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New Developments in Cardiac Imaging: The Role of MDCT

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Recently, mechanical multidetector-row CT (MDCT) systems with simultaneous acquisition of four slices and half-second scanner rotation have become available. Multidetector-row acquisition with these scanners allows considerably faster coverage of the heart volume compared to single-slice scanning. This increased scan speed can be used for retrospective gating together with 1 mm collimated slice widths. This allows coverage of the entire cardiac volume in one breath-hold and provides improved spatial resolution for MDCT angiography of the coronary arteries in comparison to electron beam computed tomography. The gantry rotation speed of 500 ms together with dedicated reconstruction algorithms make a temporal resolution of up to 125 ms feasible. A new imaging protocol using a highly concentrated contrast medium (400 mg/ml) permits depiction of smaller vessels and facilitates post-processing. This new method has the potential to rule out coronary artery disease. Preliminary results from studies in correlation with intracoronary ultrasound suggest that MDCT-technology not only offers the possibility to visualise intracoronary stenoses non-invasively, but also to differentiate plaque morphology. *J Clin Basic Cardiol 2001; 4: 253–60.*

Key words: multidetector-row computed tomography (MDCT), coronary artery disease (CAD), computed tomography angiography (CTA)

Coronary artery disease (CAD) is one of the leading causes of death in Europe and USA. In 1998, 600 thousand deaths caused by CAD were reported in Europe [1]. Almost 50 % of these patients died without prior symptoms. Direct visualization of the epicardial coronary arteries is necessary to establish the presence and focal severity of coronary lumen disease [1]. The gold-standard modality for diagnosis of CAD is coronary angiography. In 1995 over 1 million diagnostic coronary angiograms were performed in Europe, only 28 % of them with subsequent percutaneous transluminal coronary angioplasty (PTCA) [2]. These facts show the high need for reliable non-invasive imaging tools for early and preventive diagnosis of CAD.

Achenbach and Moshage introduced intravenous electron beam computed tomography (EBCT) coronary angiography as a non-invasive imaging modality for the diagnosis of coronary artery disease [3]. With EBCT imaging of the coronary arteries, data acquisition is triggered only prospectively with the patient's electrocardiogram by selecting one point in the cardiac cycle. This time point is fixed as soon as the data have been acquired. The timing for all cardiac vessels is identical with prospective triggering [3]. From conventional angiography [4, 5] as well as from EBCT [6] it is well known that the motion pattern of each of the three major coronary arteries during the cardiac cycle is different. If imaging is done only at one time point in the cardiac cycle, the results can be optimal for only one of the three major coronary arteries. This is probably the major reason for the high number of individual vessels that cannot be evaluated because of motion artifacts. This is especially true for the left circumflex and right coronary arteries. Furthermore, because of the restriction to axial, non-spiral scanning in ECG-synchronized cardiac investigations, acquisition of 3D-volume images by using EBCT can only provide limited z-resolution within a single breath-hold scan [7, 8].

Recently, mechanical multidetector-row CT (MDCT) systems with simultaneous acquisition of four slices and half-second scanner rotation have become available for general-purpose scanning [9]. Multidetector-row acquisition with these scanners allows for considerably faster coverage of the heart volume, compared to single-slice scanning [7]. This increased scan speed can be used for retrospective gating together with 1 mm collimated slice widths. This allows coverage of the entire cardiac volume in one breath-hold and provides improved spatial resolution for multidetector-row CT angiography (MDCTA) of the coronary arteries in comparison to EBCT [7, 10]. The gantry rotation speed of 500 ms together with dedicated reconstruction algorithms make a temporal resolution of up to 125 ms feasible [7].

Data Acquisition with Multislice CT

Multislice cardiac imaging can be done using two basic modes of operation for image acquisition: prospective triggering and retrospective gating:

Prospective triggering is used for sequential imaging. Compared to single slice CT and EBCT the major advantage of MDCT is the simultaneous acquisition of 4 slices per prospective ECG-trigger. The scan time to cover heart anatomy over a 120 mm volume is reduced to about 15 sec, ie well within a single breath-hold (the exact time depends on the heart rate). A sample protocol on the SIEMENS Somatom Volume Zoom for sequential cardiac CT is: 4 × 2.5 mm collimation, 500 ms rotation, 250 ms temporal resolution, a cycle time of 1.5 sec (the actual value depends on heart rate), z-coverage of 120 mm in 18 sec.

Retrospective gating is needed for spiral scanning. ECG-gating can be performed with a "relative" or "absolute" approach. In a "relative" ECG-gating approach the time delay is determined for each heart cycle individually as a certain fraction of the RR-interval. For "absolute" gating reconstruction data is picked starting with a fixed time delay after a R-peak ("absolute-delay") or at a fixed time interval before a R-peak ("absolute-reverse"). Retrospective ECG-gating was observed to improve cardiac image quality compared to prospective ECG-triggering techniques due to overlapping image reconstruction and reduced sensitivity to cardiac arrhythmia. With four-slice spiral scanning it is now for the first time possible

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to cover the entire volume of the heart within reasonable scan times using the technique of retrospective gating (Fig. 1). For continuous volume coverage without gaps the table speed (pitch) is adapted to the minimum heart rate of an individual patient [11].

Adaptive Image Reconstruction

The cardiac MDCT algorithm provides a continuous volume image of the heart with a temporal resolution equal to half the rotation time ($T_{rot}/2$) in the individual slices. With unchanged rotation time the temporal resolution can be improved by using scan data from more than one heart cycle for reconstruction of an image ("segmented reconstruction"). The partial scan data set for reconstruction of one image then consists of M projection sectors from different heart cycles [7]. Depending on the relation of rotation time and patient heart rate a temporal resolution within the interval [$T_{rot}/2$, $T_{rot}/2M$] (M equals number of used heart cycles) can be achieved. However, for a given heart rate, segmented reconstruction requires lower spiral pitch to maintain gap-less volume coverage. The resulting increase in scan time usually needs to be compensated by thicker slice-collimation and thus reduced spatial z-resolution. A compromise on spatial resolution can be avoided by extending the algorithm to a heart rate adaptive segmented reconstruction algorithm ("ACV") and restriction to maximum use of M=2 sectors. For the ACV algorithm 2 sectors (M=2) are used for reconstruction at heart rates above a certain limit only (eg 68 bpm). The conventional single-sector algorithm MSCV (M = 1) is used below that limit (Fig. 2). This adaptive approach provides appropriate temporal resolution $T_{rot}/2$ for imaging in the diastolic phase at moderate heart rates and higher temporal resolution up to $T_{rot}/4$ for higher heart rates without a need for decreased spiral pitch and reduced z-resolution. The ACV algorithm can easily be extended to the use of M > 2 sectors to achieve high temporal resolution at expense of spatial resolution for imaging in the systolic phase where compromises on spatial resolution may be acceptable [7].

