European Journal of Cardio-thoracic Surgery 36 (2009) 1011–1017

EUROPEAN JOURNAL OF CARDIO-THORACIC SURGERY

www.elsevier.com/locate/ejcts

Accuracy of dual-source computed tomography coronary angiography: evaluation with a standardised protocol for cardiac surgeons

Andre Plass [a,*], Naim Azemaj [a], Hans Scheffel [b], Lotus Desbiolles [b], Hatem Alkadhi [b], Michele Genoni [a], Volkmar Falk [a], Jurg Grunenfelder [a]

[a] *Clinic for Cardiovascular Surgery, University Hospital Zurich, Raemistr. 100, 8091 Zurich, Switzerland*
[b] *Institute of Diagnostic Radiology, University Hospital Zurich, Zurich, Switzerland*

Received 11 February 2009; received in revised form 11 June 2009; accepted 17 June 2009; Available online 30 July 2009

Abstract

Background: This study assesses the accuracy of the new dual-source computed tomography (DSCT) for detection of coronary artery disease (CAD) compared with invasive coronary angiography (ICA) with a specifically designed data presentation protocol for cardiac surgeons. **Methods:** Forty patients (30 males/10 females) underwent ICA and DSCT. Best-quality images were prepared by radiologists. Evaluation of 12 segments of significant coronary stenosis was done by two cardiac surgeons with a data presentation protocol including different coronary views in two-/three-dimensional (2D/3D) images. No beta-blockers were administered prior to DSCT. **Results:** ICA revealed CAD in 21 patients and valvular disease but no CAD in 19 patients. In DSCT, 20/21 patients were diagnosed with CAD (at least one significant stenosis per patient). In 11/21 patients, all 12 segments were assessed correctly; in 7/21 patients one segment and in 3/21 patients two segments were evaluated incorrectly. Of all 21 patients with CAD, 239/252 segments (95%) were correctly evaluated. In 18/19 patients without CAD, DSCT correctly ruled-out the ICA results in 226/228 segments (99%). In total, 465/480 segments were correctly assessed (97%). Of 480 segments, only six were considered not assessable. DSCT assessments of the segments showed a sensitivity of 91%, specificity of 99%, a positive predictive value of 92% and a negative predictive value of 99%. **Conclusions:** The accuracy of DSCT coronary angiography especially for exclusion of CAD is promising. The introduced data presentation protocol allows for the independent evaluation by cardiac surgeons after pre-arrangement from the radiologists.

Keywords: Coronary artery imaging; Dual-source computed tomography; Cardiac surgery

1. Introduction

The advent of recent multi-slice computed tomography (CT) technology has resulted in an increasing use of the modality as a cardiac imaging tool for evaluating coronary artery disease (CAD) as well as for preoperative planning for cardiac surgical interventions [1–4]. Spatial and temporal resolution has continuously increased and the quality and applicability for non-invasive coronary artery imaging has considerably improved [5–13]. In particular, the 64-slice CT technology can now be used as a reliable tool for the detection or exclusion of CAD. Thus, the Task Force on the Management of Stable Angina Pectoris of the European Society of Cardiology and the American Heart Association recommended the performance of CT coronary angiography in patients with stable angina and a low-to-intermediate pre-test probability of CAD, having a non-conclusive exercise electrocardiogram (ECG) or stress imaging test [14,18].

Although a high accuracy for diagnosis and exclusion of CAD has been consistently reported for 64-multi-slice CT, the examinations still may be affected by non-evaluable coronary artery segments mostly caused by motion artefacts and heavy calcifications in the coronary artery wall. These two limiting factors are amplified at higher and variable heart rates [12,13].

The dual-source CT (DSCT, Siemens, Germany) system represents one of the latest generations of multi-slice CT scanners, which enables a high temporal resolution of 83 ms in a mono-segment reconstruction mode. The earliest studies illustrated promising improvements of the image quality of DSCT coronary angiography, especially in patients with high heart rates and strongly calcified vessels [15–17].

Although CT coronary angiographies may now provide excellent image quality, the way into clinical routine has to be carefully reviewed for applicability. For cardiac surgeons,

* Corresponding author. Tel.: +41 44 2555 11 11; fax: +41 44 255 44 46.
E-mail address: Andre.Plass@usz.ch (A. Plass).

1010-7940/$ — see front matter © 2009 European Association for Cardio-Thoracic Surgery. Published by Elsevier B.V. All rights reserved.
doi:10.1016/j.ejcts.2009.06.027

the interpretation of CT images itself is frequently a limiting factor and represents the difference to an assessment of invasive coronary angiography (ICA). Cardiac surgeons are used to reviewing ICA alone for diagnostic purposes and clinical decision-making. By contrast, at present, multi-slice CT evaluations are prepared and evaluated by the radiologist and then multiple and preselected pictures are presented to the cardiac surgeons. It needs to be kept in mind that these preselected pictures might influence the results and therapeutic interventions, which depend heavily on image handling by the examiner. Since cardiac surgeons are generally not yet used to handling CT post-processing tools, they have to accept these preselected pictures for data evaluation and decision-making. This is even more important in view of the fact that DSCT is not only a purely diagnostic tool, but it is also increasingly used as a preoperative planning tool for cardiac surgery.

