Eur Radiol (2004) 14:169–177
DOI 10.1007/s00330-003-2197-9

Christopher Herzog
Martina Britten
Joern O. Balzer
M. G. Mack
Stefan Zangos
Hanns Ackermann
Volker Schaechinger
Stefan Schaller
Thomas Flohr
Thomas J. Vogl

Multidetector-row cardiac CT: diagnostic value of calcium scoring and CT coronary angiography in patients with symptomatic, but atypical, chest pain

Received: 22 July 2003
Revised: 4 November 2003
Accepted: 18 November 2003
Published online: 20 December 2003

M. Britten and C. Herzog contributed equally to this study

C. Herzog (✉) · J. O. Balzer · M. G. Mack · S. Zangos · T. J. Vogl
Institute for Diagnostic and Interventional Radiology,
J.W. Goethe University Frankfurt,
Theodor-Stern-Kai 7, 60590 Frankfurt/Main, Germany
e-mail: c.herzog@em.uni-frankfurt.de
Tel.: +49-69-63017277
Fax: +49-69-63017258

M. Britten · V. Schaechinger
Department of Cardiology,
J.W. Goethe University,
Frankfurt/Main, Germany

H. Ackermann
Department of Epidemiology and Medical Statistics,
J.W. Goethe University,
Frankfurt/Main, Germany

S. Schaller · T. Flohr
Division of CT,
Siemens Medical Inc.,
Forchheim, Germany

Abstract The aim of this study was to investigate the accuracy of multidetector-row cardiac CT (MDCT), calcium scoring (Ca-Sc), and MDCT coronary angiography (MD CTA) in the assessment of coronary atherosclerosis. Thirty-eight patients underwent invasive coronary angiography (CA) and MDCT (collimation 4×1 mm, pitch 1.5 mm, TI 500 ms, 120 kV, 300 mAs, and retrospective ECG-gating). Calcium scoring was calculated for the total coronary artery territory and for RCA, LCA, and LCX separately. The MD CTA served to assess the degree and the localization of stenoses. All findings were compared to invasive coronary angiography. Approximately 68.4% (390 of 570) of all coronary segments could be visualized by MDCT. Correlation coefficient for MD CTA and CA amounted to r=0.58, showing distinct differences for the individual segments. Proximal segments generally showed better correlation (range 0.81–0.77) than medial segments (range 0.91–0.20), distal segments (range 0.55–0.04), or side branches (range 0.76–0.00). Patients with hemodynamically relevant (>75%) stenoses were detected by MD CTA with 72.2% sensitivity (13 of 18) and 100% specificity (20 of 20). For Ca-Sc sensitivity ranged between 94.7% (17 of 18) and 66.7% (12 of 18), specificity between 20% (4 of 20) and 80% (16 of 20) respectively, depending on the prevailing cutoff value. Combination of both methods led to 83.3% sensitivity (15 of 18) and 100% specificity (20 of 20), reaching no level of significance as compared with Ca-Sc (p=0.73) or MD CTA (p=0.23) alone. Calcium scoring as a single method showed highest sensitivity in the detection of coronary atherosclerosis but at the expense of low specificity. In patients with no or moderate calcifications, combination with MD CTA helped to distinctly increase specificity and NPV

Keywords Multislice CT · Coronary angiography · Calcium scoring · Coronary atherosclerosis · Coronary arteries

Introduction

Calcifications of the coronary artery wall are regarded as a recognized marker of coronary atherosclerosis [1]. Electron-beam CT (EBCT) and more recently multidetector-row spiral CT [2, 3, 4, 5, 6, 7] are particularly sensitive in detecting coronary calcifications [8]. These non-invasive imaging techniques consequently are becoming increasingly important as adjuvant diagnostic modalities in the early detection of coronary atherosclerosis [8]; however, the actual validity of the technique is discussed controversially [9]. First of all, because extent and site of calcifications does not always equate with the site-specific stenosis [10]. Secondly, as it is rather the non-calci-

fied—and therefore to native CT scans invisible—atherosclerotic plaque that causes an acute cardiac incident by spontaneous rupture [11, 12]. Finally, because sensitivity and specificity of calcium scoring show a broad variance, depending on who performed the examination, what "cut-off" for hemodynamically relevant stenoses was chosen, how hemodynamically relevant stenosis was defined, and which population was examined. In a recent review of the literature, performed by Stanford and Thompson [8] ranges between 50 and 100% for sensitivity, and between 44 and 95% for specificity, respectively, were observed [8, 11, 12]. The multidetector-row CT (MDCT), in contrast to EBCT, due to an improved in-plane and z-resolution [13, 14, 15], for the first time allows CT-coronary angiography under reasonable clinical circumstances and thus renders possible visualization even of non-calcified plaques [16, 17, 18]. The aim of this study, therefore, was to investigate the accuracy of both MDCT coronary angiography (MDCTA) in the assessment of coronary artherosclerosis.