Clinical Applications

Calcium Scoring

EBCT measurement of coronary arterial calcification in large groups of individuals has provided important epidemiologic statistics regarding the relationship between coronary arterial calcification and coronary events [12, 13]. In contrast to more traditional non-invasive testing methods such as treadmill exercise, stress echocardiography and stress thallium 201, CT can be performed in patients with resting ECG abnormalities or digitalis medications, as well as those unable to exercise [12, 13].

Arterial calcification is not necessarily a relentlessly progressive process. Arterial calcification is an actively regulated process. Just as eliminating osteoprotegerin, a secreted protein, which inhibits osteoclast formation, will result in massive arterial calcification in a mouse model, it is conceivable that activation of osteoclast activity within atherosclerotic lesions might result in a net loss of calcific deposits [13]. Thus serial reproducible evaluation of arterial calcification by MDCT may provide important new information about the factors influencing the development of such lesions. Furthermore, when considering the mechanism of many sudden coronary events (rupture of a vulnerable non-obstructing plaque with subsequent thrombus formation), detection of accelerated progression of coronary calcification by serial CT could add to the risk stratification in older adults thought to be at high risk. There is currently no consensus about the meaning of the results in those individuals being evaluated: Does an increase in coronary arterial calcium in an individual patient imply an increased likelihood of future coronary events, or is it simply the case that previously unstable lesions are stabilizing? Does a decrease in coronary arterial calcification in an individual patient foretell a decreased likelihood of

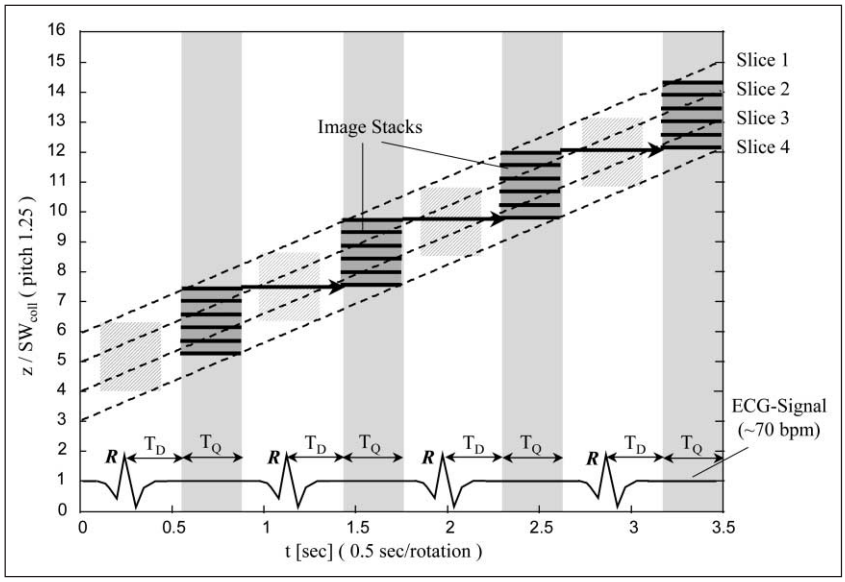


Figure 1. Reconstruction procedure with retrospectively ECG-Gated 4-Slice Spiral Scanning

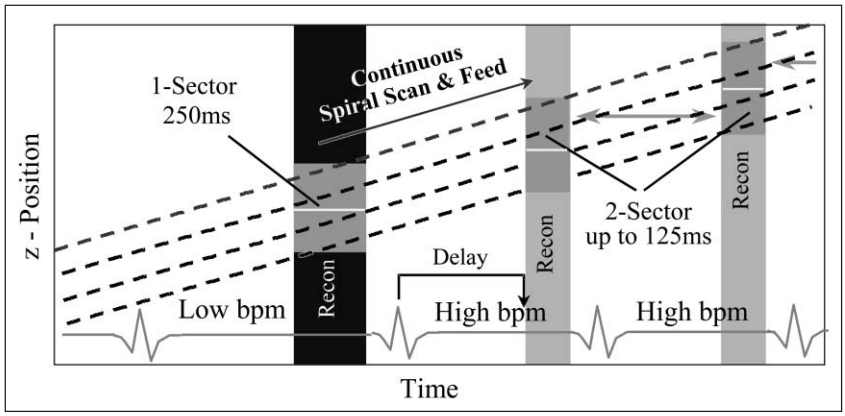


Figure 2. Retrospectively ECG-gated 4-slice spiral reconstruction with 1-sector reconstruction (black bar) for heart rates < 70 bpm and 2-sector reconstruction (2 grey bars are used for one reconstruction) for heart rates ≥ 70 bpm. The dashed lines indicate how the four detector rows travel along z-axis at a fixed speed (pitch). Using the adaptive approach gap-less volume reconstruction is possible with pitch 1.5 for all heart rates > 40 bpm.

an acute coronary event? All these questions cannot be addressed with an inter-study variability of up to 70 % for EBCT. The problem of inter-study variability has to be resolved first.

There have been several attempts to improve reproducibility of EBCT. Kajinami et al. recommended for clinical use that two scans be performed in rapid succession, using the average of the two scores [14]. Smemesh et al. suggested using an average instead of conventional peak density score to provide better reproducible measurements of calcium by double helical CT [15]. Wang suggested the acquisition of thicker (6 mm) sections [16]. Callister et al. described a volumetric method for improving the reproducibility of scoring of coronary arterial calcifications detected with electron-beam CT. They applied a post-processing technique called isotropic interpolation by using specialized software and a dedicated workstation [17]. Their method demonstrated a statistically significant improvement over the standard calcium scoring method when the latter was applied to the same data sets. Callister et al. studied an additional 27 patients on two separate occasions (1 year apart) who had known cardiac risk factors; they found changes in coronary arterial calcium scores that were significantly greater than the determined interscan variability of the technique. The volumetric score described by Callister et al. improves interscan reproducibility in the scoring of coronary arterial calcification. The technique refines the traditional calcium scoring method in two ways. First it eliminates the attenuation-scaling factor that arbitrarily gives greater weight to atherosclerotic plaques with greater attenuation (Hounsfield units). Second, by using isotropic interpolation techniques, the CT data set is reconstructed into a more precise volumetric map of coronary arterial calcium. However, the section misregistration problems encountered with electron-beam CT persist, imposing a limit on the precision of calcium scores.

