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New Perspectives of Non-Invasive Imaging with Cardiac CT

R. Haberl, P. Steinbigler

In the past few years, fast computed tomography evolved as a new diagnostic tool for cardiac diseases including calcium screening and non-invasive coronary angiography. Electron beam computed tomography (EBCT) was for over a decade the only modality to visualize structures of the heart without significant movement artifacts, however, modern spiral CT is a promising alternative: multislice CT allows data to be acquired simultaneously from 4 slices with a fast rotational time. The scanner operates in a spiral mode with the option of retrospective ECG gating. Calcium screening is performed in a single breath-hold without the application of contrast medium. CT angiography requires the administration of contrast medium via an antecubital vein. Protocols for the administration of new high-density contrast media are under investigation. This review article gives the current status of technology, indication and interpretation of results. *J Clin Basic Cardiol* 2001; 4: 241–3.

Key words: multislice computed tomography, calcium screening, CT angiography, coronary stenosis

Cardiovascular disease is the No. 1 killer in the Western world. Conventional testing in patients with suspected coronary artery disease includes bicycle stress test, stress echocardiography and stress scintigraphy as well as invasive cardiac catheterization. Significant cardiac stenosis ($\geq 75\%$) in general causes typical angina pectoris (aggravating with physical activity and responding well to sublingual nitroglycerine) and abnormal stress tests. However, only one third of myocardial infarctions directly arise from significant coronary stenosis. Much more frequently, rupture of a vulnerable plaque with subsequent thrombus formation is the reason for occlusion of a coronary artery [1–3]. Rupture of a non-obstructive plaque can hardly be anticipated, because the patient is asymptomatic – although at risk – and conventional cardiological tests are non diagnostic.

The medical need for non-invasive techniques for the diagnosis of coronary artery disease has recently been stressed by a study in 1,764 symptomatic subjects referred for invasive coronary angiography, in which significant stenosis ($> 50\%$) was found in only 53% [4].

In the past few years fast-computed tomography (CT) evolved as a new diagnostic tool for cardiac diseases. Technical advances allow freezing the heart with only little movement artifacts and resolution is high enough to visualize coronary arteries. This article gives a review of the present technology with cardiac CT.

Technical Equipment

Electron beam computed tomography (EBCT) was for a long time the only modality that allowed visualization of the heart without significant motion artifacts [5–8]. The scan time of EBCT is 100 ms or less. It is considered the gold standard for calcium scoring. An electron beam is used to produce radiation. No rotating mechanical parts are involved. EBCT is a single slice scanner, which is prospectively triggered to the ECG. This means that subsequent axial slices are scanned gated to the diastolic part of the cardiac cycle. EBCT may be used for calcium screening as well as for non-invasive cardiac angiography with contrast enhancement and for evaluation of cardiac function.

More recently, multislice cardiac scanners have been developed (MSCT) which are able to acquire data simultaneously from four slices. They can be operated in the prospec-

tive axial mode as well as in helical mode (spiral CT). In the latter mode, the patient is continuously moved through the scanner and the ECG is recorded simultaneously. Retrospective gating can be performed during post processing at any given cardiac phase. The scan time of the multidetector systems is longer compared to EBCT (250 ms vs. 100 ms), however, image quality is superior due to a higher signal-to-noise ratio, higher spatial resolution and the option of retrospective gating. Radiation exposure is higher in the spiral mode compared to the prospective mode because the patient is continuously exposed to radiation, although only a fraction of the data is needed for reconstruction of the images. Dose modulation with attenuation of radiation during systole is going to be used to reduce radiation exposure in the near future.

Helical scanners can be used for calcium screening and non-invasive coronary angiography. They are whole body scanners (whereas EBCT is more or less a cardiac scanner). New generations of multidetector CTs are already in the pipeline (16 slice scanner) and will probably be released at the end of 2002.

Technique of Calcium Scoring

For detection of coronary calcium no contrast medium is needed (native scan). With MSCT, prospective triggering may be used with a segment centered in late diastole (60–80% of RR). Four slices with a width of 2.5 mm are recorded without overlap. In retrospective mode, slice thickness is four times 2.5 mm with a pitch of 0.375. Radiation exposure of calcium scoring with retrospective mode is in the range of 1.3 mS, with prospective mode about 0.7 mS. Images are acquired during one deep breath-hold (for about 30 s). The result of cardiac scoring is immediately available after the study.

There are different methods to determine quantitatively the amount of calcium in the coronary arteries. The standard parameter is the Agatston score, which is a non-linear score being affected stepwise by the density of coronary lesions [9]. The volumetric score is a continuous score with a close correlation to the Agatston score. Finally, the mass of coronary calcium can be measured in absolute terms, if the scanner has been standardized with a specially designed phantom.

Atrial fibrillation in general does not allow a stable retrospective and prospective trigger, so, these patients in general are excluded from calcium screening.