Study design and patient characteristics

Between December 2000 and April 2002, 38 consecutive patients (30 males and 8 females) with symptomatic but atypical chest pain underwent both MDCT and coronary angiography (CA). Inclusion criteria were an intermediate pretest (i.e., pre MDCT-) likelihood for coronary artery disease (CAD) [19], but at the same time symptomatic chest pain. Intermediate pretest likelihood for CAD described a combination of atypical clinical presentation and inconclusive (stress-) ECG findings, risk factor profiles (i.e., hypertension, diabetes mellitus, nicotine abuse, presence of familial coronary atherosclerosisosis, cholesterol, high HDL, and low LDL) respectively. Patients' characteristics are displayed in Table 1. The mean time interval between both examinations totaled 17 days (range 7–23 days). Evaluation of the data was performed in accordance with the policies set by our internal institutional medical review board and all patients had given written informed consent before the examination.

Data acquisition

All MDCT scans derived from a multidetector-row spiral CT (Somatom Plus 4 VolumeZoom, WIP version VA 20/21, Siemens, Forchheim, Germany). Patients with average heart rates higher than 70 bpm previously received a short-lasting beta-blocker (Brevibloc, 100 mg, 1 ml/10 kg b.w.) in order to obtain rates of 60 bpm or less. Each patient received a plain and a contrast-enhanced examination. Scanning parameters were 120 kV and 300 mAs, 500-ms rotation time, 4×2.5 collimation, and 3.8-mm table feed per rotation for the plain series, 120 kV and 300 mAs, 500-ms rotation time, 4×1-mm slice collimation, and 1.5-mm table feed per rotation for the contrast enhanced series, respectively.

All patients received 140–160 ml of a non-ionic contrast medium (370 mg I/ml, Ultravist, Schering, Berlin, Germany) through an 18-G intravenous antecubital catheter infused with a flow rate of 3.5 ml/s. Start delay was determined by using bolus-triggering technique in the ascending aorta (30 ml contrast medium at a flow rate of 3.5 ml/s).

Image reconstruction

Image reconstruction was performed by using retrospective ECG gating [13, 20]. Reconstruction parameters were 220-mm FOV, 1.25-mm effective slice thickness, 0.5-mm increment and kernel B35, and a medium soft tissue kernel. For image reconstruction the adaptive cardiac volume reconstruction algorithm (ACV) was used, which is standardized and provided on the VA 21 software of the Siemens Plus 4 VZ CT. Maximum temporal resolution using

Table 1 Patient characteristics and coronary artery disease risk factors. *LDL* low-density lipoprotein, *HDL* high-density lipoprotein

	Number	Mean	Maximum	Minimum
Patients	38			
Male	30			
Female	8			
Age (years)		61.9	65	29
Weight (kg)		86.7	125	62
Height (cm)		174.9	192	155
Heart rate (bpm)		71.3	103	49
Blood pressure (systolic/diastolic)		131/75	203/96	100/40
Hypertension (RR>160/90)	31			
Diabetes mellitus	13			
Nicotin abuse (>1pack/day)	29			
Familial coronary artery disease	26			
Cholesterol (mg/dl)	28	220	305	127
LDL (mg/dl)		98.7	181	72
HDL (mg/dl)		49.2	99	22

this technique amounted to 125 ms. Each data set was reconstructed at multiple time points between the late systole (i.e., ascending t-wave) and the late diastole (i.e., beginning of p-wave) [21], differing from each other by 50 ms. Image reconstruction was always performed antegrade and absolute in relation to the previous R-peak.

Image evaluation

Multidetector-row cardiac CT image evaluation was done on a workstation (Wizzard, Plus4 Volume Zoom, Siemens, Erlangen, Germany) by using transverse scans and multiplanar reformations (MPR) with a matrix of 512×512 each. All data sets were blinded and subsequently assessed by two independent observers. Criteria to be analyzed were the number of segments visible on CT scans, the segmental atherosclerotic plaque load and degree of stenosis, the plaque composition, and the prevailing calcium score.

Visibility determined if a coronary artery segment could be properly evaluated or not.

The segmental plaque load was assessed following the classifications of the American Heart Association (AHA), which subdivide the coronary artery territory into 15 segments and distinguish between six different degrees of atherosclerosis [22]: (a) irregular wall outline with <25% stenosis; (b) slight stenosis (25–50%); (c) moderate stenosis (51–74%); (d) hemodynamically relevant stenosis (75%–89%); subtotal stenosis (90–99%); and (e) vascular occlusion (100%). Using a semi-automated distance measuring tool (Vessel navigator, Wizzard workstation, WIP version, Somatom Plus 4 VolumeZoom VA 21, Siemens, Erlangen, Germany), the prevailing maximal degree of stenosis was ascertained on multiplanar reformations.

Concerning plaque composition it was differed between calcified and non-calcified atherosclerotic plaques. Plaques with a mean density >130 HU were regarded as calcified, plaques with a mean density <130 HU as non-calcified [16].

Calcium score was calculated using a semi-automatically software (Calcium scoring, Wizzard workstation, Somatom Plus 4 VolumeZoom VA 21, Siemens, Erlangen, Germany). Calcium score measurements were made according to the method of Agatston et al. [24].

All findings were compared with corresponding coronary angiograms, which had been performed in different technical systems using the Judkins technique. At least four views of the left and two views of the right coronary artery system were analyzed by an experienced cardiologist who was trained in this technique. In order to avoid recall bias the observer had no knowledge of the CT results.

Plaque composition and visibility of coronary artery segments on coronary angiograms were described as either being calcified or non-calcified, visible or non-visible, respectively. The maximum degree of stenosis was determined visually.