Non-overlapping sequential scanning is the most important contributor to the interscan variability of Agatston- and volumetric Ca-Scores due to partial volume errors in plaque registration [18]. Coupling the technique of retrospective gating with nearly isotropic volumetric imaging data with the advent of multidetector-row spiral CT provides the best input data for the quantification of coronary arterial calcium volume. ECG-gated volume coverage with multidetector-row spiral CT and overlapping image reconstruction (2.5 mm collimation, 1 mm increment) was found to significantly improve the reliability of coronary calcium quantification especially for small plaques. The interscan variability could be reduced from 35 % (± 6 %) (Agatston Score, standard EBCT scan) to 4 % (± 2 %) for a volumetric score calculated from an ECG-gated multidetector-row spiral scan [19]. A spiral scan using a 2.5 mm collimation at a pitch of 2 allowed coverage of the entire z-volume of the heart in just 12 sec. Using EBCT equivalent results in terms of reproducibility could only be realized acquiring scans with "true" 1 mm feed at the expense of a scan time of approx. 90 sec and a significantly increased radiation dose due to 2 mm overlapping. Obviously, no patient can hold his breath for 90 sec, which makes this EBCT scan protocol not feasible for clinical practice. With the advent of MDCT technology true volume data acquisition has become feasible. Thus, this new technique yields significant reduction of interscan misregistration per se without need for mathematical interpolation [9, 20]. We can now begin to define the effects of treatment regimens on coronary arterial calcification and to determine whether changes in coronary arterial calcification in individual patients have predictive value for future coronary events. If these differences in calcium score over time result in a difference in event rates it is conceivable that serial measurements of calcium score by MDCT will provide a powerful and much needed predictive tool.

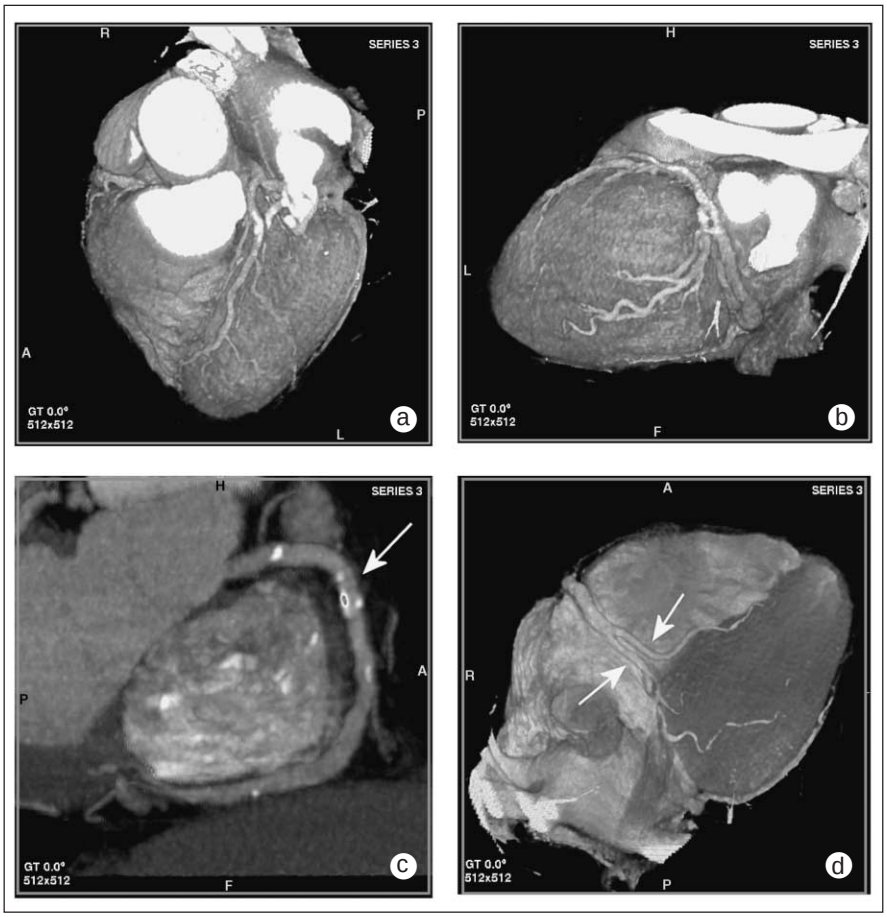


Figure 3. MDCT angiography (collimation 4 × 1 mm, pitch 1.5, 120 cc Imeron® 400). **(a)** Anterior view of left coronary artery with LAD in volume rendering technique. **(b)** Lateral view of left coronary artery with LAD and circumflex branch. **(c)** Maximum intensity projection of right coronary artery with calcified plaques (arrow). **(d)** Diaphragmatic surface with posterolateral and interventricular branches of RCA (arrows).

CT Coronary Angiography

A challenging application for cardiac CT imaging is the non-invasive assessment of the coronary arteries for diagnosis of CAD (Fig. 3, 4). Limited temporal resolution of current CT technology requires synchronization of the image acquisition to the movement of the heart by using ECG-information to provide phase consistent data in phases of low cardiac motion [7]. For sequential imaging, a prospec-

tive trigger is derived from the ECG-trace to initiate the CT-scan with a certain, user selectable delay time after the R-wave. The delay time for scan acquisition after an R-wave is calculated from a given phase parameter (eg a percentage of the RR-interval time as delay after an R-wave) for each cardiac cycle individually based on a prospective estimation of the RR-intervals. Usually, the delay is defined such that the scans are acquired during the diastolic phase of the heart cycle. From cineangiographic studies [4, 5] however, it is known that each of the coronary arteries has a distinct motion pattern in the course of the cardiac cycle. Because of their position in the coronary groove, the right coronary and the left circumflex artery have more rapid diastolic motion than the left anterior descending artery. The motion is caused mainly by atrial contraction during end-diastole [3]. This corresponds to the fact that in most EBCT studies the results for the right coronary arteries in regard to motion artifacts and image quality were worse than for the LAD [3, 21]. Recently Achenbach et al. analyzed the pattern of coronary arterial movement using EBCT [6]. They confirmed the finding that each of the three major coronary arteries has a different motion pattern during the cardiac cycle.

