The Heart Surgery Forum #2005-1167
9 (2), 2006 [Epub February 2006]
doi:10.1532/HSF98.20051167 Online address: http://cardenjennings.metapress.com/link.asp?id=112496

Sixteen-Channel Multidetector Row Computed Tomography versus Coronary Angiography in a Surgical View

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ABSTRACT

Background. Invasive coronary angiography (ICA) is the gold standard for the diagnosis of coronary artery disease and also for imaging procedures for preoperative planning of coronary artery bypass grafting (CABG). Sixteen-multidetector row computed tomography (MDCT) represents an alternative depiction of coronary vessels.

Methods. Preoperative exams included ICA and MDCT in 50 patients. Two blinded surgical readers independently investigated both diagnostic modalities regarding location, severity, and morphology of the stenoses. The right coronary artery, left anterior descending branch, and circumflex branch—each divided in 3 sections—and the left main artery with a diameter ≥1.5 mm were rated in both procedures, and the percentage of complete evaluations by MDCT was assessed.

Results. Heart rate was 72 ± 8 bpm. Forty-six percent of patients received a complete MDCT evaluation, and 54% received an incomplete MDCT evaluation. In 62% of these incompletely examined patients, 1 branch was not completely analyzable, in 31% 2 branches; and in 7% all 3 branches. In total, 9% of all segments were incompletely assessed. Investigators detected coronary stenoses in complete evaluations with a sensitivity of 94% and a specificity of 95%. Positive predictive value was 87% and negative predictive value was 98%. Plaque classification in soft and hard plaques was possible.

Conclusion. Sixteen-MDCT is not a viable alternative diagnostic tool at present. However, although the percentage of incomplete evaluated patients is more then 50%, only 9% of all segments were incompletely assessable. If this technology can be further improved, especially its software, it will become a valid diagnostic tool for coronary artery disease.

INTRODUCTION

For decades, invasive coronary angiography (ICA) has been the gold standard for diagnostic clarification of coronary artery disease and has also been the standard procedure for preoperative planning before coronary artery bypass grafting (CABG). Although coronary angiography involves only a small risk and is a safe procedure, it is still often an elaborate and uncomfortable experience for patients [Adams 1973; Levin 1982].

Imaging by multidetector row computed tomography (MDCT) is a noninvasive technique with low expenses. The first MDCT scanners were introduced in 1999 and were able to do a simultaneous acquisition of 4 slices [Achenbach 2001; Knez 2001; Kuettner 2004]. Now this MDCT technology demonstrates an increased rotation speed and 16 detector rows that improve the illustration of the coronary arteries [Nieman 2001; Kieman 2002; Ropers 2003]. In addition, this imaging procedure includes visualization and differentiation of soft and hard plaques [Becker 2001; Schroeder 2001].

This project should clarify the value of the 16-MDCT compared to coronary angiography in a surgical view for diagnosis of significant stenoses and preoperative planning.

MATERIALS AND METHODS

Patients

MDCT and ICA were performed on 50 elective patients (36 men and 14 women, with a mean age of 64 ± 9 years). These patients were divided into 2 groups. The first group included 40 patients (32 men, 8 women) with coronary artery disease. The second group consisted of 10 patients (4 men, 6 women) with normal coronary arteries, but were scheduled for valve surgery also diagnosed by transthoracic echocardiography.

Sinus rhythm <80 bpm was targeted to receive optimal image quality. Due to the basic preoperative medication with beta blockers, the postulated heart frequency for the MDCT examination was obtained without additional beta blockers. Patients allergic to iodine contrast media and with renal insufficiency (serum creatinine >120 mmol/L) were excluded from the study. The study was approved by the local ethic committee and written informed consent was obtained from all patients.

MDCT

A 16-slice MDCT scanner (Sensation 16; Siemens Medical Solutions, Forcheim, Germany) performed the imaging of the coronary vessels by the single inspiratory breath hold technique. The bolus-tracking technique (CARE-Bolus; Siemens), which determined the delay time between the start of contrast medium administration and the start of imaging,

Received September 11, 2005; received in revised form November 9, 2005; accepted November 15, 2005.