Statistical analysis

Statistical analysis was performed by using SPSS (version 10.0, SPSS, Chicago, Ill.) and BiAS (version 7.0, Epsilon Publishers, Mannheim, Germany).

All patient baseline characteristics were calculated as means±SD.

The number of coronary segments visible on MDCT scans were calculated in proportion to the segments observed on coronary angiograms. It was differed between proximal (segments 1, 5, 6, and 11), medial (segments 2, 3, 7, and 13) and distal segments (segments 4, 8, and 15) as well as side branches (segments 9, 10, 12, and 14).

Correlation between angiography (CA) and MDCT coronary angiography (MDCTA) regarding detection and grading of atherosclerotic plaques was evaluated by using Pearsons' correlation. Results were interpreted as either poor (r<0.20), fair (r=0.21–0.40), moderate (r=0.41–0.60), good (r=0.61–0.80), very good (r= 0.81–0.90), or excellent (r=0.91–1.00). Bowkers' test was applied to check the symmetry of the data distribution and to evaluate possible under/overestimation through MDCTA [23]. Correlation coefficients were calculated for all segments in total and for side branches, proximal, medial, and distal segments as well as for RCA, LCA, and LCX separately.

Sensitivity, specificity, and positive and negative predictive values of MD CTA in the detection of hemodynamically relevant stenoses (HRS) was determined on cross tables. The HRS defined stenosis >75% on the angiogram [22], i.e., AHA groups IV, V, and VI. A 95% contingency interval (CI), calculated by a standard method, was assigned to each value.

The agreement between investigators for MDCTA was calculated by means of Cohen's κ statistic, interpreting the results according to the κ value as poor (κ<0.20), fair (κ=0.21–0.40), moderate (κ=0.41–0.60), good (κ=0.61–0.80), very good (κ=0.81–0.90), or excellent (κ=0.91–1.00). A 95% CI, calculated by a standard method, was assigned to each calculated κ value.

Corelation between amount of calcium score (Ca-Sc) and extent of coronary artery disease (CAD) in total was obtained from a Kruskal-Wallis test for non-parametric data. In order to do so each patient was subdivided into one of four separate groups—no signs of atherosclerosis, single-, two-, or three-vessel disease—according to the individual CA findings and a mean Ca-Sc for each group calculated. Single-, two-, or three-vessel disease defined >75% stenosis in either one, two, or three coronary arteries [22]. The same procedure was performed for the RCA, LCA, and LCX separately. A p value of <0.05 was considered statistically significant and a p value of <0.02

highly significant, respectively. Sensitivity, specificity, and positive and negative predictive value of Ca-Sc in the detection of HRS was obtained from cross tables. Calculations were performed by using both scores >0 and >400 as cut-off values; the latter was chosen in accordance to the literature [24, 25, 26]. A 95% CI, calculated by a standard method, was assigned to each calculated value. Possible other cut-off values for the detection of HRS were determined by receiver operating characteristics (ROC) analysis.

Finally, Ca-Sc and MDCT findings were combined, and sensitivity, specificity, and positive and negative predictive value for the combined results calculated on cross tables. A 95% CI was assigned to each value and the results were tested for significance by using χ^2 contingency tables for comparison with both Ca-Sc and MDCTA results.

Results

Patient's demographics and clinical test results are presented in Table 1. Twenty-seven patients needed beta-blocker medication prior to scanning. There were no contraindications or adverse events in giving the drug. In 7 patients this only had a marginal effect and HR remained nearly unchanged. The MDCT examinations and coronary angiography were performed in all patients without any complications. On MDCT scans 68.4% (390 of 570) of all coronary segments could be visualized. Of the 180 segments that were not adequately visible on MDCT scans, 9 (5%) were located proximal, 41 (22.8%) medial, 81 (45.0%) distal, and 49 (27.2%) in side branches. Seventy-five segments (41. 6%) could not be analyzed due to size (<1.5 mm), 13 (7.2%) due to heavy calcifications, 3 (1.5%) due to both in combination, and 89 (49.4%) due to motion artifacts. In total 92.9% (145 of 152) of all proximal segments, 74.3% (113 of 152) of all medial segments, 28.9% (33 of 114) of all distal segments, and 67.8% (103 of 152) of all side branches could be evaluated.

Correlation coefficients (r) for MDCTA regarding detection and grading of atherosclerosis (AHA I-VI) ranged between 0.91 and <0.01 and showed distinct segmental differences. Excellent correlation was found for segment 7 (r=0.91), very good correlation for segments 1 (r=0.82) and 11 (r=0.81), good correlation for segments 2 (r=0.73), 5 (r=0.77), 6 (r=0.80), 9 (r=0.76), and 12 (r=0.67), moderate correlation for segments 3 (r=0.44) and 8 (r=0.55), fair correlation for segment 13 (r=0.20) and poor correlation for segments 4 (r=0.14), 10 (r=0.19), 14 (r=0.00), and 15 (r=0.04). Total correlation coefficient amounted to 0.58 (p<0.01). Bowker's test showed a non-symmetrical data distribution (p<0.01): As compared with invasive coronary angiography MDCTA underestimated 21.2% (121 of 570) and overestimated 8.6% (49 of 570) of the stenoses.

