High-resolution 64-slice helical-computer-assisted-tomographical-angiography as a diagnostic tool before CABG surgery: the dawn of a new era?

Andre R. Simon a,*, Hassina Baraki a, Jörg Weidemann b, Wolfgang Harringer c,d, Michael Galanski b, Axel Haverich a

a Department of Cardiothoracic, Transplantation and Vascular Surgery, Hannover Medical School, Carl-Neuberg Str. 1, 30625 Hannover, Germany
b Department of Radiology, Hannover Medical School, Hannover, Germany
c,d Departments of Thoracic and Cardiovascular Surgery of the Participating Centers, Lower Saxony, Germany

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Abstract

Objective: For the first time, technical developments in helical, high-resolution 64-slice computer-assisted-tomographical-scanning (CT) allows for analysis of cardiac pathology including coronary morphology. Here, we present results of a multicenter study assessing the value of CT-angiography as a preoperative diagnostic tool in identifying target vessels for coronary artery bypass grafting (CABG) surgery. Methods: Thirty-two patients aged 64±9.0 years, 30 with confirmed coronary disease (angiography or scintigraphy) and 2 controls, underwent helical CT analysis. Scans were reviewed in a blinded fashion and potential target vessels for CABG were identified by seven individual reviewers. Results were compared with those from conventional coronary angiography and with the target vessels chosen at surgery. Results showed a high positive predictive value for targeting at surgery, which was comparable for both conventional angiography and CT scan (LAD 100% vs 97%, RCx 96% vs 93%, 67% vs 56%). In one patient, who presented with clinical signs of CAD and positive scintigraphy results, conventional angiography revealed no stenotic lesion and CT scan was used to confirm main stem disease. Conclusions: CT-angiography sufficiently allows for target vessel determination for CABG. In individual cases, visual assessment of the left main coronary artery and the proximal left anterior descending artery (LAD) via CT-angiography may be superior to conventional angiography. However, while there is no difference in positive predictive targeting value, sensitivity and specificity of conventional angiography is still superior. Also, improvements in the methodology of evaluation and presentation of CT-findings are necessary. Our data suggest that CT-angiography may be used as a clinical alternative to conventional angiography in preoperative assessment for cardiac surgery.

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1. Introduction

Coronary artery disease remains to be a major cause of morbidity and mortality in the western world and selective coronary angiography (SCA) is considered to be the current gold standard for the evaluation of the severity of the disease in coronary arteries. However, the procedure is not without complications, which include the formation of pseudo-aneurysms in 1.2%, cardiac arrhythmia in 1%, stroke in 0.3%, myocardial infarction in 0.2%, bleeding and renal failure secondary to embolic disease or contrast agent [1].

The recent development of ultrafast helical, high-resolution 64-slice CT-scanning (MSHRCT) protocols allows for routine analysis of cardiac pathology including coronary morphology after intravenous injection of contrast agent. However, since virtually all patients who have suspected coronary artery disease undergo SCA regardless of age or contraindications, most studies performed to date address the postoperative analyses of bypass grafts.

Based on the results obtained in initial studies using 4- and 16-slice helical CT and ECG-gated retrospective reconstruction, which yielded sensitivities between 83% and 90% and specificities between 59% and 75% for the detection of significant lesions in the native coronary arteries [2,3] and the results obtained in numerous studies in graft analysis [2,4—17], it seems highly probable that the improvement of temporal and spatial resolution using MSHRCT should allow for accurate analyses of the native coronary arteries. Also, while conventional coronary angiography yields excellent
data on the severity of stenoses, MSHRCT allows for assessment of calcification of the coronary arteries as well as the ascending aorta. These data give valuable additional information and may have significant impact on the actual surgical procedure.