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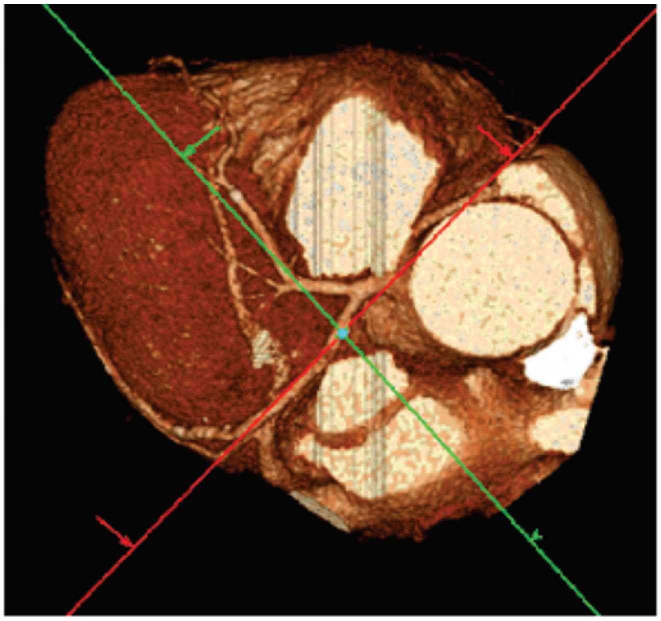

Figure 1. Cranial view to the 3D model and applying 2 perpendicular planes to the region of interest.

enabled an optimal intraluminal contrast enhancement. The patients were intravenously injected with 120 mL contrast medium (Xenetix 300; Guerbet Laboratories, Roissy, France). A power injector (CT Injector; Ulrich Medical, Ulm-Jungingen, Germany) administered this procedure with a flow of 4 mL/sec. Ten seconds after the start of the contrast medium injection the repetitive low-dose monitoring examinations (120 kV, 10 mA, 0.5 second scanning time, 1 second interscan delay) were performed. After reaching the preset contrast enhancement level of 150 Hounsfield units, the MDCT examination was automatically initiated. The contrast medium bolus was followed by 30 mL saline chaser bolus administered at the same rate.

The gantry rotation time of 0.375 seconds (pitch, 0.25) was one of the fastest existing at the time of this study. The X-ray tube voltage was 120 kV and the effective tube current was 550 mA. Data acquisition was performed in a cranio-caudal direction with a nominal section thickness of 16 × 0.75 mm and a table feed of 3 mm per rotation. The raw data of the examined hearts were generated with an increment of 0.5 mm and a slice thickness of 1 mm. The utilization of these data for reconstructions was accomplished in 5% steps of the RR interval and using a BF 30 medium soft-tissue kernel.

Axial computed tomography (CT) images were reconstructed from the CT raw data using a slice thickness of 1 mm and an increment of 0.5 mm. For image reconstruction, a segmented adaptive cardiac reconstruction algorithm was used [Nieman 2001]. Depending on the individual anatomy, the reconstructed field-of-view was individually fitted to the actual cardiac size in each patient (field of view: 211 mm; standard deviation: 19; range: 182-268; image matrix: 512 × 512 pixels).

MDCT Image Analysis

The whole dataset was saved in the picture and archiving system. For better orientation, longitudinal and transverse sections of the coronary were performed in volume rendering mode, illustrated in Figure 1. To evaluate the stenoses, coronaries were reconstructed in 2 planes at a 90° angle with a multiplanar reconstruction technique. The combination of a 3D-heart model and 2D images in 2 planes allows different views to the interior of the coronary vessels. This approach is demonstrated in Figure 2.