Patients with hemodynamically relevant (>75%) stenoses were detected on MDCTA with 72.2% sensitivity (13 of 18; 95% CI: 46.5, 90.3%) and 100% specificity (20 of 20; 95% CI: 86.1, 100%). The PPV amounted to 100% (13 of 13; 95% CI: 79.4, 100%), NPV to 80.0% (20 of 25; 95% CI: 59.3, 93.2%; Table 2). One HRS was missed due to motion artifacts and two others due to small vessel size (<1.5 mm) or heavy calcifications. The κ value between investigators was 0.809 (0.866–0.961) equivalent to a good agreement.

Kruskal-Wallis test showed a statistically highly significant correlation between amount of Ca-Sc and degree of CAD (p<0.01). Patients (n=20) with no signs of atherosclerosis in CA presented median total scores of 104 (range 0–1459), patients with >75% stenosis and single-vessel disease (n=12) median scores of 408 (range 0–1873), patients with >75% stenosis and two-vessel disease (n=3) median scores of 482 (range 23–2450), and patients with >75% stenosis and three-vessel disease (n=3) median scores of 3740 (range 2635–4716; Table 3). A significant correlation was also found on the level of the main vascular branches (Table 3).

Patients with hemodynamically relevant stenoses (>75%) were identified by the pure presence of calcified plaques (Ca-Sc>0) with 94.4% sensitivity (17 of 18; 95% CI: 72.7, 99.9%) and 20.0% specificity (4 of 20; 95% CI: 5.7, 43.7%). The PPV amounted to 51.5% (17 of 33; 95% CI: 33.5, 69.2%), NPV to 80% (4 of 5; 95% CI: 28.4–99.5%; Table 2). The ROC analysis revealed no conclusive cut-off point for predicting the presence of HRS on the basis of calcium score values, showing an area beneath the curve of only 0.23 (Fig. 1); thus, a com-

Table 2 Sensitivity and specificity of calcium scoring (Ca-Sc) and CT coronary angiography for the detection of hemodynamically relevant stenoses (>75%). Results for each technique alone and in combination. *MDCTA* multidetector-row cardiac CT coronary angiography, *PPV* positive predictive value, *NPV* negative predictive value

	Sensitivity	Specificity	PPV	NPV
Ca-Sc (>0)	17 of 18 (94.4)	4 of 16 (25.0)	17 of 33 (51.5)	4 of 5 (80.0)
Ca-Sc (>400)	12 of 18 (66.7)	4 of 16 (25.0)	12 of 16 (75.0)	16 of 22 (72.7)
MDCTA	13 of 18 (72.2)	20 of 20 (100)	13 of 13 (100)	20 of 25 (80.0)
MDCTA+Ca-Sc	3 of 15 (20.0)	20 of 20 (100)	15 of 15 (100)	20 of 23 (87.0)

Numbers in parentheses are percentages

Table 3 Correlation between degree of coronary heart disease (CHD) and amount of Ca-Sc. Kruskal-Wallis test results. *RCA* right coronary artery, *LCA* left coronary artery, *LCX* left circumflex branch

	Degree of CHD	Ca-Sc (range)	*p* value
RCA	<75% stenosis	30.4 (0–1306.7)	<0.01
	>75% stenosis	412.6 (24.9–2287)	
LCA	<75% stenosis	76.6 (0–1630.1)	0.01
	>75% stenosis	531.7 (0–1674)	
LCX	<75% stenosis	0 (0–441)	0.04
	>75% stenosis	133 (0–1357)	
Total	No vessel >75% stenosis	104 (0–1459)	<0.01
	1 vessel >75% stenosis	408 (0–1873.7)	
	2 vessels >75% stenosis	482 (23–2450.6)	
	3 vessels >75% stenosis	3740 (2635–4716)	

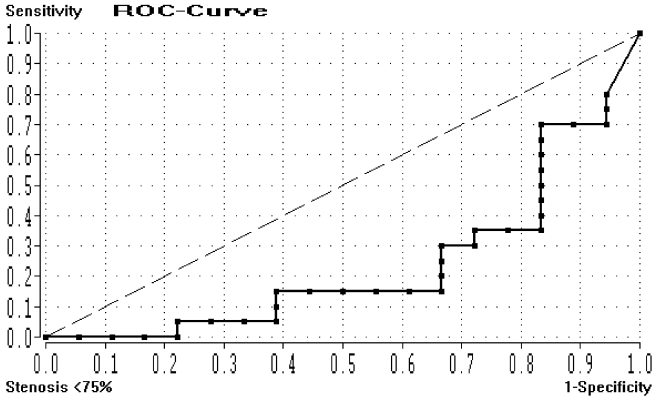

Fig. 1 Receiver operating characteristics (*ROC*) curve for multidetector-row CT calcium scoring. Values on the x-axis represent 1-specificity; on the y-axis, the sensitivity. No conclusive cut-off point for predicting the presence of hemodynamically relevant stenoses on the basis of calcium score values could be found. The area beneath the curve amounts to only 0.23

monly accepted score value of 400 [25, 26] was chosen as a suited cut-off point. Using this approach, sensitivity was 66.7% (12 of 18; 95%; CI 41.0–86.7%), specificity 80% (16 of 20; 95% CI: 56.3–94.3%), PPV 75.0% (12 of 16; 95% CI: 47.6–92.7%), and NPV 72.7% (16 of 22; 95% CI: 49.8–89.3%).