This study evaluates the accuracy of the new DSCT system for the diagnosis of CAD as compared to ICA as a reference standard. In addition, it elucidates the applicability of a standardised evaluation protocol and the feasibility of DSCT both as a diagnostic and a preoperative planning tool for cardiac surgeons.

2. Methods

2.1. Patients

Forty patients (30 male, 10 female, age 68 ± 11 years) underwent DSCT and ICA within 6 weeks. In 21 patients, a known CAD was present, while 19 patients suffered from valvular heart disease without known CAD. Patients with allergy to iodinated contrast media, renal insufficiency (serum creatinine >140 mmol l^{-1}) and previous cardiac procedures such as stenting or bypass surgery were excluded from CT. The study protocol was approved by the local ethics committee and written informed consent was obtained from all patients.

2.2. Dual-source computed tomography acquisition

For the DSCT (Somatom Definition, Siemens Medical Solutions, Germany) examinations the following scanning parameters were used:

Slice Collimation of 2 mm $\times$ 64 mm $\times$ 0.6 mm by means of a z-flying focal spot, *Detector Collimation* of 2 mm $\times$ 32 mm $\times$ 0.6 mm, *Slice thickness* of 0.75 mm, *Increment* of 0.5 mm, *Gantry rotation time* of 0.33 s, *Tube voltage* of 120 kV, *Tube current* of 350 mAs per rotation and *Pitch* 0.2—0.5 (adapted to the heart rate). ECG-based tube current modulation for radiation dose reduction was used in all patients: at mean heart rates (HR) below 60 b.p.m.; full tube current was applied from 60% to 70%, at 61—70 b.p.m. from 50% to 80% and at HRs above 70 from 30% to 80% of the R—R interval [19]. The effective radiation dose of this protocol ranged between 7 and 9 mSv [20].

All patients received a single dose of 2.5 mg isosorbiddinitrate s. l. (Isoket, Schwarz Pharma, Monheim, Germany). After 2 min, 80 ml contrast media at a concentration of 320 mg ml^{-1} (Visipaque 320 mg ml^{-1}, GE Buckinghamshire, UK) was intravenously injected followed by a 30 ml saline chasing bolus at a flow rate of 5.0 ml s^{-1}. The scanning delay was defined by bolus tracking with a region of interest (ROI: mean diameter 10.1 ± 5.6 mm, range 7.5—17.0 mm) placed in the ascending aorta. The image acquisition started 5 s after the signal attenuation reached the predefined threshold of 100 Hounsfield units (HU).

2.3. Image reconstruction

CT angiograms were reconstructed during mid-to-end diastole at following phases of the R—R interval, depending on the heart rate. In case of non-diagnostic image quality, additional reconstructions were performed in 5% steps of the R—R interval within the full tube current window.

For calcium scoring, non-overlapping images with a slice width of 3 mm were reconstructed from the non-enhanced DSCT images using a medium—sharp convolution kernel (B35f). In addition, reconstructions were performed using a hard—sharp convolution kernel (B46f) to compensate for blooming artefacts in case of vessel calcifications.

The patients received no additional beta-blockers next to their routine baseline medication, independently of their heart rate.

All images were transferred to an external workstation (Wizard, Siemens) equipped with cardiac post-processing software (syngo Circulation, Siemens, Germany). In an additional step, the radiologist assessed the scan including calculation of the Agatston calcium score (CS) and prepared the data in the following standardised evaluation protocol for reviewing.

2.4. Standardised evaluation protocol

1. Multiphase reconstruction in the full-tube current window with a predefined kernel and slice thickness (Kernel B26, B46: optional, slice thickness 0.75 mm and 0.5 increment) of the raw data by the radiologist.
2. The Agatston CS of the patient was calculated for risk stratification by the radiologist.
3. Standardised images and image sequences are selected by the radiologist for the cardiovascular surgeon. The selection presented to the cardiac surgeon contained different image viewing techniques and illustrations:
   - Curved multi-planar reconstruction (cMPR) of the RCA, LAD and CX (Fig. 1),
   - Axial view dataset including choice of different phases (%) + optional two further planes + 3D illustration in volume-rendering technique (Fig. 2).
4. The cardiovascular surgeon is then able to assess the coronary arteries by using the prepared standardised data presentation protocol (axial view dataset, cMPR and 3D illustration).