Contrast Administration Protocol

The different motion pattern of the individual coronary vessels calls for an individual reconstruction for each vessel in regard to position in the cardiac cycle. This can only be obtained if the data set contains data from all phases of the cardiac cycle. EBCT imaging only allows for sequential prospectively triggered acquisition [3]. The user has to select the phase of reconstruction in advance without being able to adapt or optimize it afterwards. Only one phase can be selected for all three vessels, ie a compromise has to be made in regard to optimal time point for the individual vessels. The only means to achieve a reconstruction adapted to the phase to the cardiac cycle is retrospective gating [22].

In addition to the advantages of phase selective image reconstruction, ECG-gated spiral scanning provides continuous volume coverage and better spatial resolution in the patients' longitudinal direction as images can be reconstructed with overlapping increment. A 3D-volume image can be reconstructed with a voxel size of about $0.5 \times 0.5 \times 1.0$ mm based on a scan with 1 mm slice-collimation and reconstruction with submillimeter image increment [7]. This is important for visualization of the right and left circumflex coronary arteries, which run perpendicular to the imaging plane. With EBCT these vessels are visualized with lower spatial resolution than the LAD, which is oriented parallel to the imaging plane [3]. ECG-triggered sequential scanning is restricted to non-overlapping adjacent slices. ECG-gated spiral acquisition allows for imaging in a complete cardiac cycle using the same scan data set, thus providing cardiac function information. ECG-triggered acquisition targets only one specific phase of the cardiac cycle. Furthermore, retrospective analysis of the ECG with manual repositioning of the R-wave indicators results in less sensitivity to heart rate changes during the scan. With prospective ECG-triggering, the estimation of the next RR-interval may be wrong when heart rate changes are present (eg arrythmia, vasalva manoeuvre) and scans may be placed in inconsistent heart phases.

The imaging protocol for multislice CT angiography of the coronary arteries is relatively straightforward. To establish the scan delay time a test bolus of 15 ml CM and 20 ml saline chaser bolus is used. The circulation time is determined by measurements of CT density values in the ascending aorta. Imaging commences at the circulation time plus 3 s. A bolus of 120 ml non-ionic contrast (400 mg I/ml) is injected through an 18-gauge catheter into an antecubital vein at 4 ml/sec followed by a 50 ml saline chaser bolus [20].

The concentration of 400 mg I/ml was selected for the imaging protocol, because it is important to achieve a high concentration rapidly. Higher attenuation values are thus achieved in the arteries with the same amount of contrast medium as compared to the standard iodine concentration (300 mg I/ml). This permits depiction of smaller vessels, facilitates postprocessing and reduces the overall volume of contrast medium required by approximately 30 %. The methodological details related to the protocol and the main advantages of high concentration contrast agents are summarized in Table 1 and 2.

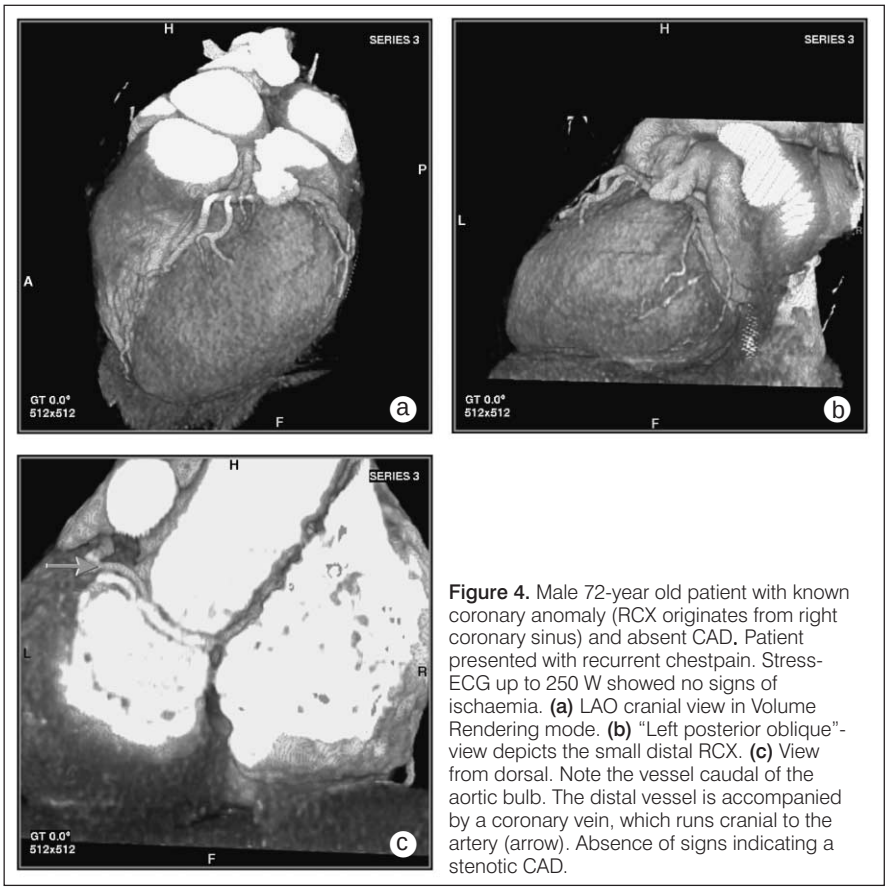


Figure 4. Male 72-year old patient with known coronary anomaly (RCX originates from right coronary sinus) and absent CAD**.** Patient presented with recurrent chestpain. Stress-ECG up to 250 W showed no signs of ischaemia. **(a)** LAO cranial view in Volume Rendering mode. **(b)** "Left posterior oblique"-view depicts the small distal RCX. **(c)** View from dorsal. Note the vessel caudal of the aortic bulb. The distal vessel is accompanied by a coronary vein, which runs cranial to the artery (arrow). Absence of signs indicating a stenotic CAD.