Combination of Ca-Sc and MD CTA led to 83.3% (15 of 18) sensitivity (95% CI: 58.6, 96.4%) and 100% (20 of 20) specificity (95% CI: 86.1, 100%) for the detection of HRS. The PPV amounted to 100% (15 of 15; 95% CI: 81.9, 100%), NPV to 87.0% (20 of 23; 95% CI: 66.4–97.2%; Table 2). Combination of both methods thus increased NPV of calcium scoring by 7% and specificity by 80%; however, neither compared with Ca-Sc (p=0.73) nor to MD CTA (p=0.23), a level of significance was reached.

Discussion

In the present study calcium scoring as a single method showed the highest sensitivity in the detection of CAD. In general, high calcium scores more likely predict hemodynamically relevant stenoses than low scores [1, 9]; however, determination of a suited cut-off value, allowing both a highly sensitive and specific identification of hemodynamically relevant stenoses, in our patients' collective proved to be difficult. This is a contradiction to other studies, which previously reported appropriate values [25, 26], and may be due to the small number of patients examined in the present study. The guidelines for interpretation of coronary artery calcium scores link EBCT scores greater than 400 in asymptomatic patients with "a high likelihood of significant coronary stenosis" [25, 26]. In addition, Becker et al. described a high correlation coefficient between EBCT and MDCT for all quantification algorithms and concluded that MDCT should be considered an additional screening tool for CAD [27]. Using a cut-off value of 400, in the present study a sensitivity of 67% and a specificity of 80% was obtained. Similar results were reported by Agatston et al. who verified in a large clinical series that calcium scores above 300 predicted severe (e.g., >50%) stenoses with 74% sensitivity and 81% specificity [24]; however, these observations referred only to the 60- to 69-year-old age group, whereas in younger persons scores of 50 sufficed to predict severe stenoses with comparable sensitivities and specificities, respectively. The patient's mean age in our study amounted to 61.9 years.

Although EBCT and MDCT quite sensitively identify calcified plaques, the problem with calcium scoring is that the extent and site of calcification often does not always equate with site-specific stenosis [1]. This may be one of the reasons for the low sensitivity observed in this study even if a score of 400 was chosen as cut-off value for hemodynamically relevant stenosis: 3 patients (17%) with HRS had scores below 30. Bormann et al. found that calcium scores were not predictive of a significant stenosis at the calcification site and that no ROC curve could be found that would suggest a clinically useful calcium score as an indicator of more than 70% stenosis at the same anatomic site [10]; however, in their trial only one patient had a significant stenosis in the absence of calcifications.

In a series of 150 patients undergoing EBCT scanning and coronary angiography in two other institutions, Stanford et al. found only one patient with greater than 50% stenosis in the absence of calcification. This fits