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Technique of Non-Invasive CT-Angiography

Multidetector cardiac CTs are well suited to visualize coronary arteries after contrast enhancement. The scanner should be operated in the helical mode with a reconstructed slice thickness of 1.2 mm and an overlap of 50 %. 120 ml of contrast medium is administered via the cubital vein (3–4 ml/s). The contrast medium should have a high iodine concentration, so that the lower volume delivered does not result in inadequate contrast enhancement. A test bolus should be given to determine cardiac cycle time. As an alternative, the Marconi MX 8000 automatically checks the increase of contrast density in the aorta and automatically starts the acquisition process. Radiation exposure with CT-angiography amounts to about 3–5 mS. However, a decrease of dose is strongly warranted.

Prior to CT-angiography the content of coronary calcium should be determined. In case of severe to extensive calcifications (volume score > 1000, calcium mass > 80 mg) it makes no sense to proceed to CT-angiography, because calcifications and movement artifacts make CT-angiography difficult to interpret. After determination of the cardiac cycle time, contrast medium is administered via the cubital vein and the scanner started in the high-resolution mode. After scanning,

retrospective gating is performed by automatic reconstruction of up to 10 phases of the ECG (Marconi MX 8000). Most experts use the 2-dimensional original data to scroll through the slices and make the diagnosis. For demonstration purposes, different reconstruction algorithms are available. Different reconstruction algorithms are available which have been designed to allow a better 3-dimensional reconstruction of coronary arteries. Surface shaded display (SSD) deletes all voxels below a pre-defined density threshold. Maximum intensity projection (MIP) uses the voxel with maximum intensity. Volume rendering and (curved) MPRs have been used to image coronary arteries. For best image quality, heart rate should be below 70 bpm. If the intrinsic heart rate is higher, an intravenous or peroral β -blocker is recommended (ie metoprolol 50 mg).

An example of the excellent images achieved by non-invasive CT-angiography injecting 120 ml of contrast agent with a high iodine concentration (400 g iodine per L) is provided in Figure 1 and 2.

Discussion

Future Perspectives of Calcium Screening

There is a huge amount of data that calcium in coronary arteries is a definite proof of atherosclerosis. Nevertheless, dispute will not end whether or not this is clinically relevant information for routine evaluation of a patient with suspected coronary artery disease. In principle, three categories of patients have to be separated:

- the patient with manifest coronary artery disease, typical angina and clear signs of ischaemia in conventional stress testing definitely is not a candidate for calcium scoring.
- In asymptomatic individuals we know that prognosis for future cardiac events is worse if calcium is present, depending on age and gender of the patient. Calcium progresses significantly over time unless the patient vigorously combats his risk factors and takes statins to reduce his lipid levels. However, there is no study available which shows that treatment in these patients – identified on the elevated basis of calcium-scores – improves prognosis for cardiac events. However, (although this is not a recommendation derived from evidence based medicine) the overall view of data induced us to advise asymptomatic individuals with a positive calcium score as follows: change lifestyle, exercise more, keep on diet, refrain from smoking and – if necessary – take statins to achieve a LDL-cholesterol level of below 100 mg/dl [10].
- In patients with atypical chest pain and inconclusive signs of myocardial ischaemia in stress testing there is a definite recommendation to perform calcium scoring: exclusion of coronary calcium defines a subset of patients with an extremely low risk of significant coronary stenosis. In these patients invasive procedures may be omitted (up to 30 % of patients) [5] (Table 1). Thereby, calcium scoring may be an effective filter before invasive diagnostics.

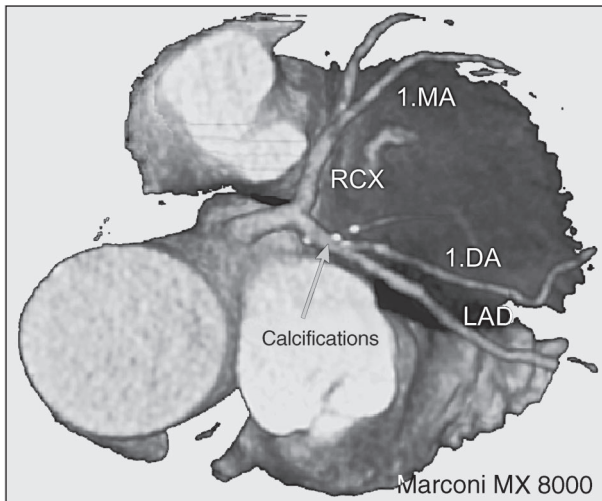


Figure 1. Non-invasive coronary angiography with multislice CT. The coronary tree can be assessed up to the level of side branches.

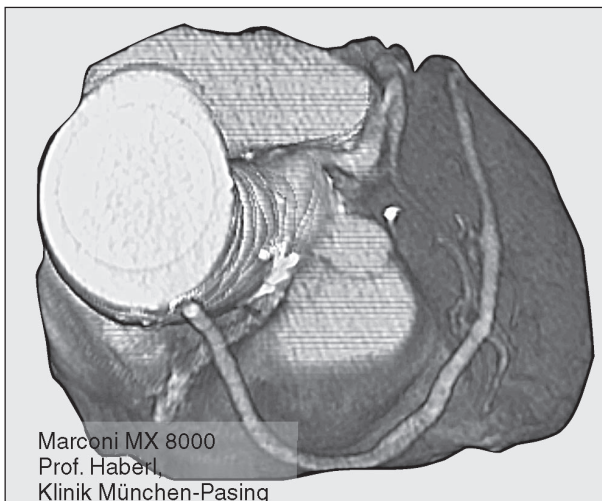


Figure 2. MDCT angiography of a coronary bypass. The jump graft is free of stenoses. It leads to the LAD and jumps to the circumflex artery.