Scan Protocol

The scan protocol for the CTA *per se* is a spiral scan using 4×1 mm collimation (resulting in 1.25 mm slice-width), 500 ms rotation time (with ACV up to 125 ms temporal

resolution), 120 kV, 300 mA and 0.6 mm image reconstruction increment. With pitch 1.5 the scan time for a 100 mm scan range is ≈ 33s, the effective patient dose is ≈ 6 mSv. A virtually "frozen" 3D-volume image can be reconstructed in the diastolic phase with a voxel size of about 0.6 × 0.6 × 1.0 mm based on a contrast enhanced scan with 1 mm slice-collimation and reconstruction with submillimeter image increment. Data from the CT angiography is transferred to a computer workstation for postprocessing. The method of choice for display is volume rendering and maximum intensity projection (MIP) and not surface rendering as used by most investigators for EBCT angiography. In surface rendering, much of the volumetric data is lost. Volume-rendering uses the information from all the voxels in a stack of images in order to create a space-filling picture, meaning data are not lost during the rendering process (Fig. 5, 6). MIP images are used for the temporal and spatial resolution of cardiac multislice image data, which even allows for virtual angioscopy of the coronary arteries.

MDCT demonstrated high overall sensitivity and specificity of 0.86 and 0.96, respectively, and high negative predictive value (0.98) for coronary angiography using retrospective gating to detect significant stenoses (> 50 % reduction in diameter) in the proximal, middle and distal coronary arteries [23]. This study included the distal segments in the evaluation. In addition, all vessels were included in the evaluation, no segment was excluded due to technical limitations [23]. Achenbach et al. reported a sensitivity of 92 % for detection of high grade stenoses in only the proximal and middle coronary arteries when excluding vessels that could not be evaluated, however, when including all vessels the sensitivity was only 69 % for just the proximal and middle segments [3]. Image quality and diagnostic accuracy in CTA of the coronary artery can be significantly improved by high-resolution MDCT with individual selection of different time points for reconstruction during the cardiac cycle for each of the three major coronary arteries, using a non-ionic contrast medium with high iodine content. Nieman et al. studied 35 patients without previous surgery using iomeprol (350 g per L). In the 31 patients without previous coronary surgery, 173 (73 %) of the 237 proximal and middle coronary segments were assessable. In the assessable segments, 17 of 21 significant stenoses (> 50 % reduction of vessel diameter) were correctly diagnosed. The non-assessable segments included four lesions. Misinterpretations were mainly the result of severe calcification of the vessel wall. Segments with implanted stents were poorly visualised, but stent patency could be assessed in all cases. Of the 17 segments of bypass grafts, 15 were assessable and four of five graft lesions were detected. Two cases of anomalous coronary anatomy could be visualised well [24]. Achenbach et al. investigated the method's ability to identify high- grade coronary artery stenoses and occlusions [25]. They studied a total of 64 consecutive patients by MDCT. All coronary arteries and side branches with a luminal diameter > 2.0 mm were assessed concerning evaluability and the presence of high-grade stenoses (> 70 % diameter stenosis) or occlusions. Of 256 coronary arteries (left main, left anterior descending, left circumflex and right coronary artery, including their respective side branches), 174 could be evaluated (68 %). In 19 patients (30 %), all arteries were evaluable. Artifacts caused by coronary motion were the most frequent reason for unevaluable arteries. Overall, 32 of 58 high-grade stenoses

Table 1. Protocol MDCTA Coronary Arteries

- Precontrast scan (low dose, collimation 4 × 2.5 mm)
- Circulation Time: 20 cc CM (400 mg/cc), 20 cc NaCl
- CT density in ascending aorta over 20 sec following 10 sec pi, every 2 sec
- Antecubital vein
- Iomeron 400 (400 mgI/cc)
- Biphasic injection: 50 cc@ 4cc/sec, then 2.5 cc/sec
- Volume: 120-140 cc

Table 2. High Concentration Contrast Agents

- High concentration of iodine must be rapidly reached
- Increase of attenuation values in the arteries with the same amount of iodine compared to standard iodine concentration (300 mgI/ml)
- Depiction of smaller vessels
- Facilitates postprocessing
- Reduction of the overall amount of c.m. of approx. 30 %