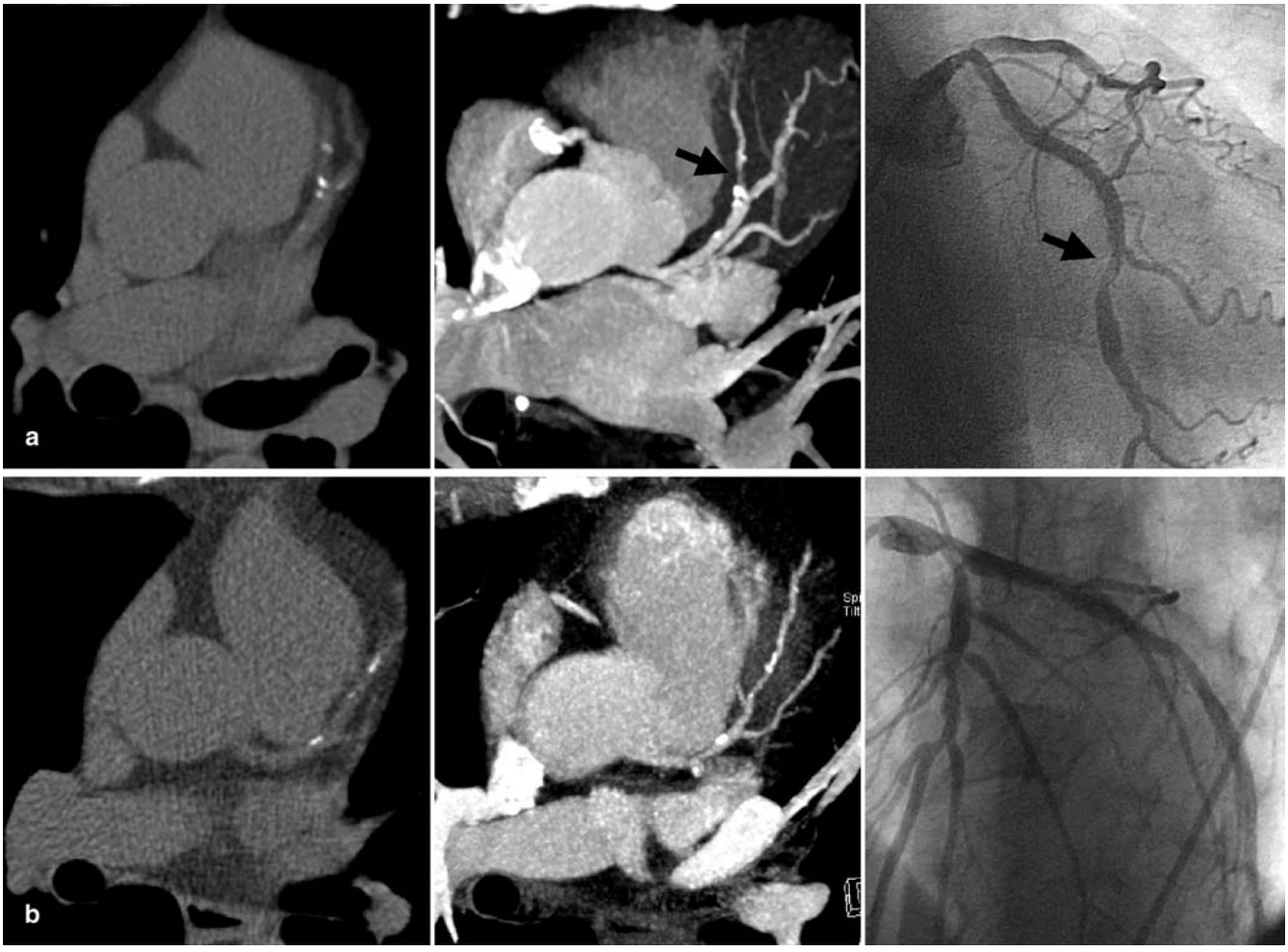

Fig. 2a,b Imaging examples of how multidetector-row cardiac CT coronary angiography (MDCTA) may increase the diagnostic value of MDCT calcium scoring. All four CT images represent transverse slices with a view from caudal. **a** Images of a 56-year-old symptomatic patient with only minor calcifications in the left coronary artery (LCA; calcium score 54) equivalent to a low risk for significant coronary stenosis. The MDCTA, however, revealed a >75% stenosis in the medial LCA (segment 7; *arrows*). Findings were confirmed by coronary angiography. **b** A 63-year-old symptomatic patient presenting in the course of preventive care. Calcium score was 36, and plaques were restricted to medial and distal segments of the LCA. The MDCTA and coronary angiography confirmed the score results by hemodynamically relevant "soft plaques." Note that for better orientation, all MDCTA images above are shown using maximum intensity projection technique. The MDCTA evaluation, however, was done on multiplanar reformations images and transverse slices

with the results from our institution where also only one of the 18 patients had an HRS in the absence of calcifications. Rumberger suggested that the presence of calcifications may be used to predict associated atherosclerosis somewhere within the coronary artery system with high sensitivity, but that the extent of calcification at a given anatomic site may be less useful in predicting luminal narrowing identified on coronary angiograms [25]. The present study thus aimed to determine the potential benefit that additive computerized coronary angiography may have upon the prediction of significant stenosis. The MDCTA as a single method correlated poorly with angiographic findings in terms of grading the prevailing atherosclerotic wall changes. Hemodynamically relevant stenoses also were detected with only 72.2% sensitivity. Four of the five missed stenoses were either located within small segments or were hidden by heavy calcifications: a possible explanation why our results were worse than those reported by other authors (Table 4) [18, 28, 29, 30, 31, 32], who either concentrated on the proximal and medial coronary artery segments or excluded heavy calcified segments from evaluation; however, by combining calcium scoring and computerized coronary angiography sensitivity of MDCTA was augmented to 83% (Fig. 2). Even more importantly, specificity and NPV for calcium scoring could be increased to 100 and 87%, respectively. Both methods in combination thus were able to identify healthy individuals with high accu-

Table 4 Sensitivities and specificities of MDCTA in the detection of hemodynamically relevant stenosis (>75%)

Reference	No. of patients	Sensitivity (%)	Specificity (%)
[18]	64	71.6	95.5
[28]	64	91	84
[2, 3, 17, 26, 27, 29]	48	82	97
[4, 32]	27	76	93
[30]	31	91	97
[6, 16, 31, 34]	102	86	93

racy. All 3 patients in whom an HRS was missed using this combined approach had their main findings within small side branches of the LCX. Only 2 patients needed a PTCA intervention; however, the still insufficient results regarding sensitivity address the need for scanners with increased spatial and temporal resolution, such as, for example, 16-row technology, multi-segment reconstruction, or flat-panel CT.

The small number of patients included limits the informational value of our results. The authors tried to make allowance for this by including confidence intervals for all relevant values. Their large variability indicates that accuracy for sensitivity, specificity, NPV, and PPV is low. This may also explain the difficulty in determining a suited cut-off calcium score value for hemodynamically relevant stenoses. Plotting of ROC curves and determination of sensitivities and specificities, respectively, therefore may be critical; however, the number of patients per year presenting with symptomatic but atypical chest pain is small and thus collection of more data is only feasible over a much longer time period. The results thus should be considered preliminary and the authors call for a subsequent, larger prospective multi-center study.

Despite these limitations, our diagnostic strategy nevertheless has been distinctly altered in a way that symptomatic patients with atypical chest pain and negative or low (<400) calcium scores now always receive additional MDCTA, whereas symptomatic patients presenting with atypical chest pain and high (>400) calcium scores exclusively undergo calcium scoring without any further examination (Fig. 3). In addition, with reference to the ACC/AHA consensus document, no patient receives diagnostic cardiac MDCT without in-depth previous clinical assessment through a cardiologist or at least experienced general practitioner [9].