Thus, MSHRCT may represent an alternative, even superior diagnostic tool when compared to SCA. Accordingly, we initiated a multicenter, proof of concept study in which the value of CT-angiography as a preoperative diagnostic tool in identifying target vessels for CABG surgery was assessed and compared to the results obtained via routine coronary angiography. Our hypotheses were as follows:

1. Helical, high-resolution 64-slice CT-scanning allows for accurate analysis of coronary morphology.
2. Based on MSCT data, target vessels for CABG surgery can be identified.
3. MSCT yields additional data, not obtained by SCA.
4. The risk/benefit ratio justifies the use of MSHRCT instead of CA

2. Material and methods

This was a pivotal, proof of concept study. Thus, patients were identified from a potential patient population, who were already scheduled for routine cardiac surgery. The primary indication for CT was a suspicion of severe aortic calcification in angiography and/or any other reason to obtain a chest CT prior to surgery. Out of this population, patients for MSHRCT were chosen based on the following parameters:

- Regular heart rate.
- Heart rate not in great excess of 60 bpm.
- No known allergy.
- No contraindication for beta-blocking agents.
- No renal insufficiency.

Based on these parameters, 32 patients (24 men, 8 women, aged 64 ± 9.0 years), 30 with confirmed coronary disease (angiography or scintigraphy) and 2 control patients were identified and underwent MSHRCT scanning and analysis.

Departments involved: Department of Thoracic and Cardiovascular Surgery, Klinikum Braunschweig, Department of Cardio-thoracic Surgery, Herz-Kreislauf-Klinik Bevensen, Department of Cardiac Surgery, Klinikum Oldenburg, Department of Thoracic and Cardiovascular Surgery, University of Goettingen., Department of Cardiac Surgery, Schuechtermann-Klinik, Bad Rothenfelde, Department of Thoracic and Cardiovascular Surgery, Hannover Medical School, Department of Radiology, Hannover Medical School, Hannover, Germany

2.1. Helical, high-resolution 64-slice CT-scanning

Scans were performed in a Lightspeed VCT 64-slice scanner (GE) using an electrocardiographically gated scan algorithm with the following protocol: 120 kV, 650 mAs tube current, 0.35 s rotation time, simultaneous acquisition of 64 slices, 0.6 mm slice/rotation, 13 cm/s.

One hour prior to scanning, all patients received a control ECG to analyze rate and rhythm. If the patients’ heart rate exceeded 60 bpm, heart rate control was achieved by beta blockade using metoprolol p.o. Directly prior to scanning, additional i.v. metoprolol was administered to achieve a heart rate of less than 60 bpm, if necessary. At scanning time, patients received 80 ml contrast agent (Imeron 400) at 5 ml/s, followed by 20/20 ml contrast/saline and finally 30 ml saline i.v. The total duration of the scan and data processing ranged between 30 and 60 min.

2.2. Image reconstruction

ECG-correlated image reconstruction was performed on a GE workstation with the use of a scan reconstruction algorithm that provided a high temporal resolution in the center of the scan field. Reconstruction of overlapping axial cross-sectional images was performed with an increment of 0.5 mm starting at 70% of the R–R interval. When necessary, additional reconstructions were performed to avoid motion artifacts, deviating from the original R–R interval.

2.3. Selective coronary angiography

Arterial catheterization and selective conventional angiography of the coronary arteries were used as the standard of reference against which MSHRCT was compared. For the purpose of the study, the routine SCA performed prior to inclusion in the study was used.

2.4. Analysis

The obtained scans were reviewed in a blinded fashion and potential target vessels for CABG were identified by seven individual reviewers (six cardiac surgeons and one radiologist) based on the following protocol:

1. Location of the lesion.
2. Categorization of stenoses based on a classification of four grades: 0 = no stenosis, 1 = non significant, 2 = significant stenosis and 3 = occlusion.
3. Identification of potential target vessels for anastomoses.

The location of the lesion in the coronary tree was based on the 16-segment model of the American Heart Association. A stenosis of more than 70% was categorized as significant. Total occlusion was defined as the complete interruption of antegrade blood flow on invasive angiography and complete absence of contrast within the lumen at the site of the stenosis or total interruption of the vessel on MSHRCT. On SCA, severe calcium was identified as radiopacities seen without injection of contrast agent. On MSHRCT, calcifications within the vasculature which obscured the underlying lumen were defined as severe calcification.

The reviewers were given the dataset of the MSHRCT reconstruction, but were unaware of the invasive angiographic data at the time of review. The analysis of lesion severity and complexity on the computed tomographic angiograms was performed individually from the axial, multiplanar and three-dimensional reformatted images.
The results of the analyses were compared with those from:

- the conventional coronary angiography and
- the target vessels chosen at surgery.