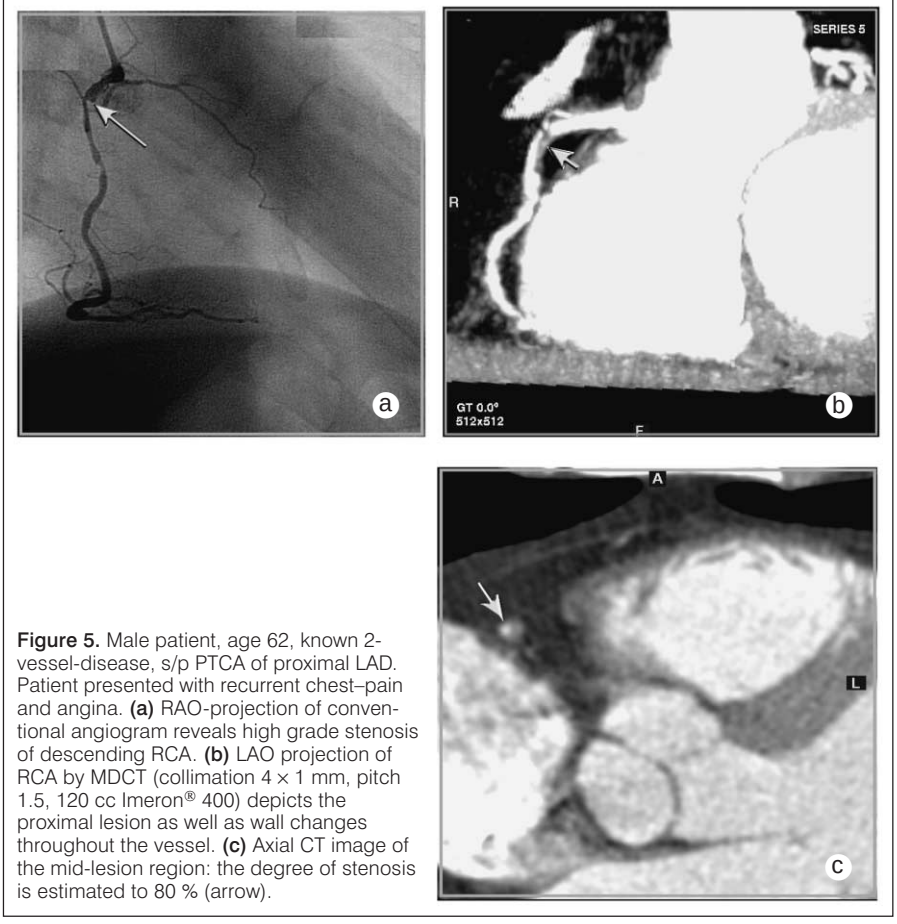
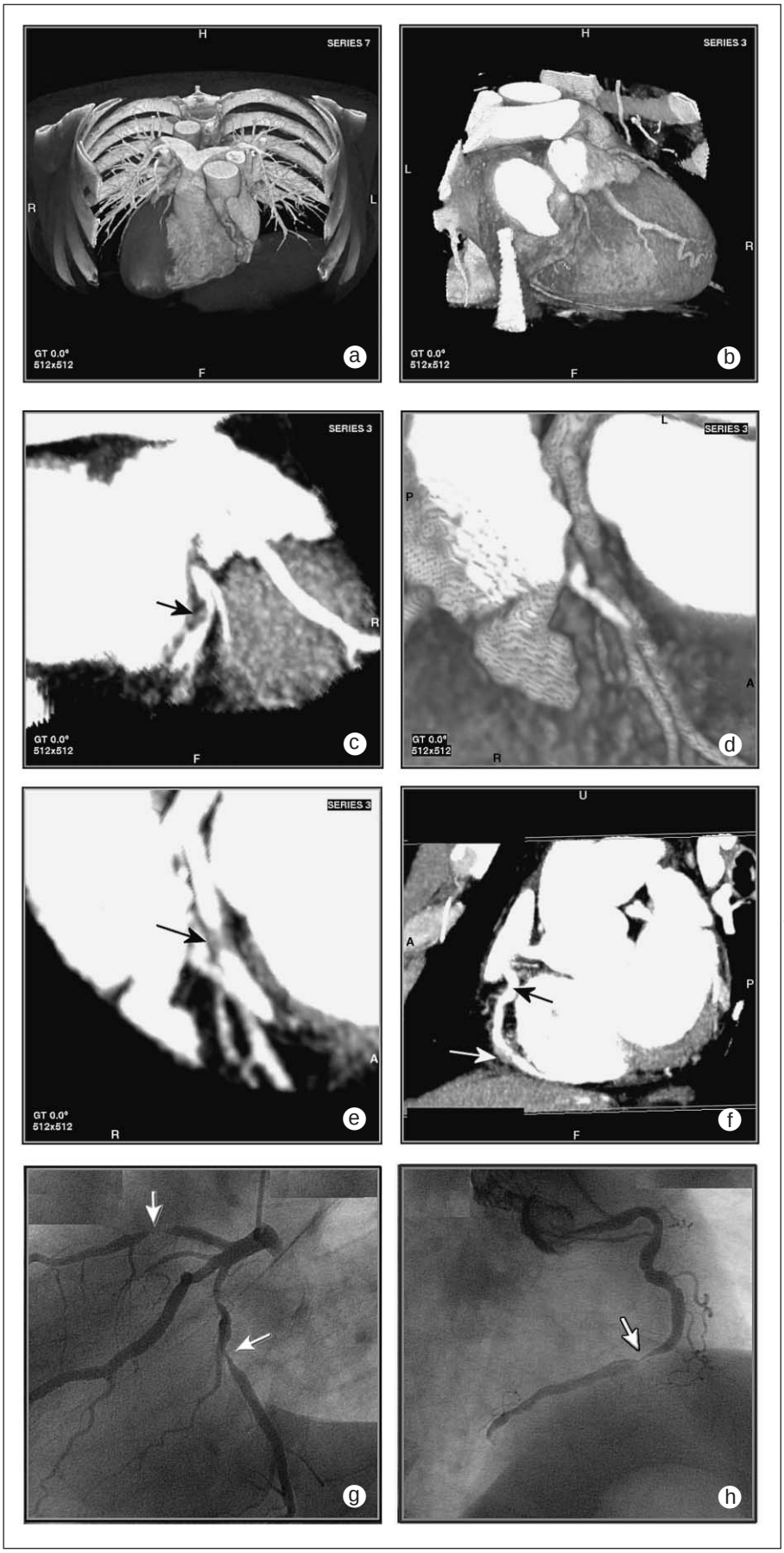


Figure 5. Male patient, age 62, known 2-vessel-disease, s/p PTCA of proximal LAD. Patient presented with recurrent chest–pain and angina. **(a)** RAO-projection of conventional angiogram reveals high grade stenosis of descending RCA. **(b)** LAO projection of RCA by MDCT (collimation 4 × 1 mm, pitch 1.5, 120 cc Imeron® 400) depicts the proximal lesion as well as wall changes throughout the vessel. **(c)** Axial CT image of the mid-lesion region: the degree of stenosis is estimated to 80 % (arrow).



and occlusions were detected by MSCT (58 %). In evaluable arteries, 32 of 35 lesions were detected, and the absence of stenosis was correctly identified in 117 of 139 arteries (sensitivity, 91 %; specificity, 84 %). If analysis was extended to all stenoses with > 50 % diameter reduction, sensitivity was 85 % (40 of 47) and specificity was 76 % (96 of 127) [25].

In the presence of intracoronary stents, high-density artifacts combined with partial volume effects may prevent adequate assessment of the small vessel lumen within the struts of the stent. However, patency can be assessed if enhancement by contrast medium is observed in the vessel segment distal to the stent. Assessability of the stented segments is expected to increase with the improvement of spatial resolution and the use of less radio-opaque alloys for stents. Coronary-artery bypass grafts, because of their size and relative immobility, can be reliably imaged. In patients with an anomalous origin or course of the coronary arteries, MDCT displays, in contrast to conventional angiography, a three-dimensional map of the coronary anatomy, which allows easy identification

