle, and distal vessel segments (including side branches) are summarized in *Table 1*.

Image quality was rated as being excellent in 61% (612/1005), good in 31% (310/1005), and adequate in 8% (83/1005) of all segments with the best results in the proximal coronary arteries. No vessel segment had to be excluded from analysis. Calcifications were present in 49% (494/1005) of all coronary branches, 36% of them (180/494) being referred to as massive calcifications causing beam hardening artifacts decreasing lumen visualization. Consequently, the most common cause for impaired image quality resulted from severely calcified vessel walls (56%; 229/393). Motion artifacts were recognized in 5% (51/1005) of the coronary vessels in 24% of the patients (16/67). Of these patients (13/16), 81% had heart rates ≥ 75 beats per minute (median 78 per minute, range 67–90). Most motion artifacts affected the mid-RCA (28%; 14/51), 71% of these patients (10/14) had elevated heart rates ≥ 75 beats per minute (median 80 per minute, range 70–90). However, of the 51 observed motion artifacts, 47 led to an only slight impairment of image quality with the vessel being still evaluative. In the four segments with motion artifacts degrading the image quality to adequate, two were responsible for false-negative ratings. A case with typical motion artifacts is demonstrated in *Figure 1*. Low vessel opacification was found in $\sim 8\%$ (77/1005) of the coronary arteries, most of them in the PLA (30%; 20/67), and the RPDA (31%; 21/67). Overlaying adjacent structures were recognized less frequently as cause of decreased image quality (4%; 36/1005). In all cases, both reasons lead to an only slight degradation of image quality from excellent to good.

From a total of 176 haemodynamically significant stenoses detected with ICA, 165 were correctly recognized with CT coronary angiography. The overall sensitivity was 94% (165/176; 95% CI: 90.2–96.2), the specificity was 97% (805/829; 95% CI: 96.4–97.6), the positive

predictive value was 87% (165/189; 95% CI: 84.0–89.6), and the negative predictive value was 99% (805/816; 95% CI: 97.9–99.2). Three lesions were missed because of motion artifacts: one in the mid-RCA, one in the distal LCX, and one in the posterior descending artery. Depending on the grade of diameter reduction, severely calcified lesions were judged as being either stenotic or non-stenotic. Eight lesions were missed because of severe wall calcification: two in the distal RCA, two in the mid-LAD, one in the distal LAD, two in the first diagonal branch, and one in the distal LCX. Twenty-four lesions observed with CT coronary angiography were false-positive and all were located in severely calcified vessel segments: four in mid-RCA, two in the distal RCA, five in mid-LAD, two in distal LAD, one in the first diagonal branch, five in the proximal LCX, three in distal LCX, and two in the PLA branch. *Figure 2* demonstrates an example for coronary artery stenosis detection by MSCT and ICA.

Regarding a patient-based analysis, all patients without CAD could be correctly identified with CT. In all patients with CAD at least one significant lesion was correctly classified with CT.

Discussion

To become a clinically accepted tool for the examination of patients with suspected CAD, the main requisite for CT coronary angiography includes the complete visualization of all therapeutic relevant coronary arteries without excluding segments.³ With four-slice CT, a sensitivity of 58–86% for the detection of coronary stenosis has been reported,^{10–14} but up to 32% of the vessels had to be excluded from analysis because of a decreased image quality.¹⁰ Using 16-slice CT, overall sensitivity including all segments was reported to be between 73 and 95%, depending on the diameter of the segment, the modality of analysis, and the patient selection criteria.^{2–4,15} However, in some studies evaluation was limited to branches having a diameter >2 mm.^{3,15} In this study, we evaluated all arteries being >1.5 mm in diameter, and no segment had to be excluded from analysis, thereby finding a sensitivity of 94% and a specificity of 97% for the detection of significant coronary stenoses. Because of different patient populations and imaging protocols compared with the earlier mentioned studies, a direct comparison of study results is not permitted. Nevertheless, the data reported herein using a 64-slice CT scanner suggest a certain improvement regarding diagnostic accuracy. The high negative predictive value of 99% in this study furthermore suggests an important future role of CT coronary angiography for reliably excluding CAD in patients with an equivocal clinical presentation, who may currently undergo a cost-extensive ICA.¹⁶

Recent studies have reported two major limitations for reliable assessment of all coronary segments: motion artifacts and severe coronary calcifications.^{2–4} Regarding motion artifacts, no additional β -blockers prior to the CT examination were administered in this