2.5. CT data analysis and protocol

For the assessment of coronary segments we used a modified scheme of 12 instead of 15 segments, according

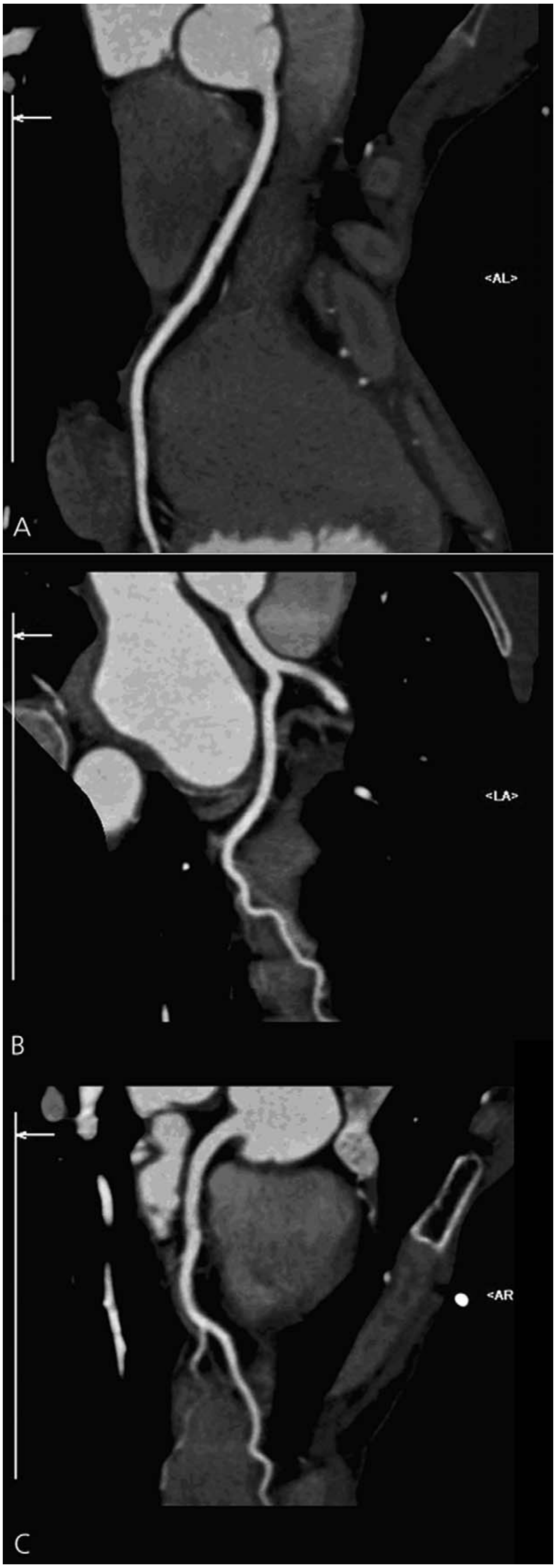

Fig. 1. Curved multi-planar reconstruction of normal coronary arteries without significant stenosis and calcification. RCA (A), LAD (B), CX (C).

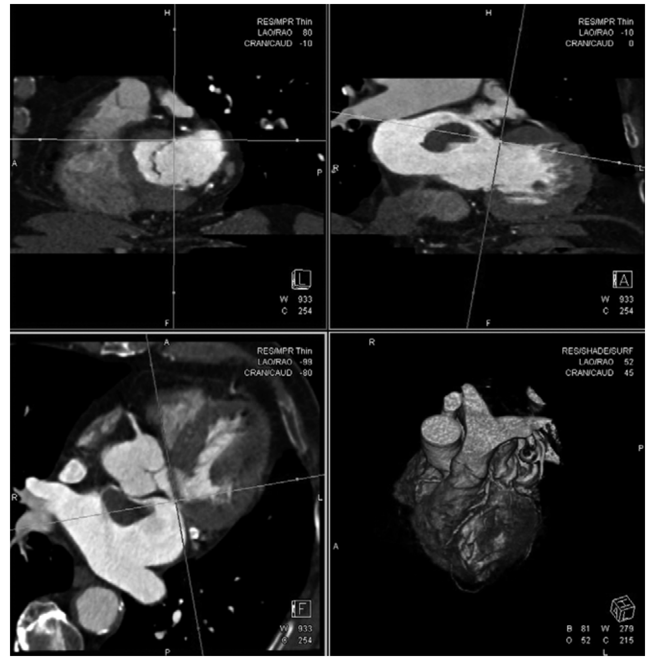

Fig. 2. Screen view with three different planes of reconstructions in 2D for diagnostic and rotational 3D illustration for preoperative planning.

to the guidelines of the American Heart Association (AHA) [21].