Even though, the above analyses were performed in a blinded fashion, they do, as does the interpretation of a routine SCA, represent subjective interpretations of the processed CT data. Thus, in order to determine the reproducibility and inter-individual differences of the results the standard deviations of the resulting data were calculated for each identified lesion.

A standard deviation of $>0.5$, which results if one reviewer’s result deviates by more than 2 or two reviewers deviate by more than 1, was considered to be beneath the level of reproducibility for the basis of a clinical decision.

Data analysis was performed with the software SPSS 11.0 (SPSS Inc, Chicago, Ill).

3. Results

3.1. Analysis of coronary morphology via MSCRCT

Coronary morphology was analyzed after processing of the data set obtained for the patient. Fig. 1 depicts a three-dimensional reconstruction of the heart and ascending aorta. Next, a three-dimensional, rotatable reconstruction of the aortic root and coronary tree was obtained (Fig. 2) by a subtraction algorithm. In addition, a two-dimensional view of the coronary was calculated using a reconstructive algorithm, in order to allow further assessment of the severity of identified lesions (Fig. 3).

3.2. Identification of target vessels for CABG surgery based on MSHRCT data

Based on the prepared datasets, individual reviewers identified potential target vessels using CT data and the SAC.

Table 1

<table>
<thead>
<tr>
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<th>CT-angiography</th>
<th>Conventional angiography</th>
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<tr>
<td>LAD territory</td>
<td>Sensitivity (%)</td>
<td>Specificity (%)</td>
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<tr>
<td>CT-angiography</td>
<td>85</td>
<td>63</td>
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<tr>
<td>Conventional</td>
<td>93</td>
<td>100</td>
</tr>
<tr>
<td>Cx territory</td>
<td>Sensitivity (%)</td>
<td>Specificity (%)</td>
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<tr>
<td>CT-angiography</td>
<td>84</td>
<td>56</td>
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<tr>
<td>Conventional</td>
<td>100</td>
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<tr>
<td>RCA territory</td>
<td>Sensitivity (%)</td>
<td>Specificity (%)</td>
</tr>
<tr>
<td>CT-angiography</td>
<td>80</td>
<td>49</td>
</tr>
<tr>
<td>Conventional</td>
<td>100</td>
<td>59</td>
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A bypass graft was indicated on LAD territory in 24 by CT-angiography and in 27 by conventional angiography and performed in 29 patients during surgery. In the CX territory 23 lesions for grafting were identified by CT-angiography versus 28 by conventional angiography. Grafts were placed in 27 patients during surgery. In the RCA territory 11 sites were indicated via CT-angiography and 14 by conventional angiography with 14 patients being grafted at surgery (Table 1).

Based on these data, resulting agreement of the MSHRCT and SCA was calculated. The results are given in Table 2. Fig. 4 illustrates the dataset obtained form MSHRCT and SAC in parallel.

3.3. Data obtained using MSHRCT not obtained by SCA

In addition to identification of potential sites for anastomoses, the MSHRCT yielded data pertaining to calcification of the vasculature. Severe calcification was noted in 12 patients in MSHRCT versus 3 patients in SCA (Fig. 4). Noted calcifications were compared to findings during surgery. Fig. 5 illustrates the LAD of a patient as an exemplary case.

In addition MSHRCT allowed the detection of an ostial stenosis, not visible during routine SCA (Fig. 5).

In cases in which occluded coronary arteries were present, MSHRCT allowed for superior visualization of the territory distal to the occlusion (Fig. 6), when compared to SCA.