◀ **Figure 6.** Male patient, age 55, with "situs inversus" and 2-vessel-disease, s/p PTCA of proximal RCA and prox. LAD, a 60 % lesion of distal RCA was left untreated. **(a)** Anterior view (volume rendering mode) of thorax with ventral thorax wall cut away depicts situs inversus. **(b)** RAO projection of RCX and prominent marginal branch in volume rendering mode. No high-grade lesion can be readily appreciated. **(c)** MIP of RCX clearly shows a lesion (arrow). The degree of stenosis is estimated at 70 %. **(d)** RAO cranial view of proximal LAD in volume rendering mode. The high-grade lesion was not clearly delineated in this view. **(e)** MIP-image clearly depicted the lesion of the proximal LAD. **(f)** MIP of RCA in "left posterior oblique"-projection. The arrow depicts the distal RCA lesion. The black arrow shows the area of the former dilatation, no restenosis present. **(g)** LAO cranial view of LAD and RCX with conventional angio. The arrows depict the lesions in each of the vessels. **(h)** RAO view of RCA by conventional angiography. Note the progress of the former 60 % lesion to a high-grade lesion and the absent restenosis of the proximal RCA.

of a high-risk course of a coronary artery between the pulmonary artery and the aorta. Despite these satisfying initial results, some technical limitations remain. Although manual repositioning of the R-wave indicators during retrograde gating improves the synchronisation of acquisition intervals between consecutive heartbeats, cardiac motion artifacts cannot be entirely prevented. Especially absolute arrhythmia and atrial fibrillation as well as frequent extrasystoles might cause artifacts. Movement of the patient, such as breathing, also causes motion artifacts, which can be reduced by thorough instruction before scanning. The presence of extensive calcifications can complicate correct assessment of the lumen of the coronary arteries. The high-contrast calcium depositions cannot be sufficiently isolated from the contrast-enhanced vessel lumen and may result in non-assessable segments or misinterpretation. Nevertheless, severe calcification of the coronary arteries is related to coronary-artery disease, and its detection will contribute to clinical decision-making.

Plaque Imaging

One of the most important findings, however, of the ongoing studies is that MDCTA allowed detection and assessment of non-calcified lipid-rich plaques [26]. Preliminary results from studies in correlation with intracoronary ultrasound suggest that MDCT-technology not only offers the possibility to visualise intracoronary stenoses non-invasively, but also to differentiate plaque morphology [27]. Lesion composition and severity of stenoses were compared to the findings of intracoronary ultrasound, which currently represents the gold-standard for *in vivo* analysis of coronary plaque morphology [28]. The MDCT criteria based on density measurements expressed by Hounsfield units showed good correspondence with the criteria of echogenity used for intracoronary ultrasound [29]. Thus, this new technology holds promise to allow for the non-invasive detection of rupture-prone soft coronary lesions and may have the option to lead to early onset of therapy [30, 31].

Functional Imaging

With ECG-gated multsilice spiral scanning 2D or 3D images can be reconstructed in incrementally shifted heart phases with a temporal resolution of up to 125 ms. With multiplanar reformation, the heart can be displayed in any desired plan, such as the short and long axis. This allows functional analysis in a one stop shopping approach for every patient undergoing CTA of the coronary arteries. From the same spiral data a 4D reconstruction of the beating 3D-heart is feasible that covers a complete heart cycle.

Patient Dose

During ECG-gated spiral imaging of the heart data are acquired with overlapping spiral pitch and continuous X-ray exposure. Thus, ECG-gated spiral acquisition requires higher patient dose than ECG-triggered sequential acquisition for comparable signal-to-noise ratio. When performing multiple reconstructions in different cardiac phases for optimal image quality of individual vessels all spiral data are used for image reconstructions and no data are omitted. To obtain the same diagnostic information multiple sequential acquisitions would have be to performed with repeated injections of contrast material. This would eventually result in the same or even higher X-ray exposure. However, developments are under way that allow for a reduction of X-ray exposure for ECG-gated spiral acquisition by prospectively ECG-controlled online modulation of the tube output [32]. By reduction of the tube output during heart phases that are not likely to be targeted by the ECG-gated reconstruction dose savings up to 50 % are possible. This technique promises to maintain the important benefits of ECG-gated spiral scanning with X-ray exposure comparable to ECG-triggered sequential acquisition.

Conclusion

In conclusion, the emergence of MDCT will have significant impact on cardiac imaging. This new method has the potential to rule out coronary artery disease. Cardiac calcium scoring and CTA of the coronary arteries as well as functional analysis are no longer limited to a dedicated EBCT scanner only available at a few major medical centers. Imaging can be performed in a one-stop shopping approach on a standard body CT scanner. With further technical improvements, this non-invasive method might become an alternative diagnostic approach in patients with known or suspected coronary artery disease.