Right coronary artery (RCA):	Segment 1 → proximal Segment 2 → middle Segment 3 → distal (including the Crux) Segment 4 → posterior descending artery
Left main artery (LM):	Segment 5
Left anterior descending artery (LAD):	Segment 6 → proximal Segment 7 → distal Segment 8 → 1st diagonal branch
Left circumflex artery (CX):	Segment 9 → proximal Segment 10 → 1st marginal branch Segment 11 → distal Segment 12 → posterolateral artery

Our protocol is developed to best meet the needs of cardiac surgeons for diagnostic and for preoperative planning of potential bypass grafts. All segments with a diameter of at least 1.5 mm at their origin were included in the analysis.

Calcifications were quantified with dedicated scoring software (Syngo CaScore, Siemens). All lesions on more than two contiguous pixels with attenuation values greater than 130 HU were marked by the radiologist and the CS in each patient was computed by using the Agatston method [23]. The Agatston score represents the area score multiplied by an attenuation factor, which is based on the peak HU of the lesion.

Two independent cardiac surgeons performed all the readings at the original workstation (Wizard, Siemens). They described the image quality of each coronary segment as being good, as restricted but diagnostic or as poor and not assessable. The evaluation was performed with the protocol mentioned above in a blinded fashion; the readers were unaware of the clinical history of the patient. Significant stenosis was defined as luminal diameter narrowing exceeding 50%.

2.6. Invasive coronary angiography

ICA was performed according to standard techniques. The contrast agent medium consumption including the levogram averaged 140 ml. The multiple views were recorded on a CD-ROM and two cardiac surgeons aware of the patients' clinical history but blinded to the results from DSCT analysed the images with regard to the presence (defined as luminal reduction of >50%) or absence of significant stenoses. Coronary arteries with diameter as large as 1.5 mm were subdivided into 12 segments as described above for the CT examinations.

2.7. Statistical analysis

The location and number of significant stenoses were documented and compared to the results from ICA, which was considered the standard of reference.

The sample size was determined based on a segment-based analysis of accuracy. Assuming 12 segments per patient, a z-test with a 0.05 two-sided significance level will have >90% power to detect the difference between proportions of 90% and 95% when the number of segments is 480.

To account for the clustered nature of the data (i.e., the fact that there were not 480 independent vessel segments but instead clusters of segments in 40 patients), generalised estimating equation was applied for stenosis evaluation to account for clustering of coronary artery segments within patients.

Sensitivity, specificity, positive predictive value and negative predictive value were calculated from chi-square tests of contingency, and the 95% confidence intervals were calculated. Quantitative variables were expressed as mean ± standard deviation and categorical variables as frequencies or percentages. Calculations are performed for the group with evaluable segments and vessels and for all patients together, including non-evaluable segments and branches.

Statistics for diagnostic accuracy of DSCT were calculated on a segment-based, a vessel-based and on a patient-based analysis, the latter defined as the presence of at least one significant stenosis or absence of any significant stenosis in each patient. As previously suggested [10], the patient-based analysis was also performed including all patients censoring any non-evaluative coronary segment by CT as false positive, because every patient with any non-evaluative segment would undergo ICA in clinical practice. For comparison of the continuous variables, the Student's t-test was used; a p-value of <0.05 was considered statistically significant.

3. Results

ICA and DSCT were successfully performed in all 40 patients without complications. A total of 480 segments were assessed. The effect of clustering of coronary artery segments within each patient for coronary artery stenosis was not significant ($p = 0.09$), justifying the assumption that the coronary artery segments can be analysed independently.

The mean heart rate during CT was 76 ± 9 b.p.m. with a range of 35—88 b.p.m. In 16 patients HR was <60 b.p.m., in 15 between 60 and 70 b.p.m. and in 20 patients it was >70 b.p.m. In four patients, the HR was more than 80 b.p.m. Of the 41 patients, 21 (51%) used no beta-blockers before and during the scan, in 20 (49%) patients beta-blockers were already prescribed. Of the patients with HR >80 b.p.m., only one did not take beta-blockers.

ICA excluded CAD in 19 patients with valvular heart disease. In 21 patients, ICA showed single-vessel disease in four (19%), two-vessel disease in eight (38%) and three-vessel disease in nine (43%) patients.

3.1. DSCT evaluation of patients

CAD (at least one significant stenosis per patient) was found in 20 of 21 patients with DSCT. In one patient with a single-vessel disease, CAD was missed by DSCT (i.e., one false-negative segment, 11 true positive segments).

In 11 of 21 patients with CAD, all 12 segments were assessed correctly. In seven of 21 patients one segment was evaluated incorrectly or was not diagnostic and 11 segments were rated correctly. In three of 21 patients, two segments were evaluated incorrectly or as not evaluable and 10 segments were rated correctly.

In 18 of 19 patients without CAD at ICA, results from DSCT confirmed the findings. In one patient without CAD, two segments of the RCA could not be evaluated in the DSCT due to poor image quality.