4. Discussion

The success of MSHRCT in imaging coronary arteries is the result of its ability to overcome problems associated with cardiac motion and the increase in spatial and temporal resolution. With the heart in constant motion, HRMSCT uses electrocardiogram gating to capture data at points during the cardiac cycle when cardiac motion is minimized. In addition, tube modulation algorithms are available for reduction of the dose of radiation. This emergence of high-resolution, high-speed multi-slice computed tomography as an investigational tool for coronary artery disease has prompted numerous studies on its accuracy in patients with ischemic symptoms before and after coronary artery bypass grafting and the development of 64-slice CTscanners with their accompanying software have led to HRMSCT becoming an alternative to SCA in diagnosis of graft occlusion and stenosis after coronary artery bypass grafting. Furthermore, HRMSCT has been

| Table 2 comparison of results obtained CT-angiography and conventional angiography |
|---------------------------------|-------------------------------|-----------------|-----------------|-----------------|-----------------|
|                                 | Sensitivity (%)                | Specificity (%)  | Positive predictive value (%) | Negative predictive value (%) | Measure of agreement (Kappa) |
| **LAD territory**               |                               |                 |                               |                               |                              |
| HRMSCT versus SCA              | 87                            | 67              | 96                            | 35                            | 0.378                        |
| **Cx territory**               |                               |                 |                               |                               |                              |
| HRMSCT versus SCA              | 84                            | 56              | 93                            | 35                            | 0.32                         |
| **RCA territory**              |                               |                 |                               |                               |                              |
| HRMSCT versus SCA              | 76                            | 57              | 76                            | 57                            | 0.331                        |

Fig. 4. The heart of a patient is shown during surgery. There are calcifications visible in the LAD territory. The corresponding HRMSCT image is on the right side. The SCA is negative (not shown).

Fig. 5. The figure depicts SCA (left) and HRMSCT (right) images of a patient with severe ostial left main stem disease. The lesion was only visible on the HRMSCT (arrow), while no lesion was detectable in the SCA.

Fig. 6. SCA (left) and HRMSCT (right) images of a patient with occlusion of the right coronary artery are shown. While the occlusion (arrow) is clearly visible on both images, the HRMSCT depicts the right coronary artery distal to the occlusion and thus yields important data, not available in the SCA.
shown to accurately exclude the presence of coronary stenoses in selected patient populations. While the possible applications of this technique are constantly evolving, SCA still remains to be the gold standard in clinical every day routine and it remains unclear whether HRMSCT has the potential to replace SCA as a tool to assess a patient’s need and suitability for revascularization. Accordingly, there is only limited literature available on its use to assess patients for CABG surgery.

Based on the above, we analyzed, whether HRMSCT could be used as a true alternative tool, replacing SCA in the assessment of patients and potential target vessels prior to coronary artery bypass grafting based on four particular questions:

(1) Does helical, high-resolution 64-slice CT-scanning allow for accurate analysis of coronary morphology?
(2) Can target vessels for CABG surgery be identified based on MSCT data?
(3) Does MSCT yield additional data, not obtained by coronary angiography?
(4) Does the risk/benefit ratio justify the use of MSCT instead of CA?

The reconstructed datasets in our study allowed for easy analyses of the coronary morphology, on which the identification and classification of stenoses was based. Our analysis demonstrates that the results obtained by HRMSCT are comparable with those obtained by routine SCA for coronary artery graft stenosis and occlusion. While sensitivity and specificity of conventional angiography is still superior to results obtained by HRMSCT, the most important result is represented by the positive predictive value, since this represents the accuracy of the surgeon’s decision during grafting and there is no significant difference between SCA and HRMSCT in positive predictive targeting value. One drawback of the study may be that we have only identified the target vessel and not the site of the actual anastomosis. However, we believe this to be of minor relevance because first, the anastomosis is always placed distally to the significant stenosis, thus the site is pre-programmed; and secondly, the final decision as to exactly where to place the graft is made intraoperatively, based upon visual and tactile inspection.

In this context, it is important to mention that in addition to the data on which the surgeon bases his decision to target a particular coronary artery for bypass grafting, we have demonstrated that HRMSCT yields additional data, which may influence the planning and course of the actual surgery. For instance, the calcifications visible on HRMSCT may influence the choice to use arterial or venous grafts, as well as the decision to schedule a more junior or senior surgeon for the operation. Furthermore, HRMSCT has shown to give superior data in selected cases with severe ostial stenoses, where conventional SCA showed no stenotic lesion. This superiority may also be evident in severe disease of the left main stem, where selective intubation of the coronary sometimes results in imminent ischemia and or arrhythmia, prohibiting SCA, or the lesion is almost impossible to detect on SCA, while being clearly visible on HRMSCT (Fig. 5). Furthermore, HRMSCT yields data concerning the ascending aorta, which cannot be obtained by SCA.