The reconstructed data were presented for readout on a Leonardo workstation (Siemens) by using a dedicated, commercially available software tool for interactive cardiac functional analysis (Syngo Argus 2.0; Siemens). Two blinded

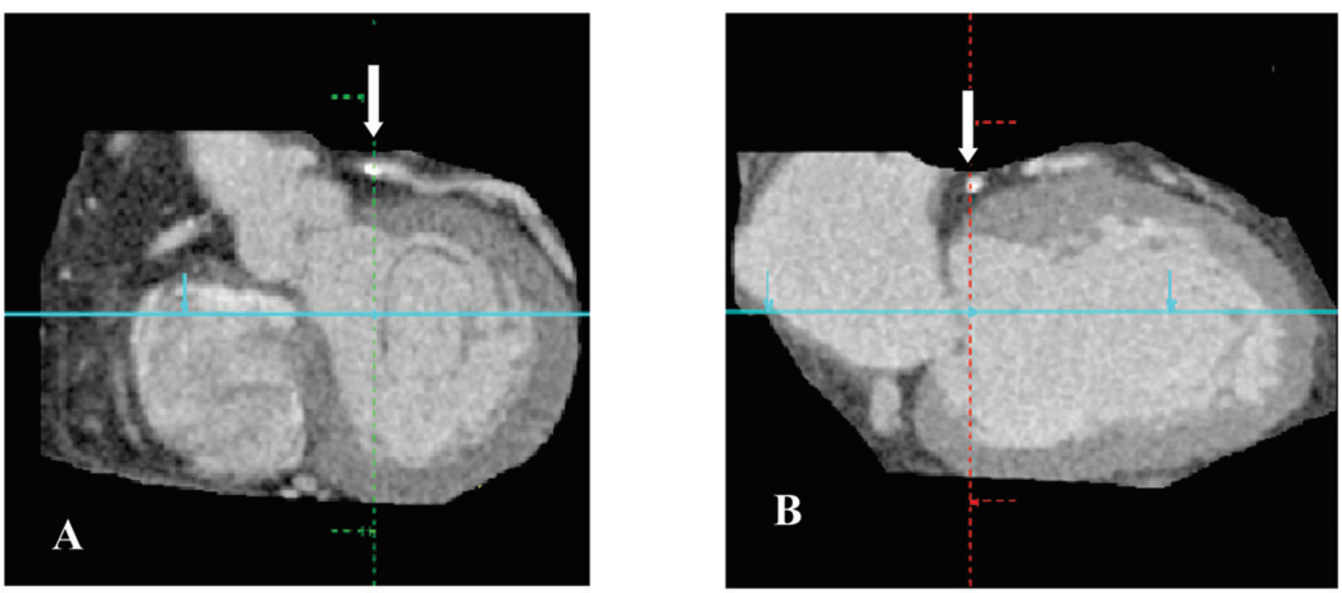

Figure 2. Longitudinal (A, arrow) and orthogonal (B, arrow) section of the left coronary artery with a visible calcified plaque.

reviewers of the clinic for cardiovascular surgery investigated the MDCT scans regarding location, severity, and morphology of the stenoses of 10 segments for each patient. The 4 main branches—the left main (LM), left anterior descending (LAD), circumflex (CX), and right coronary artery (RCA)—were rated in both procedures, including ≥1.5 mm side branches. The proximal, middle, and distal part of each mentioned branch except for the LM was interpreted and differentiated as evaluable, with a secured assessment of the segments, or nonevaluable, which included poorly analyzable parts. In addition, attention was paid to contingent intravascular plaques. Appraisal factor was the quality of these plaques. The quality was classified as either calcified or noncalcified (soft) plaques.

Conventional ICA

A conventional selective coronary angiography was performed according to standard techniques. For this study, a Integris Allura 9 biplane angiography (Philips, Bothell, WA, USA) was used. The contrast medium (Ultravist, Schering) consumption, including the levogram, averaged 140 mL. Two different types of catheter (Cordis; Johnson & Johnson, New Brunswick, NJ, USA) were applied: to illustrate the coronary vessels we used a Judkins catheter; for levograms, a pigtail catheter.

The multiple views were saved on a CD-ROM, and 2 blinded readers, who were cardiac surgeons, examined the images for preoperative surgical planning. They examined the assessments of the CT angiograms of the same scheme of 10 segments already named and evaluated the locations of possible stenosis diameter as a percentage of the reference diameter in 2 orthogonal planes.