Overall, 29 of 40 (73%) patients could be evaluated completely, correctly and conclusive by DSCT; in the other patients, no more than two segments were incorrectly evaluated or were non-assessable: in seven patients, one segment and in four patients two segments were incorrect or non-assessable (Fig. 3).

3.2. DSCT evaluation of coronaries

The RCA showed the lowest sensitivity and specificity of all coronaries with 88% and 75%, respectively, whereas the specificity increased to 86% in the assessment if only evaluable coronaries were involved (Table 1).

The Agatston CS for all coronaries was 823 ± 947. The coronaries with a significant stenosis had a CS of 1187 ± 1110, range 17—3157. The CS of coronaries without a significant

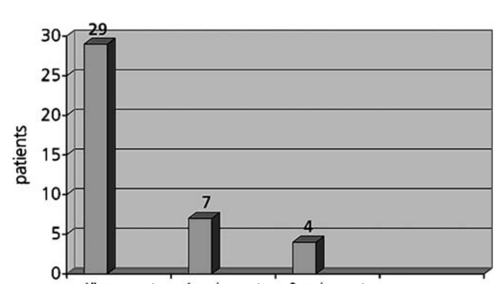

Fig. 3. Segment evaluation with regard to patients: In 29 patients all segments (12/12) were assessed correctly, in 7 patients one segment (1/12) and in 4 patients two segments (2/12) were falsely rated or not assessable.

Table 1
Diagnostic accuracy for coronary (RCA, LM, LAD, CX) and segment evaluation: It will be differentiated between assessment of *all* coronaries respective segments including the non-evaluable coronaries respective segments (considered as false-positive) and the *only evaluable* coronaries respective segments.

		Sensitivity	Specificity	PPV	NPV
RCA	All	88 (62—99)	**75 (53—90)**	**70 (46—88)**	90 (68—99)
	Only evaluable	88 (62—99)	**86 (64—97)**	**82 (57—96)**	90 (68—99)
LM	All	100 (69—100)	97 (83—99)	91 (59—99)	100 (88—100)
	Only evaluable	100 (69—100)	97 (83—99)	91 (59—99)	100 (88—100)
LAD	All	94 (71—99)	**96 (78—99)**	**94 (71—99)**	96 (78—99)
	Only evaluable	94 (71—99)	**100 (85—100)**	**100 (79—00)**	96 (78—99)
RCX	All	82 (48—98)	**97 (82—99)**	**90 (56—99)**	93 (78—99)
	Only evaluable	82 (48—98)	**100 (88—100)**	**100 (66—100)**	93 (78—99)
Segments	All	91 (80—97)	**98 (96—99)**	**83 (71—92)**	99 (97—99)
	Only evaluable	91(80—97)	**99 (98—99)**	**92 (82—98)**	99 (97—99)

Bold, RCA specificity and PPV values.

stenosis was 355 ± 570, range 0—1970. There was a significant difference of the CS between coronaries with and without significant stenosis ($p < 0.003$).

3.3. DSCT evaluation of segments

In 21 patients with CAD, 239 of 252 segments (95%) and in 19 patients without CAD 226 of 228 (99%) segments were correctly evaluated. In total, 465 of 480 segments (97%) in all patients were correctly assessed.

Of the 480 segments, 361 showed a good image quality and 113 were of reduced quality but still diagnostic. Only six segments in four patients were considered not assessable.

In all assessable segments, there were nine false ratings, five FN and four FP segments, two FN/three FP because of strong calcifications, three segments because of small diameters (2 FN/1 FP) and one segment because of motion artefacts. Six out of nine false ratings occurred in segments of reduced but still diagnostic image quality. The other three falsely assessed segments appeared in images considered of good quality: in one segment a small diameter led to an under-estimation of a significant stenosis while in two segments strong calcifications led to an over-estimation of non-significant stenoses.

The sensitivity for diagnosing a significant stenosis with DSCT when including all segments was 91% with a specificity of 98%, positive predictive value of 83% and negative predictive value of 99%.

In the evaluable segments, the specificity increased to 99% and the positive predictive value improved from 83% to 92%.

4. Discussion

With the new DSCT used for non-invasive coronary angiography, an additional step into clinical routine has been made. Besides the better convenience for the patients due to the non-invasiveness of the procedure and the short examination time (on average 10 s scan time, 15 min room time), use of cardiac CT is important also from an economic point of view. A diagnostic catheter coronary angiography examination (without interventions and excluding eventual costs from complications) costs at least 4 times more than a DSCT coronary angiography examination (in Switzerland, the cost of diagnostic ICA is approximately 3500.-CHF, while DSCT is approximately 700.-CHF). This difference in costs between both diagnostic imaging technologies can be relevant in the future. On the other hand, if there are two different diagnostic modalities available which show comparable results, in a competitive market, the costs for an ICA will probably also decrease over time.