Reasons for decreased image quality ^c									
Low opacification	6 (3/50)	—	—	18 (3/17)	11 (2/18)	18 (6/33)	12 (4/33)	41 (20/49)	45 (21/47)
Motion artefacts	34 (17/50)	—	74 (14/19)	18 (3/17)	6 (1/18)	3 (1/33)	21 (7/33)	6 (3/49)	19 (9/47)
Calcium deposits	60 (30/50)	100 (14/14)	26 (5/19)	64 (11/17)	66 (12/18)	73 (24/33)	61 (20/33)	45 (22/49)	23 (11/47)
Adjacent structures ^d	—	—	—	—	17 (3/18)	6 (2/33)	6 (2/33)	8 (4/49)	13 (6/47)
Diagnostic accuracy									
Sensitivity	93 (41/44)	100 (18/18)	95 (19/20)	67 (4/6)	78 (7/9)	100 (8/8)	100 (2/2)	100 (13/13)	100 (2/2)
Specificity	96 (151/157)	100 (49/49)	92 (43/47)	97 (59/61)	98 (57/58)	100 (59/59)	100 (65/65)	96 (52/54)	100 (65/65)
Positive predictive value	87 (41/47)	100 (18/18)	83 (19/23)	67 (4/6)	88 (7/8)	100 (8/8)	100 (2/2)	87 (13/15)	100 (2/2)
Negative predictive value	98 (151/154)	100 (49/49)	98 (43/44)	97 (59/61)	97 (57/59)	99 (59/59)	99 (65/65)	100 (52/52)	99 (65/65)

Dist, distal; LM, left main artery; LPDA, left posterior descending artery segment; NA, not applicable; OM, obtuse marginal branch; Prox, proximal; RPDA, right posterior descending artery segment. Significant stenosis was defined on both CT and ICA as >50% diameter reduction in all vessels ≥ 1.5 mm in lumen diameter.

^aResults for LAD, LCX, and RCA represents summarized measurements of dependent segments (LAD: proximal, mid, and distal LAD; LCX: proximal and distal LCX; RCA: proximal, mid, and distal RCA).

^bMean diameter of the proximal part of the segment.

^cRate of reasons for decreased image quality were calculated from all vessel segments scored other than excellent.

^dContrast-enhanced ventricle or cardiac vein.

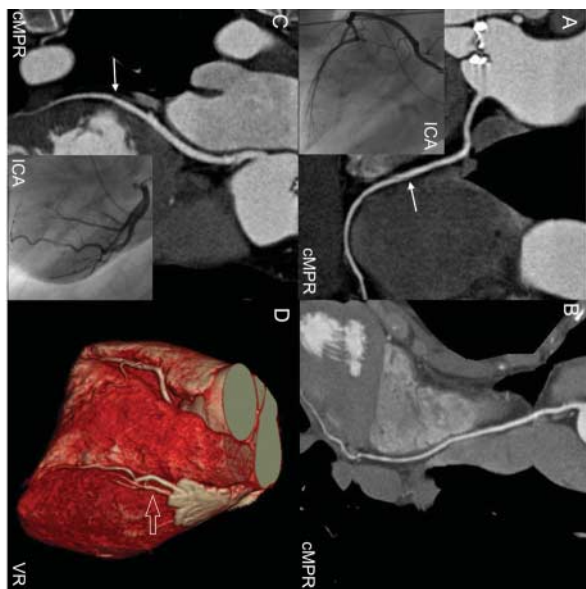


Figure 1. Normal coronary arteries with 64-slice CT coronary angiography and ICA in a 74-year-old woman admitted for suspected CAD. Curved multi-planar reformations (cMPR) of the RCA (A), LAD (B), and LCX (C) demonstrate no stenosis. Some slight motion artifacts are present in mid-RCA and distal LCX (arrows), but image quality was rated as good in those segments. VR image (D) delineates the three-dimensional course of the coronary arteries and also presenting venous opacification by not disturbing artery visualization (open arrow). Corresponding ICA demonstrates normal right (inlay in A) and left coronary arteries (inlay in C).