Statistical Analysis

This study assays the applicability of a new method of analyzing the images of the 16-MDCT as to the detection of stenoses in ≥1.5 mm diameter segments. Conventional coronary angiography was used as a standard of reference. The MDCT images of the coronary arteries of both groups (pathologic/nonpathologic coronary vessels) were evaluated by 2 blinded observers

The 3 main coronary vessels were evaluated for stenoses and plaques. The RCA, LAD, and CX were subdivided into 3 parts, the proximal, middle, and distal third. The LM was considered as 1 branch without any fragmentation. The locations and number of the stenoses and plaques were documented. Afterwards, these results were compared with the results of the coronary angiography, which is the standard of reference.

Sensitivity, specificity, and negative and positive predictive values using a 95% confidence interval were stratified. Undetected lesions were classified as false negative results. Furthermore, the MDCT images of the patients suffering from valve disease and normal coronary angiographies were appraised for false positive results. The categorical data of the analyses that include both assessable and nonassessable segments were presented with absolute frequencies and percentages. The concordance between both reviewers for diagnosing significant coronary artery stenosis was calculated by the Cohen's kappa-value [Cohen 1960] and appraised according to the instructions of Landis and Koch [Landis 1977].

RESULTS

This study included 50 patients: 36 men and 14 women with a body mass index of 27 ± 6 kg/m^2. The heart rate was 72 ± 8 bpm and scanning time amounted to 30 sec ± 7 sec. The MDCT procedures succeeded without any complications in 48 patients. The MDCT examination of 1 patient had to be aborted because of an allergic reaction to the contrast medium. In another patient, the contrast medium was injected paravascularly, and the procedure had to be discontinued.

For 38 patients, coronary angiography illustrated severe coronary artery disease. Four patients suffered a 1-vessel disease, 11 patients a 2-vessel disease, and 23 patients a 3-vessel disease. Ten different parts of the coronary artery system of each patient, 380 sections total, were evaluated. One hundred thirty-six of 380 segments were constricted.

A group of 10 patients with valve disease but normal coronary angiography was examined. In total, a control of 40 normal branches were examined by MDCT, sectioned in the same way described above; in total, 100 different parts were investigated. In 46% of the patients (22/48), the coronary arteries were completely evaluated from the proximal to the distal part. In 54% (26/48) of the patients, the assessment of coronary arteries by MDCT imaging was incomplete.

This means that vessel assessments of 26 patients were not complete. The LM was completely evaluated in all patients. The other 3 assessed branches were affected (RCA, CX, LAD). In 62% (16/26) of these patients, 1 branch was not completely evaluable; in 31% (8/26), 2 branches; and in 7% (2/26), all 3 branches (Figure 3).

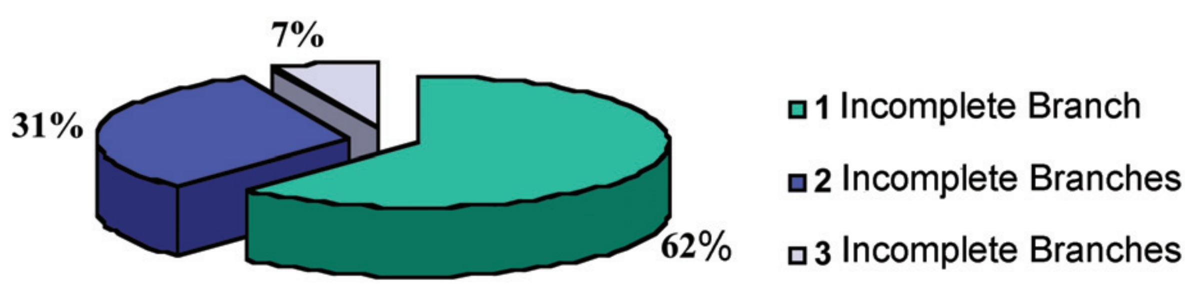

Figure 3. Percentages of incomplete examinations of patients by means of the number of incomplete evaluated branches.