The new DSCT technology with an excellent temporal resolution and thus improved image quality at higher and variable heart rates makes an administration of beta-blockers before the examination unnecessary. It enables the assessment of more segments that previously were not amenable to diagnosis. Especially strongly calcified coronaries can now be much better evaluated and the diagnosis of relevant stenoses can be made due to the improved differentiation between calcification and contrast in the vessel lumen. This clearly represents an advantage when CAD should be excluded in patients scheduled for valve surgery.

In this study, DSCT scans of 18 of 19 patients with valvular heart disease but no CAD in the ICA were completely evaluable and significant stenoses could be excluded in all segments. This is one of the most important findings of this study which affirms the concept that non-invasive coronary angiography by CT should routinely be used as filter test for CAD in patients with valvular heart disease undergoing cardiac surgery [22]. Estimated radiation doses of DSCT are in the range of 7—9 mSv being in the range of effective radiation dose values from diagnostic conventional catheter angiography, the latter varying from 6 to 22 mSv [24,25]. DSCT as a diagnostic and preoperative planning tool has significantly improved compared to the previous models; however, there is still a small percentage of segments which are not evaluable, and, in addition, another small number of segments which are falsely assessed. We found that six segments were not diagnostic, which resulted in an incomplete assessment in four patients. If these non-assessable segments are considered as false-positive, then the positive predictive value would drop from 90% to 83%. However, with the exception of one patient, CAD could be confirmed in all other patients who were diagnosed with ICA.

Although only 3% of all segments (15/480) were falsely evaluated or not assessable, only 52% (11/21) of the patients with CAD have been completely and correctly evaluated. In almost half of the patients with CAD, at least one non-assessable or wrongly evaluated segment was found with DSCT that would have made an ICA necessary. This fact clearly demonstrates the limitation of this imaging tool. However, more important is that cardiac surgeons are conversant about DSCT and that they are able to use this imaging technology as they are doing now with ICA.

We believe that in all patients with valvular disease, to exclude coronary artery disease, a DSCT examination should be performed independent of the patient characteristics. If the examination is not completely conclusive, an ICA can be subsequently performed. This holds true also in preoperative patients for non-cardiac procedures in whom a coronary assessment is necessary and in patients with less then two risk factors without a history of CAD.

The use of multi-slice CT has been already listed in the ACC/AHA guidelines pronouncing the increasingly important role of this imaging tool. However, the continuous development of this technology will need constant adaptation to the guidelines by the cardiological, cardiac surgical as well as radiological societies.

A further technical aspect is the choice of a hard—sharp image view, that is, the selection of kernel BF 46 instead of kernel BF 26. This higher kernel enables a better differentiation of strongly calcified arteries for the detection of stenosis. Despite the clear improvements of DSCT, strong calcifications still pose a problem. In the present study, five segments were incorrectly assessed due to strong calcifications. Therefore, coronary assessments with strong calcifications should be assessed by an experienced observer who is able to apply all technical options in viewing CT-scans.

The readers, both cardiac surgeons, applied for this study a specifically designed protocol. The protocol was developed in cooperation with radiologists and should simplify the evaluation procedure of DSCT for cardiac surgeons for diagnostic and potential cardiac surgical planning purposes. During the evaluation procedure, a radiologist has to be present to support the surgeon in image handling; however, the interpretation of the images was exclusively done by the surgeon. An important aspect of this study and point of discussion is the education and training of cardiac surgeons to obtain the skills to read cardiac CT scans. Both the cardiac surgeons of this study, who together reached a high accuracy for cardiac CT assessments, have been using this technique for several years. We believe that with more practice, and also with workshops, cardiac surgeons can be completely trained in image handling and will be aware of the technical options, possibilities and limitations of the software.

In this study, the accuracy to detect significant stenosis and/or to exclude CAD compared to ICA was evaluated. The selection of patients for DSCT in this study can be considered as biased because all patients were already scheduled for cardiac surgery. However, due to the mixture of patients with coronary disease and others with valvular disease and normal coronaries, which was unknown to the examiners, the bias can be seen as small.

DSCT examinations can be used in selected patients and conditions as an exclusion tool of CAD. However, as soon as significant stenoses are detected or if DSCT is inconclusive, ICA is performed for further treatment decision (medication, PCI or CABG). Therefore there is still some percentage of unnecessary ICA due to suboptimal management.

Diagnostic assessment and planning of treatment strategies are overlapping procedures. The optimised planning of treatment strategy requires a multidisciplinary team consisting of radiologists, cardiologists and cardiac surgeons. All participants should be aware of the different image techniques, mainly ICA and DSCT, including technology, data handling and assessment. This would be the optimal situation and basis for the discussion of the results and decision of the therapeutic strategy.