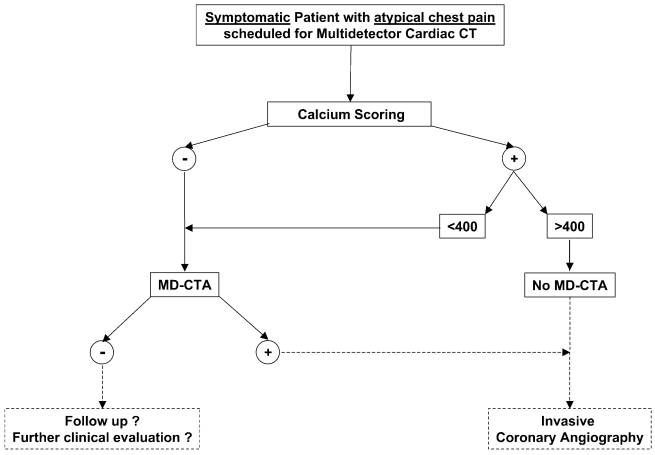

Fig. 3 Flow chart of our diagnostic procedure in choosing the optimal examination protocol for MDCT coronary artery imaging. All asymptomatic and all symptomatic patients with atypical chest pain initially receive native MDCT for calcium scoring. The MDCTA is only applied in asymptomatic patients with positive calcium scores and symptomatic patients with atypical chest pain who present with calcium scores below 400

Conclusion

In conclusion, new technical developments, such as 16-row MDCT [33, 34, 35], may further increase the potential of MDCTA and thus positively influence its future role in cardiac risk stratification. In addition, the role of calcium scoring needs to be reviewed, particularly as the absence of universally accepted standards for the detection and quantification of coronary calcifications still displays a severe impediment to the implementation and acceptance of this technique; thus, the need for an easily reproducible parameter in the assessment of coronary artery calcium seems to inspire the development of several alternative scoring methods such as volume scoring or quantitative assessment of the absolute calcium mass. Volume scoring appears to affect less variability in volume and mass quantification than calcium scoring according to the method of Agatston [24]. Scoring based on the hydroxyapatite mass, a physical quantitative measure, represents a new but not less promising approach. In an experimental setting Ulzheimer and Kalender observed better reproducible and comparable results than for calcium scoring and volume scoring–even if the measurements were undertaken on different scanners [36]; however, further large-scale, prospective, multicenter studies are necessary to evaluate the exact role of these exciting new calcium-scoring methods and also to estimate the potential of MDCTA as an alternative method for cardiac risk stratification.