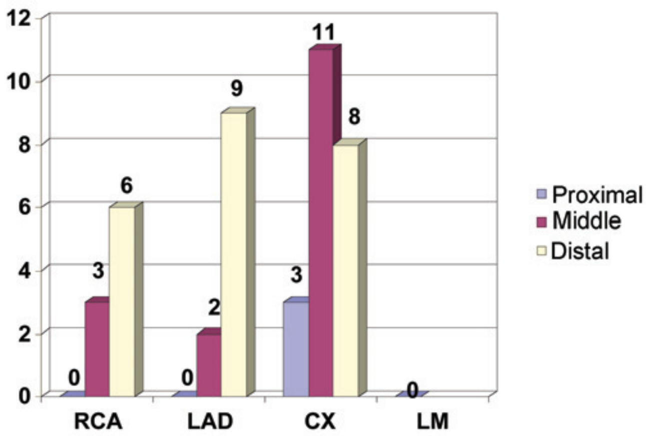

Figure 4. Numbers of inappropriate assessments in correlation to different segments of different branches.

Seven of the incompletely evaluable branches were completely nonassessable (RCA in 3 patients, LAD in 2, and CX in 2). Nine segments of the RCA could not be completely analyzed. The proximal part was always completely evaluable and 3 middle and 6 distal segments were nonassessable. For the LAD, 2 middle parts and 9 distal parts could not be evaluated and and for the CX an incomplete assessment resulted in 3 proximal, 11 middle, and 8 distal parts. Figure 4 provids a summary of this analysis. Nine percent (42/480) of all segments were only insufficiently assessable.

One hundred nine stenoses of different characteristics were detected by MDCT imaging due to calcified and noncalcified plaques. Seven percent (8/109) of these stenoses were so distinctive that differentiation between a high-grade stenosis or an occlusion was possible. Figure 5 illustrates strong calcifications of the LAD.

The sensitivity and specificity of all analyzed patients constituted 80% (109/136) and 89% (306/344), respectively. The assessments of all completely evaluated patients increased the sensitivity to 94% (109/116) and the specificity to 95% (306/322). The positive predictive value of the MDCT to detect patients with coronary artery disease was 87%, the negative predictive value amounted to 98%. The routine preoperative coronary angiography was inconspicuous for 10 patients in this study. In the MDCT, the total number of false positive evaluated branches of the control group was 8 (20%).

The RCA was affected for false positive results twice, both in the proximal part. The LM was also affected twice, in the middle and distal parts, and the LAD had 3 false positive results (2 proximal, 1 middle part). The circumflex branch had 1 false positive result in the middle part. The apportionment of false positive results is clarified in Figure 6. Three CX branches were not completely evaluable. There was no differentiation possible between an occlusion or a high-grade stenosis. The characteristics of soft and hard calcified lesions could be clearly classified by MDCT imaging (Figure 7). This study includes no statistical information about the plaque quality.

We evaluated 12 patients who were blinded twice. In 2 patients, the evaluation of the circumflex branch showed different results. The interobserver agreement with a kappa value of 0.86 showed a very good interobserver agreement.

DISCUSSION

In different studies, the MDCT imaging technique for coronary arteries has been advertised as a valuable future alternative to standard angiography [Kuettner 1977; Nieman 2002; Ropers 2003]. Most of them were done in a radiological or cardiological view. Particularly because more than 45% of all coronary angiographies are of diagnostic nature without any intervention [Leber 2003], a noninvasive procedure such as MDCT would be much more comfortable for the patients, as well as cost-saving. This study demonstrates the benefit and usefulness of 16-MDCT imaging for cardiac surgeons with