However, as long as the majority of cardiac surgeons are unable to evaluate CT examinations for diagnosis of CAD and potential CABG planning at the DSCT workstation (like they have been doing with ICA since decades) and the DSCT images are only presented by the radiologist with the cardiac surgeon listening passively, instead of an active co-working of radiologist and cardiac surgeon and in addition an independent assessment of the cardiac surgeon alone, DSCT will not and cannot be used in the clinical routine for diagnostic and, especially, planning of cardiac treatment strategies.

The cardiac surgeon should not only focus on DSCT as an imaging technology for diagnostic and preoperative planning being presented by the radiologist, but one should also concentrate on learning to assess CT scans by handling the soft- and hardware at the CT workstation.

5. Conclusions

The diagnostic accuracy of DSCT coronary angiography is high and is also applicable in patients with higher heart rates and strong vessel wall calcifications. At present, non-invasive coronary angiography with DSCT represents a valid alternative diagnostic tool especially for exclusion of CAD in patients with few risk factors in clinical routine and should be implemented as a filter test, instead of ICA.

The introduced data presentation protocol for evaluation of CAD is easy to handle and enables cardiac surgeons to interpret DSCT examinations practically independently after pre-arrangement of the images by radiologists. Cardiac surgeons should get involved and trained to use this CT imaging technique in dedicated workshops.

References

[1] Wijns W. Diagnosis of coronary artery disease: In search of a "One-Stop Shop"? J Nucl Med 2005;46:904—5.
[2] Goldstein JA, Gallagher MJ, O'Neill WW, Ross MA, O'neil BJ, Raff GL. A randomized controlled trial of multi-slice coronary computed tomography for evaluation of acute chest pain. J Am Coll Cardiol 2007;49:863—71.
[3] Flohr TG, Schoepf UJ, Ohnsorge BM. Chasing the heart. New developments for cardiac CT. J Thorac Imaging 2007;22:4—16.
[4] Gasparovic H, Rybicki FJ, Millstine J, Unic D, Byrne JG, Yucel K, Mihaljevic T. Three dimensional computed tomographic imaging in planning the surgical approach for redo cardiac surgery after coronary revascularization. Eur J Cardiothorac Surg 2005;28:244—9.
[5] Kachelriess M, Ulzheimer S, Kalender W. ECG-correlated image reconstruction from subsecond multi-slice spiral CT scans of the heart. Med Phys 2000;27:1881—902.
[6] Ohnesorge B, Flohr T, Becker C, Kopp AF, Schoepf UJ, Baum U, Knez A, Klingenbeck-Regn K, Reiser MF. Cardiac imaging by means of electro-