References

1. Wielopolski PA, van-Geuns RJ, de-Feyter PJ, Oudkerk M. Coronary arteries. Eur Radiol 1998; 8: 873–85.
2. Windecker S, Maier-Rudolph W, Bonzel T, Heyndrickx G, Lablance JM, Morice MC, Muhlberger V, Neuhaus KL, Piscione F, van den Brand M, Wijns W, Meier B. Interventional Cardiology in Europe 1995. Eur Heart J 1996; 20: 484–95.
3. Achenbach S, Moshage W, Ropers D, Nossen J, Daniel WG. Value of electron-beam computed tomography for the noninvasive detection of high-grade coronary-artery stenoses and occlusions. N Engl J Med 1998; 339: 1964–71.
4. Paulin S. Coronary angiography: a technical, anatomic, and clinical study. Acta Radiol 1964; 233S: 1–215.
5. Potel MJ, Rubin J, MacKay SA, Aisen A, Al-Sadir J, Sayre RE. Methods for evaluating cardiac wall motion in three dimensions using bifurcations points of the coronary arterial tree. Invest Radiol 1983; 18: 47–57.
6. Achenbach S, Ropers D, Holle J, Muschiol G, Daniel WG, Moshage W. In-plane coronary arterial motion velocity: measurement with electron-beam CT. Radiology 2000; 216: 457–63.
7. Ohnesorge B, Flohr T, Kopp AF, Becker C, Baum U, Knez A, Klingenbeck-Regn K, Reiser M. Cardiac imaging by means of electrocardiographically gated multisection spiral CT: Initial experience. Radiology 2000; 217: 564–71.
8. Ohnesorge B, Flohr T, Becker C, Knez A, Kopp AF, Fukuda K, Reiser MF. Herzbildgebung mit schneller, retrospektiv EKG-synchronisierter Mehrschichtspiral-CT. Radiologe 2000; 40: 111–7.
9. Klingenbeck-Regn K, Schaller S, Flohr T, Ohnesorge B, Kopp AF, Baum U. Subsecond multislice computed tomography: basics and applications. Eur J Radiol 1999; 31: 110–24.
10. Kopp AF, Ohnesorge B, Flohr T, Georg C, Schröder S, Küttner A, Martensen J, Claussen CD. Multidetektor CT des Herzens: Erste klinische Anwendung einer retrospektiv EKG-gesteuerten Spirale mit optimierter zeitlicher und örtlicher Auflösung zur Darstellung der Herzkranzgefäße. Fortschr Röntgenstr 2000; 172: 1–7.
11. Kopp AF, Georg C, Schröder S, Claussen CD. CT-Angiographie der Herzkranzgefäße bei koronarer 3-Gefäß-Erkrankung. Fortschr Röntgenstr 2000; 172: M3–M4.
12. Wexler L, Brundage B, Crouse J, Detrano R, Fuster V, Maddahi J, Rumberger J, Stanford W, White R, Tauber K. Coronary artery calcification: pathophysiology, epidemiology, imaging methods, and clinical implications. Circulation 1996; 94: 1175–92.
13. Sechtem U. Electron beam computed tomography: on its way into mainstream cardiology? Eur Heart J 2000; 21: 87–91.
14. Kajinami K, Seki H, Takekoshi N, Mabuchi H. Quantification of coronary artery calcification using ultrafast computed tomography: reproducibility of measurements. Coron Artery Dis 1993; 4: 1103–8.
15. Broderick LS, Shemesh J, Wilensky RL. Measurement of coronary artery calcium with dual-slice helical CT compared with coronary angiography: evaluation of CT scoring methods, interobserver variations, and reproducibility. Am J Roentgenol 1996; 167: 439–44.
16. Wang S, Detrano RC, Secci A, Tang W, Doherty TM, Puentes G, Wong N, Brundage BH. Detection of coronary calcification with electron-beam computed tomography: evaluation of interexamination reproducibility and comparison of three image-acquisition protocols. Am Heart J 1996; 132: 550–8.
17. Callister TQ, Cooil B, Raya SP, Lippolis NJ, Russo DJ, Raggi P. Coronary artery disease: improved reproducibility of calcium scoring with an electron-beam CT volumetric method. Radiology 1998; 208: 807–14.
18. Ohnesorge B, Becker C, Kopp AF, Fischbach RM, Flohr T. Reproducibility of coronary calcium scoring with EBCT and ECG-gated multi-slice spiral CT. Radiology 2000; 217 (P): 233.

19. Kopp AF, Schröder S, Küttner A, Heuschmid M, Ohnesorge B, Georg C, Claussen CD. Assessment and quantification of coronary lesions by noninvasive multislice computed tomography and intracoronary ultrasound: first results. Radiology 2000; 217 (P): 375.
20. Kopp AF, Ohnesorge B, Flohr T, Schroeder S, Claussen CD. Multidetector-row CT for the noninvasive detection of high-grade coronary artery stenoses and occlusions: first results. Radiology 1999; 213 (P): 435.
21. Schmermund A, Rensing BJ, Sheedy PF, Bell MR, Rumberger JA. Intravenous electron-beam computed tomographic coronary angiography for segmental analysis of coronary artery stenoses. J Am Coll Cardiol 1998; 31: 1547–54.
22. Kopp AF, Schröder S, Küttner A, Heuschmid M, Georg C, Ohnesorge B, Kuzo R, Claussen CD. Retrospectively ECG-gated multislice computed tomography angiography of coronary arteries: Selective optimization of image reconstruction window. Radiology [In press].
23. Kopp AF, Schröder S, Küttner A, Ohnesorge B, Heuschmid M, Georg C, Claussen CD. Multidetector-row CT for noninvasive coronary angiography: Results in 102 patients. Radiology 2000; 217 (P): 375.
24. Nieman K, Oudkerk M, Rensing BJ, van Ooijen P, Munne A, van Geuns RJ, de Feyter PJ. Coronary angiography with multi-slice computed tomography. Lancet 2001: 357: 599–603.
25. Achenbach S, Giesler T, Ropers D, Ulzheimer S, Derlien H, Schulte C, Wenkel E, Moshage W, Bautz W, Daniel WG, Kalender WA, Baum U. Detection of coronary artery stenoses by contrast-enhanced, retrospectively electrocardiographically-gated, multislice spiral computed tomography. Circulation 2001; 103: 2535–8.
26. Schröder S, Kopp AF, Baumbach A, Kuettner A, Georg C, Ohnesorge B, Herdeg C, Claussen CD, Karsch KR. Non-invasive characterisation of coronary lesion morphology by multi- slice computed tomography: a promising new technology for risk stratification of patients with coronary artery disease. Heart 2001; 85: 576–8.
27. Kopp AF, Schröder S, Baumbach A, Küttner A, Georg C, Ohnesorge B, Heuschmid M, Kuzo R, Claussen CD. Non-invasive characterisation of coronary lesion morphology and composition by multislice computed tomography: First results in comparison with intracoronary ultrasound. European Radiol [In press].
28. Zamorano J, Erbel R, Ge J. Vessel wall changes in the proximal non-treated segment after PTCA. An in vivo intracoronary ultrasound study. Eur Heart J 1994; 15: 1505–11.
29. Schröder S, Kopp AF, Baumbach A, Küttner A, Georg C, Ohnesorge B, Herdeg C, Claussen CD, Karsch KR. Non-invasive detection and evaluation of atherosclerotic plaques with multi-slice computed tomography. JACC 2001; 37: 1430–5.
30. Schröder S, Kopp AF, Ohnesorge B, Flohr T, Baumbach A, Kuettner A, Herdeg C, Karsch KR, Claussen CD. Accuracy and reliability of quantitative measurements in coronary arteries by multi-slice computed tomography: experimental and initial clinical results. Clin Radiol 2001; 56: 466–74.
31. Schröder S, Kopp AF, Baumbach A, Kuettner A, Herdeg C, Rosenberger A, Selbmann HK, Claussen CD, Oberhoff M, Karsch KR. Noninvasive detection of coronary lesions by multislice computed tomography: Results of the new age pilot trial. Catheter Cardiovasc Interv 2001; 53: 352–8.
32. Ohnesorge B, Flohr T, Becker C, Kopp AF, Knez A, Reiser M. Dose evaluation and dose reduction strategies for ECG-gated multi-slice spiral CT of the heart. Radiology 2000; 217(P): 487.

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