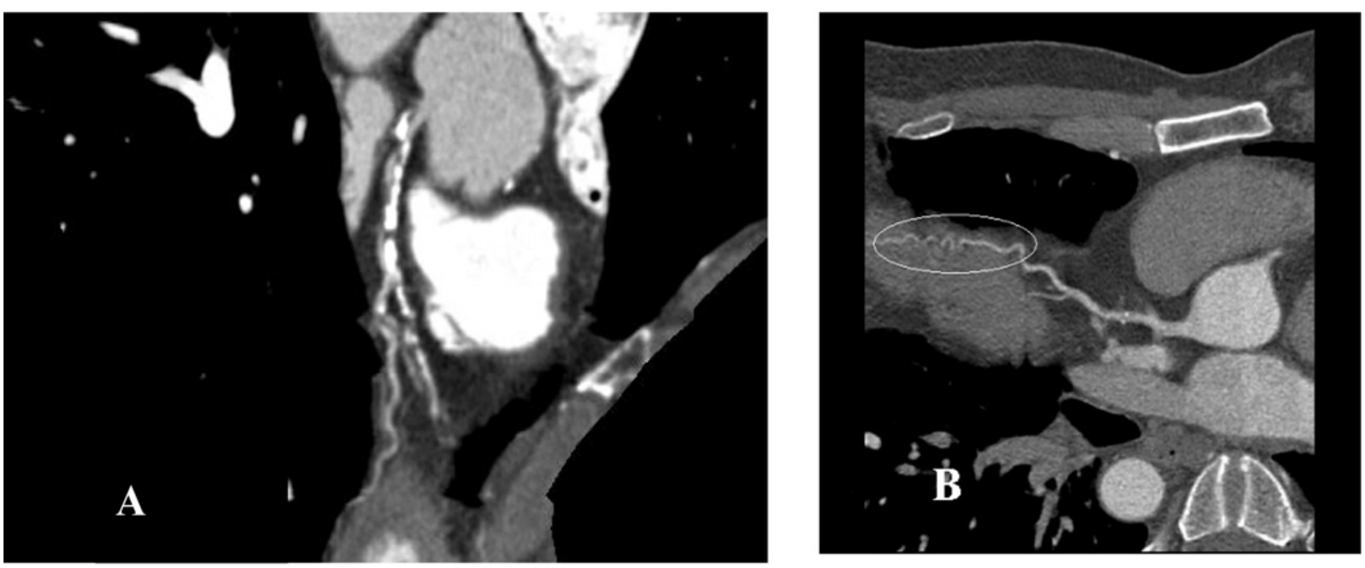

Figure 5. Strong calcifications of the left anterior descending artery (A), small diameter of the middle and distal segments of the left anterior descending artery (B).

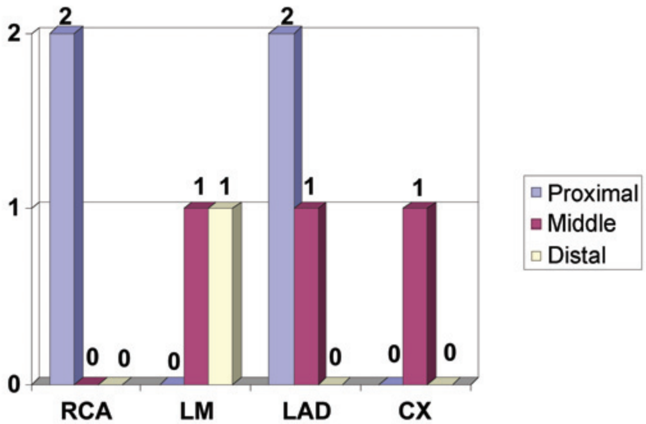

Figure 6. False positive pathologic findings of the different sections of the coronary vessels by the multidetector computed tomography.

regard to preoperative planning of CABG and valve surgery. For patients suffering from valve disease, the coronary angiography is performed to exclude any coronary disease.

Several studies have compared MDCT to standard coronary angiography in the past [Knez 2001; Nieman 2001; Nieman 2002; Leber 2003; Ropers 2003; Kuettner 2004]. The already well-known disadvantages of cardiac imaging by MDCT were confirmed by this study. The image quality decreases in patients suffering from arrhythmia or tachycardia. However, in our study we did not routinely administer additional beta-blockers to lower the heart rate because most of the patients were already preoperatively treated by beta-blockers. In general, tachycardia is occasionally a problem for image quality, but in our study it did not require any intervention. In contrast, arrhythmia is still an unsolved factor that can make MDCT imaging of the heart impossible. In this study, we filtered out arrhythmic patients before examination, but still there were occasionally rhythm limitations that led to decreased image quality. Other reasons for suboptimal image quality are blurring, stair-step artifacts, and motion artifacts.