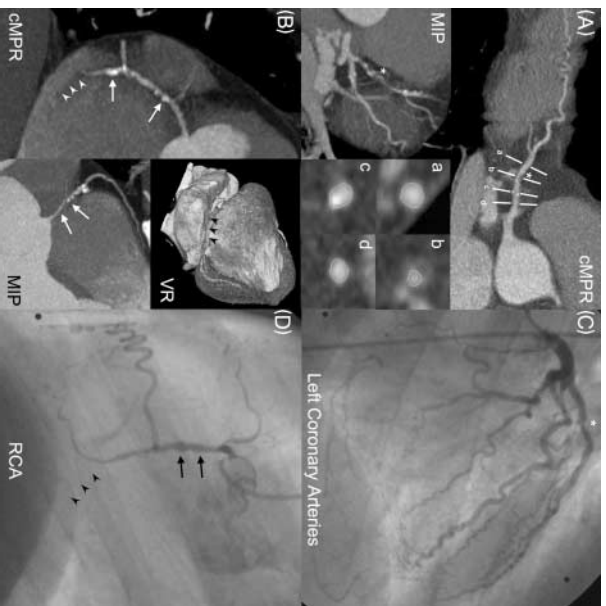


Figure 2. Sixty-four-slice CT coronary angiography and ICA in a 44-year-old man with atypical chest pain. cMPR (A), MIP, and perpendicular cut-planes (inlays a–d) delineate multiple non-calcified plaques in mid-LAD, one leading to a haemodynamically significant stenosis (asterisk, cut-plane b). In the RCA, cMPR (B), VR image, and MIP demonstrate multiple non-significant wall irregularities in the mid-segment (arrows) and occlusion of the distal segment (arrowheads). As shown in the ICA (C and D), all lesions were correctly identified.

study resulting in a heart rate between 48 and 89 beats per minute. By selecting several reconstruction intervals relative to the cardiac cycle, it was possible to compensate for motion artifacts in the majority of affected vessels by individually choosing the phase with minimal vessel motion for each segment. In general, image quality was decreased with higher heart rates, but only two significant lesions were missed because of severe heart motion. Regarding coronary calcifications, half of the coronary segments in this study contained wall calcifications, 18% being severe calcifications causing beam hardening artifacts with a decrease in lumen visualization. Calcium deposits were found to be responsible for eight false-negative and all 24 false-positive judgments with CT. In addition, all false-positive lesions also appeared in ICA as wall irregularities.

Reflecting our experience with cardiac 16-slice CT, improved spatial and temporal resolution of the new scanner generation increases image quality and facilitates the assessment of CAD. Moreover, the scanning time is shortened to <12 s, allowing a decreased breath-hold time, a better exploitation of contrast-media with less enhancement of adjacent structures, and a lower dose of applied contrast media.

We acknowledge the following limitations of this study. First, some specific segments (e.g. PLA branches and posterior descending artery) harboured only a low number of significant stenoses. Secondly, nearly two-thirds of the study patients were referred prior to coronary artery bypass surgery presenting with a high rate of severe wall calcifications and three-vessel disease. Therefore, patient selection bias may possibly limit the transfer of these results to clinical practice. Especially, the assumption that MSCT angiography can reliably rule out CAD cannot be demonstrated on the basis of the results with this high CAD prevalence cohort. Furthermore, this setting with patients having a high pre-test probability of the disease may have resulted in an overestimation of the ability of MSCT to detect and to rule out stenoses. Thirdly, no quantitative coronary angiography was performed and stenoses were semi-quantitatively assessed with both ICA and MSCT. This method of stenosis evaluation may have been influenced by a subjectivity bias. However, a kappa value of 0.95 corresponds to an excellent inter-observer agreement and may argue against such a subjectivity bias. On the other hand, such a high inter-observer agreement may be difficult to be obtained in a cohort of patients with a lower prevalence of CAD. Next, the radiation exposure inherent with CT may be a limitation of the technique. The most effective way to reduce radiation exposure is prospective ECG tube current modulation (ECG pulsing).¹⁷ We did not apply this technique because of a possible impairment of image quality during early-diastole, a phase which is often crucial when evaluating the RCA. To reduce radiation exposure, instead of quantitative calcium scoring on additional non-contrast scans, we descriptively assessed arterial wall calcifications on CT coronary angiography. In addition, the implemented anatomy based dose regulation software significantly reduces effective radiation doses.¹⁸ Finally, MSCT and ICA were not

performed simultaneously, but the median delay between the two test was small with regard to the natural progression of CAD.¹⁹

In conclusion, our initial results suggest that 64-slice CT allows a non-invasive assessment of haemodynamically significant CAD with a high diagnostic accuracy. Extensive arterial wall calcifications still impair vessel assessment, but no segment had to be excluded from analysis. Further prospective studies have to analyse the threshold of vessel size and heart rate sensible for reliable assessment of coronary artery stenosis, and should aim in examining patient populations with a low pre-test probability of CAD in whom catheterization could be avoided.

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