Table 1. Calcium scoring with EBCT in symptomatic patients. 30 % of patients without stenoses did not exhibit coronary calcium. So, exclusion of coronary calcium may be used as an effective filter before invasive procedures [4]

	No calcium	EBCT	With calcium
No stenoses (n = 824)	n = 244 (30 %)		n = 580 (70 %)
Angio			
With stenoses			
> 50 % (n = 940)	n = 5 (0.5 %)		n = 935 (99.5 %)

For calcium screening we face the following challenges in the future:

1. Standardization of the protocols are strongly needed.
2. Calcium should be measured in absolute terms (mg/dl) comparable throughout the world of different scanners.
3. Reproducibility of calcium scoring is a major issue, especially if progression in follow-up studies is used as a parameter for treatment. Studies are needed to find out whether helical scans with retrospective gating are definitely more reproducible than axial slices with prospective triggering.
4. Prospective studies in asymptomatic individuals are needed and on the way (MESA, RECALL).

Future Perspectives of Non-Invasive Coronary Angiography

The technical improvements of temporal and spatial resolution allow visualizing of coronary arteries and other structures of the heart with a surprisingly good image quality. Helical scanners are superior to EBCT because of a better signal-to-noise ratio, higher resolution and the option of retrospective gating. At present, spiral CT is definitely superior to MRI to image coronary arteries.

Six recent clinical trials comparing non-invasive coronary angiography to the conventional invasive procedure in a total of 362 patients have shown that this technique has a sensitivity of 76–91 % and a specificity of 84–97 % in visualizing stenoses both in asymptomatic individuals and after surgery (CABG, PTCA, stenting) (Table 2). Consequently, in clinical practice this technique may already be used today to exclude coronary stenosis in coronary arteries and major side branches, to evaluate patency of coronary bypasses (including arterial bypasses) and stents. Newer results indicate that non-calcified plaques may also be visualized, but the clinical value of these findings is still unclear.

Further developments of this technique are warranted also for cost-containment, as its costs amount to less than half the expenditure for a conventional invasive angiography procedure.

Future Challenges and Perspectives

1. Technical improvements are necessary to shorten the scan time even more and increase spatial resolution. This will also allow study of patients with a heart rate higher than 70 bpm and the use of submillimeter slices. Also motion artifacts and radiation exposure should be reduced. Different technical approaches have been proposed; a 16 slice detector machine will be probably available at the end of 2002.

Table 2. Results of CT-angiography

First Author, Journal, Year	n	Sensitivity %	Specificity %	Non Evaluable [§]
Achenbach Circulation 2001	64	91	84	32
Knez Z Kardiol 2001 abs	48	82	97	8
Kopp Radiology 2001 abs	102	91	87	—
Nieman Lancet 2001	31	81	97	27
Schroeder Z Kardiol 2001 abs	90	83	95	21
Wichter RoFo 2001 abs	27	76	93	17

[§]Not evaluable because of motion artifacts or severe calcification

2. Protocols of contrast administration have to be improved: the application of contrast medium is a crucial part of the study that may contribute substantially to outcome. New high-density media are under investigation and different injection protocols (ie biphasic) have to be tested.
3. Randomized studies are strongly needed to assess plaque visualization and effect of treatment (eg statins) on these plaques.

Conclusions

Spiral CT is a promising non-invasive alternative with a very positive perspective for the future. Technical improvements, new protocols for contrast media administration and increased experience of the investigators will certainly allow cutting down the number of merely diagnostic invasive procedures, which amount to up to 50 % of all cardiac catheterizations right now. However, the technique is not only designed to replace catheterizations, but has the potential to give us additional important information not accessible with other techniques (Figure 3).

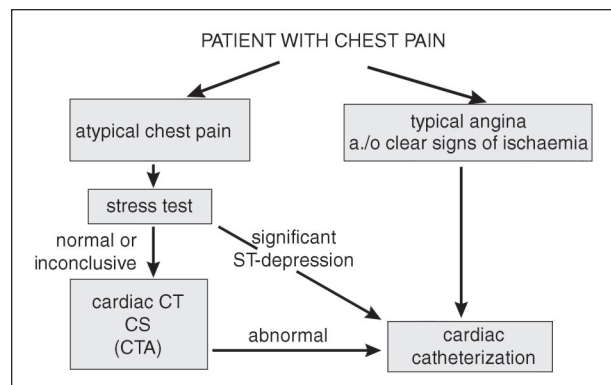


Figure 3. Diagnostic value of different imaging modalities

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