A further limiting factor was strong calcifications of the coronary arteries. The Hounsfield units of the calcifications are similar to the contrast medium and it can be impossible to distinguish them from the vessel wall. The data handling by the existing software is, at the moment, very often limited in solving this problem. Strong calcifications of the LAD are illustrated in Figure 5A.

In this context, MDCT only provides a snapshot. This static technique based on the principle of intravenous injection of a contrast agent before MDCT examination leads to an antegrade and retrograde filling and causes a general spread of the dye throughout the whole vessel system of the body, including the coronary vessels. This in turn also causes an antegrade and a retrograde enhancement of the coronary arteries. This could potentially cause a problem of differentiation between a high-grade stenosis and an occlusion. In this study, in 7% (8/109) of the patients no differentiation was possible between a partial or complete stenosis of the coronary artery evaluated by coronary angiography as an occlusion. In contrast, coronary angiography uses a catheter tech-

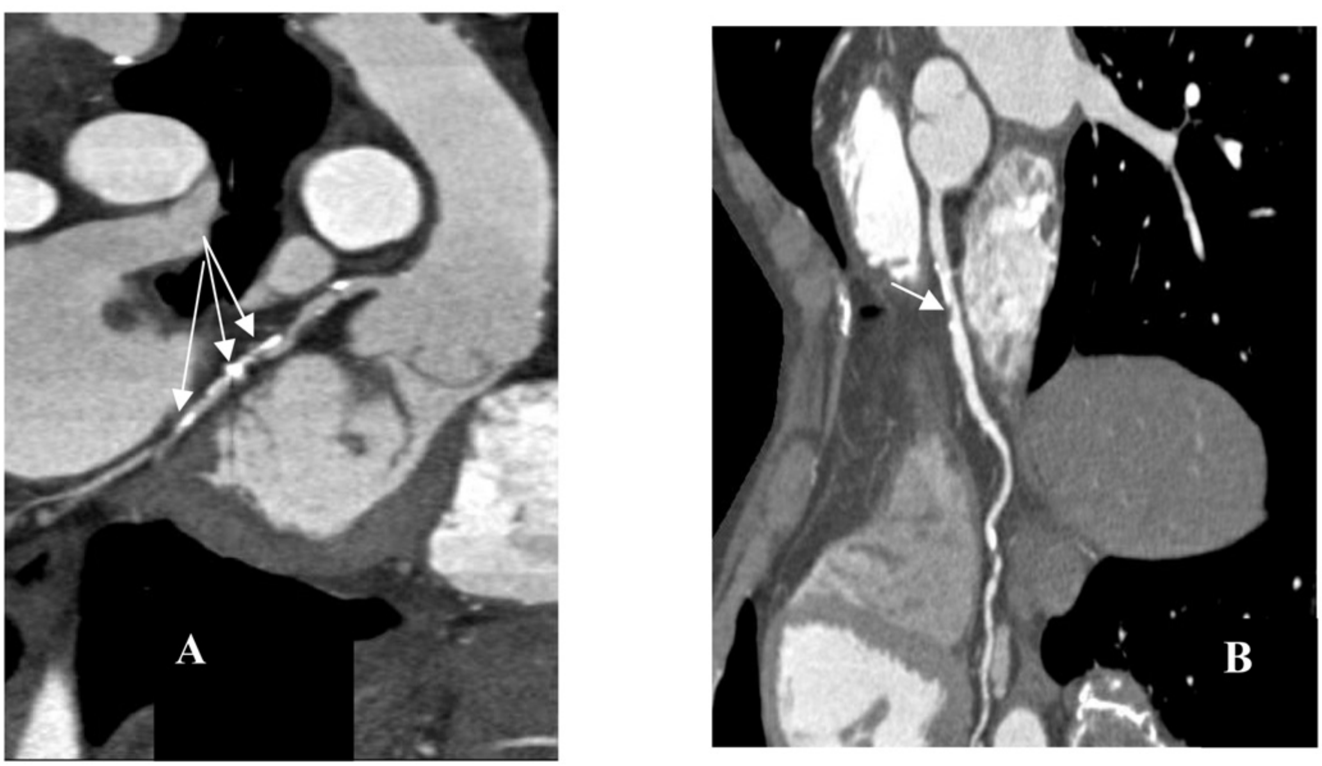

Figure 7. Multiple calcified plaques of the circumflex branch (A, arrows) and soft plaque of the right coronary artery (B, arrow).

nique that administers the dye directly antegrade in the vessel of interest. Furthermore, a small diameter of <1.5 mm could only be incompletely evaluated because it is impossible to get an optimal internal view of the vessel. This limitation is illustrated in Figure 5B. In 11 out of 420 cases the diameter of the vessel was too small for adequate assessment.