cardiographically gated multisection spiral CT: initial experience. Radiology 2000;217:564—71.
[7] Achenbach S, Ulzheimer S, Baum U, Kachelriess M, Ropers D, Giesler T, Bautz W, Daniel WG, Kalender WA. Noninvasive coronary angiography by retrospectively ECG-gated multi-slice spiral CT. Circulation 2000;102: 2823—8.
[8] Flohr T, Schoepf UJ, Kuettner, Halliburton S, Bruder H, Suess C, Schmidt B, Hofmann L, Yucel EK, Schaller S, Ohnesorge BM. Advances in cardiac imaging with 16-section CT-systems. Acad Radiol 2003;10:386—401.
[9] Ropers D, Baum U, Pohle K, Anders K, Ulzheimer S, Ohnesorge B, Schlundt C, Bautz W, Daniel WG, Achenbach S. Detection of coronary artery stenoses with thin-slice multi-detector row spiral computed tomography and multiplanar reconstruction. Circulation 2003;107:664—6.
[10] Kuettner A, Beck T, Drosch T, Kettering K, Heuschmid M, Burgstahler C, Claussen CD, Kopp AF, Schroeder S. Diagnostic accuracy of non-invasive coronary imaging using 16-detector slice spiral computed tomography with 188ms temporal resolution. J Am Coll Cardiol 2005;45:123—7.
[11] Leber AW, Knez A, von Ziegler F, Becker A, Nikolaou K, Paul S, Wintersperger B, Reiser M, Becker CR, Steinbeck G, Boekstegers P. Quantification of obstructive and nonobstructive coronary lesions by 64-slice computed tomography: a comparative study with quantitative coronary angiography and intravascular ultrasound. J Am Coll Cardiol 2005;46:147—54.
[12] Leschka S, Alkadhi H, Plass A, Desbiolles L, Grunenfelder J, Marincek B, Wildermuth S. Accuracy of MSCT coronary angiography with 64-slice technology: first experience. Eur Heart J 2005;26:1482—7.
[13] Raff GL, Gallagher MJ, O'Neill WW, Goldstein JA. Diagnostic accuracy of noninvasive coronary angiography using 64-slice spiral computed tomography. J Am Coll Cardiol 2005;46:552—7.
[14] Budoff MJ, Achenbach S, Blumenthal RS, Carr JJ, Goldin JG, Greenland P, Guerci AD, Lima JA, Rader DJ, Rubin GD, Shaw LJ, Wiegers SE, American Heart Association Committee on Cardiovascular Imaging and Intervention, Council on Cardiovascular Radiology and Intervention, and Committee on Cardiac Imaging, Council on Clinical Cardiology. Assessment of coronary artery disease by cardiac computed tomography: a scientific statement from the American Heart Association Committee on Cardiovascular Imaging and Intervention, Council on Cardiovascular Radiology and Intervention, and Committee on Cardiac Imaging, Council on Clinical Cardiology. Circulation 2006;114:1761—91.
[15] Reimann AJ, Rinck D, Birinci-Aydogan A, Scheueringer M, Burgstahler C, Schroeder S, Brodoefel H, Tsiflikas I, Herberts T, Flohr T, Claussen CD, Kopp AF, Heuschmid M. Dual-source computed tomography: advances of improved temporal resolution in coronary plaque imaging. Invest Radiol 2007;42:196—203.
[16] Flohr TG, McCollough CH, Bruder H, Petersilka M, Gruber K, Suss C, Grasruck M, Stiersdorfer K, krauss B, Raupach R, Primak AN, Küttner A, Achenbach S, Becker C, Kopp A, Ohnesorge BM. First performance evaluation of a dual-source CT (DSCT) system. Eur Radiol 2006;16: 256—68.
[17] Scheffel H, Alkadhi H, Plass A, Vachenauer R, Desbiolles L, Gaemperli O, Schpis T, Frauenfelder T, Schertler T, Husmann L, Grunenfelder J, Genoni M, Kaufmann PA, Marincek B. Accuracy of dual-source CT coronary angiography: First experience in a high pre-test probability population without heart rate control. Eur Radiol 2006;16:2739—47.
[18] Fox K, Garcia MA, Ardissino D, Buszman P, Camici PG, Crea F, Daly C, De Backer G, Hjemdahl P, Lopez-Sendon J, Marco J, Morais J, Pepper J, Sechtem U, Simoons M, Thygesen K, Priori SG, Blanc JJ, Budaj A, Camm J, Dean V, Deckers J, Dickstein K, Lakakis J, McGregor K, Metra M, Morais J, Osterspey A, Tamargo J, Zamorano JL, Task Force on the Management of Stable Angina Pectoris of the European Society of Cariology, ESC Commitee for Practice Guidelines (CPG). Guidelines on the management of stable angina pectoris: executive summary: the Task Force on the Management of Stable Angina Pectoris of the European Society of Cardiology. Eur Heart J 2006;27:1341—81.
[19] Leschka S, Scheffel H, Desbiolles L, Plass A, Gaemperli O, Valenta I, Husmann L, Flohr TG, Genoni M, Marincek B, Kaufmann PA, Alkadhi H. Image quality and reconstruction intervals of dual-source CT coronary angiography: recommendations for ECG-pulsing windowing. Invest Radiol 2007;42:543—9.
[20] Stolzmann P, Scheffel H, Schertler T, Frauenfelder T, Leschka S, Husmann L, Flohr TG, Marincek B, Kaufmann PA, Alkadhi H. Radiation dose estimates in dual-source computed tomography coronary angiography. Eur Radiol 2008;18:592—9.
[21] Austen WG, Edwards JE, Frye RL, Gensini GG, Gitt VL, Griffith LS, McGoom DC, Murphy ML, Roe BB. A reporting system on patients evaluated for coronary artery disease. Report of the Ad Hoc Committee for Grading of Coronary Artery Disease, Council on Cardiovascular Surgery, American Heart Association. Circulation 1975;51:5—40.
[22] Scheffel H, Leschka S, Plass A, Vachenauer R, Gaemperli O, Garzoli E, Genoni M, Marincek B, Kaufmann PA, Alkadhi H. Accuracy of 64-slice computed tomography for the preoperative detection of coronary artery disease in patients with chronic aortic regurgitation. Am J Cardiol 2007;15:701—6.
[23] Agatston AS, Janowitz WR, Hildner FJ, Zusmer NR, Viamonte Jr M, Detrano R. Quantification of coronary artery calcium using ultrafast computed tomography. J Am Coll Cardiol 1990;15:827—32.
[24] Kuon E, Robinson DM, Empen K, Dahm JB. Fluoroscopy time — an overestimated factor for patient radiation exposure in invasive cardiology. Rofo 2005;177:812—7.
[25] Coles DR, Smail MA, Negus IS, Wilde P, Oberhoff M, Karsch KR, Baumbach A. Comparison of radiation doses from multislice computed tomography coronary angiography and conventional diagnostic angiography. J Am Coll Cardiol 2006;46:1840—5.