References

1. Wexler L, Brundage B, Crouse J, Detrano R, Fuster V, Maddahi J et al. (1996) Coronary artery calcification: pathophysiology, epidemiology, imaging methods, and clinical implications: a statement for health professionals from the American Heart Association. Circulation 94:1175–1192
2. Becker CR, Schoepf UJ, Reiser MF (2001) Methods for quantification of coronary artery calcifications with electron-beam and conventional CT and pushing the spiral CT envelope: new cardiac applications. Int J Cardiovasc Imaging 17:203–211
3. Becker CR, Knez A, Leber A, Treede H, Ohnesorge B, Schoepf UJ et al. (2002) Detection of coronary artery stenoses with multislice helical CT angiography. J Comput Assist Tomogr 26:750–755
4. Fischbach R, Heindel W (2000) Detection and quantification of coronary calcification: an update. Fortschr Rontgenstr 172:407–414
5. Hong C, Becker CR, Schoepf UJ, Ohnesorge B, Bruening R, Reiser M (2002) Coronary artery calcium: absolute quantification in non-enhanced and contrast-enhanced multi-detector row CT studies. Radiology 223:474–480
6. Kopp AF, Ohnesorge B, Becker C, Schroder S, Heuschmid M, Kuttner A et al. (2002) Reproducibility and accuracy of coronary calcium measurements with multi-detector row versus electron-beam CT. Radiology 225:113–119
7. Ohnesorge B, Flohr T, Fischbach R, Kopp AF, Knez A, Schroder S et al. (2002) Reproducibility of coronary calcium quantification in repeat examinations with retrospectively ECG-gated multisection spiral CT. Eur Radiol 12:1532–1540
8. Stanford W, Thompson BH (1999) Imaging of coronary artery calcification: its importance in assessing atherosclerotic disease. Radiol Clin North Am 37:257–272
9. American College of Cardiology/American Heart Association (2000) Expert consensus document on electron-beam computed tomography for the diagnosis and prognosis of coronary artery diseaese. Circulation 102:126–140
10. Bormann JL, Stanford W, Stenberg RG (1992) Ultrafast tomographic detection of coronary artery calcification as an indicator of stenosis. Am J Card Imaging 6:191–196
11. Falk E (1983) Plaque rupture with severe pre-existing stenosis precipitating coronary thrombosis: characteristics of coronary atherosclerotic plaques underlying fatal occlusive thrombi. Br Heart J 50:127–134
12. Schmermund A, Baumgart D, Gorge G, Seibel R, Gronemeyer D, Ge J et al. (1997) Coronary artery calcium in acute coronary syndromes: a comparative study of electron-beam computed tomography, coronary angiography, and intracoronary ultrasound in survivors of acute myocardial infarction and unstable angina. Circulation 96:1461–1469
13. Flohr T, Ohnesorge B (2001) Heart-rate-adaptive optimization of spatial and temporal resolution for electrocardiogram-gated multislice spiral CT of the heart. J Comput Assist Tomogr 25:907–923
14. Fuchs T, Krause J, Schaller S, Flohr T, Kalender WA (2000) Spiral interpolation algorithms for multislice spiral CT. Part II: Measurement and evaluation of slice sensitivity profiles and noise at a clinical multislice system. IEEE Trans Med Imaging 19:835–847
15. Ohnesorge B, Flohr T, Becker C, Kopp AF, Schoepf UJ, Baum U et al. (2000) Cardiac imaging by means of electrocardiographically gated multisection spiral CT: initial experience. Radiology 217:564–571
16. Kopp AF, Schroeder S, Baumbach A, Kuettner A, Georg C, Ohnesorge B et al. (2001) Non-invasive characterisation of coronary lesion morphology and composition by multislice CT: first results in comparison with intracoronary ultrasound. Eur Radiol 11:1607–1611
17. Becker CR, Knez A, Leber A, Hong C, Treede H, Wildhirt S et al. (2000) Initial experiences with multi-slice detector spiral CT in diagnosis of arteriosclerosis of coronary vessels. Radiologe 40:118–122
18. Vogl TJ, Abolmaali ND, Diebold T, Engelmann K, Ay M, Dogan S et al. (2002) Techniques for the detection of coronary atherosclerosis: multi-detector row CT coronary angiography. Radiology 223:212–220
19. Diamond GA, Forrester JS (1979) Analysis of probability as an aid in the clinical diagnosis of coronary artery disease. N Engl J Med 300:1350–1358
20. Ohnesorge B, Flohr T, Becker C, Knez A, Kopp AF, Fukuda K et al. (2000) Cardiac imaging with rapid, retrospective ECG-synchronized multilevel spiral CT. Radiologe 40:111–117
21. Herzog C, Abolmaali N, Balzer JO, Baunach S, Ackermann H, Dogan S et al. (2002) Heart-rate-adapted image reconstruction in multidetector-row cardiac CT: influence of physiological and technical prerequisite on image quality. Eur Radiol 12:2670–2678
22. American College of Cardiology/American Heart Association (1991) Guidelines for cardiac catheterization and cardiac catheterization laboratories. American College of Cardiology/American Heart Association Ad Hoc Task Force on Cardiac Catheterization. J Am Coll Cardiol 18:1149–1182
23. Bowker A (1948) A test for symmetry in contingency tables. J Am Stat Assoc 43:572–574
24. Agatston AS, Janowitz WR, Hildner FJ, Zusmer NR, Viamonte M, Detrano R (1990) Quantification of coronary artery calcium using ultrafast computed tomography. J Am Coll Cardiol 15:827–832
25. Rumberger JA, Brundage BH, Rader DJ, Kondos G (1999) Electron beam computed tomographic coronary calcium scanning: a review and guidelines for use in asymptomatic persons. Mayo Clin Proc 74:243–252
26. Becker CR, Knez A, Ohnesorge B, Schoepf UJ, Flohr T, Bruening R et al. (2000) Visualization and quantification of coronary calcifications with electron beam and spiral computed tomography. Eur Radiol 10:629–635
27. Becker CR, Kleffel T, Crispin A, Knez A, Young J, Schoepf UJ et al. (2001) Coronary artery calcium measurement: agreement of multirow detector and electron beam CT. Am J Roentgenol 176:1295–1298
28. Achenbach S, Daniel WG, Moshage W (2001) Recommendations for standardization of EBT and MSCT scanning. Herz 26:273–277
29. Becker CR, Ohnesorge BM, Schoepf UJ, Reiser MF (2000) Current development of cardiac imaging with multidetector-row CT. Eur J Radiol 36:97–103

30. Nieman K, Oudkerk M, Rensing BJ, van Ooijen P, Munne A, van Geuns RJ et al. (2001) Coronary angiography with multi-slice computed tomography. Lancet 357:599–603
31. Kopp AF, Schroeder S, Kuettner A (2000) Multidetector-row CT for non-invasive coronary angiography: results in 102 patients. Radiology 217:487
32. Fischbach R, Wichter T, Juergens KU (2001) Multidetector-row spiral CT of the coronary arteries: comparison with coronary angiography. Fortschr Roentgenstr 173:26
33. Jakobs TF, Becker CR, Wintersperger BJ, Herzog P, Ohnesorge B, Flohr T et al. (2002) CT angiography of the coronary arteries with a 16-row spiral tomograph: effect of spatial resolution on image quality. Radiologe 42:733–738
34. Kopp AF, Heuschmid M, Claussen CD (2002) Multidetector helical CT of the liver for tumor detection and characterization. Eur Radiol 12:745–752
35. Wintersperger BJ, Herzog P, Jakobs T, Reiser MF, Becker CR (2002) Initial experience with the clinical use of a 16-detector-row CT system. Crit Rev Comput Tomogr 43:283–316
36. Ulzheimer S, Kalender WA (2003) Assessment of calcium scoring performance in cardiac computed tomography. Eur Radiol 13:484–497