Only differentiation between evaluable and nonevaluable segments is arguable in our view. In the clinical routine, and especially for preoperative planning, the main focus is to determine if there is any significant stenosis visible. Only if the quality of the imaging is good enough to differentiate between a significant and insignificant stenosis will a surgeon rely on this diagnostic tool for preoperative planning.

This study demonstrated more than 50% not completely analyzable patients, but the level of incomplete evaluated branches and segments was very low. However, the percentage of complete examinations of the patients is ultimately the main criterion and therefore prevents the MDCT from being used in the clinical routine. However, given further progress in the software these 9% nonassessable segments could be lowered even further and the number of incomplete examinations of patients would be automatically and rapidly reduced.

For calculation of the sensitivity and specificity, a differentiation between all analyzed patients of the study (complete and incomplete) and patients with a complete evaluation was performed. It resulted in a high sensitivity (94%) and specificity (95%) of the MDCT examinations if a complete evaluation was possible. Another advantage is the differentiation between soft and hard plaques by the MDCT imaging compared to standard angiography (Figure 7). It is advantageous for a surgeon to preoperatively define the location of anastomosis. In addition, this opportunity for plaque differentiation could be used as a preventive diagnostic tool. Soft plaques are prone to rupture and can cause myocardial infarction. These soft lesions are not visible in the coronary angiography and the MDCT now offers the possibility of early detection. Sensitivity and specificity to diagnose and differentiate soft and hard plaques were not mentioned in this study because it was a quality analysis and not a soft plaque quantity analysis. For a comparable evaluation of soft plaques, evaluation of imaging techniques other than coronary angiography are necessary, and at the moment the gold standard is intravascular ultrasound [Achenbach 2004]. For the stability of soft plaques, a secured graduation is still difficult. Consequently, there is no estimation of the possibility of a plaque rupture and therefore no therapeutic algorithm exists. However, this might be possible in the future with further improved imaging techniques.

Different studies already illustrated the high value of calcium scoring by the MDCT compared to coronary angiography [Becker 2000; Becker 2001; Leber 2001; Schroeder 2001]. In a number of cases, hard plaques can not be accurately estimated because of the density of the calcium that can comply with the contrast enhancement of the coronary lumen. MDCT examinations of patients suffering from valve disease (aortic/mitral valves) with normal coronary arteries were compared to standard coronary angiography. There is the possibility that the MDCT imaging offers the possibility of additional information and illustration if coronary angiography is not possible. However, we found stenoses in these patients that were not visible in the coronary angiography. If there was no clinical relevance, we relied on the coronary angiography and considered these stenoses as false positive. In conclusion, this imaging technique could offer a future possibility for screening patients with a risk for coronary artery disease or for persons with cardiovascular risk factors.

This study illustrates the advantages and the still-existing limiting factors for coronary artery imaging. The whole MDCT procedure requires only a short time and is only minimally inconvenient for the patients. Another advantage is the evaluation of plaques in an early stage and the differentiation of soft and hard plaques. This could help prevent myocardial infarctions caused by ruptured soft plaques as well as help preoperative planning to locate possible anastomotic sites.

The main disadvantage is the incomplete evaluation of the coronary system. There is still a high percentage, more then 50%, of not completely analyzable patients. For this reason MDCT is, at the moment, not utilizable for preoperative planning in the clinical routine and is still not a viable alternative to coronary angiography. However, the advantages of the MDCT are impressive, and the number of incomplete evaluated segments (9%) is very low. Given a further improvement of the software and logistical handling, MDCT could be a valid and established tool in the future for screening coronary artery disease in the clinical routine.

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