Since best image quality is obtained in patients with heart rates of less than 65 beats per minute, beta blockade was administered prior to HRMSCT if the heart rate exceeded this. Beta blockade, of course is not without risk, especially in patients with chronic obstructive pulmonary disease (COPD) [9], a fact that may lead to a restriction of the technique to patients without COPD. Another patient group, which is currently not yet ideally suited for HRMSCT angiography is represented by patients in atrial fibrillation with an irregular heart rate, which poses difficulties for the gating and tube current algorithms. In these patients, results obtained by SCA are currently clearly superior to those by HRMSCT.

Another disadvantage of HRMSCT is the higher radiation dose compared to SCA with a maximum effective dose in women between 6.8 and 14 mSv versus a maximum of 6 mSv during SCA. These exposures yield lifetime risk of 0.07% (HRMSCT) versus 0.02% (SCA) of inducing a fatal cancer in the general (i.e., age- and gender-averaged) population [18]. While SCA has a lower mean radiation dose, both procedures are located within the intermediate level of risk group necessitating only moderate societal benefit to be justified for use.

However, SCA has an additional, non-radiogenic risk of mortality (excluding contrast reactions) of 0.11% which results in a cumulative overall risk of mortality of SCA of 0.13%. This is almost two-fold higher than that for HRMSCT angiography (0.07%) and demonstrates that CT angiography is a non-invasive, low morbidity investigational technique which can be used as the basis for indications and surgical decisions as to the target vessels for bypass grafting during surgery.

In conclusion, we were able to demonstrate that HRMSCT allows for accurate analysis of coronary morphology and that target vessels for CABG surgery can be identified with high accuracy and reproducibility. Also, we could demonstrate that HRMSCT yields additional data, not obtained by coronary angiography. Based on the risk/benefit ratio, which justifies the use of HRMSCT instead of SCA, we conclude that CT angiography can replace SCA in clinical routine. Based on our results, we have initiated a randomized trial, comparing CT angiography to SCA.

References

Dr P. Kohl (Liege, Belgium): Could you tell us which subgroup of patients, in your opinion, do not require angiography anymore, but in whom you would go ahead and operate according to the 64-slice CT?

Dr Simon: Well, at this point a prerequisite is that you have a patient who is not in atrial fibrillation or has a heartbeat, a regular heartbeat, which is, at maximum, 60 beats per minute.

Dr Kohl: But you can decrease it with beta blocking agents.

Dr Simon: Yes, but in patients in whom you cannot reduce the frequency down to around 50 beats per minute with the technique now available, it is of no use, really; the quality is not high enough. But if you have an elderly patient with, let’s say, peripheral artery disease, a regular heart rate, and no renal disease, that is a good patient to take into your CT scanner and put him through there, because you will get additional information, for instance about the aorta, calcification and all that.

Now maybe with the new electron beam scanners that will come around shortly, the atrial fibrillation or the rate, will not be an issue anymore.

Mr P. Smith (London, United Kingdom): I stand to be corrected, but I believe the technology has moved on considerably since the technology of your machine. I think you referred to a dual-source 64-slice CT in your last two slides?

Dr Simon: Yes.

Mr Smith: Could you perhaps comment on the advantages of dual-source that you saw, particularly as regards not needing beta blockers and the radiation load and the accuracy of the specificity and sensitivity?

Dr Simon: There are new software algorithms available and there are new hardware techniques available which considerably shorten the scan time, however, these are all bought again, to my knowledge, with an increase in radiation dose, and this is a concern people have right now. My personal feeling is that if you are 80 years old, you shouldn’t be concerned about the radiation dose and that this is really not an issue, however, in Germany it is a big issue. So while there was definitely advancement, we don’t have another scanner. We have the 64-slice scanner. We are hoping to get an electron beam scanner, which will be a totally different ball game. But given the better hardware that is available, the quality can be improved further, you are absolutely right, and it justifies using this technique in more cases.

Dr P. Bertolini (Verona, Italy): A very practical question and it is, we have a lot of patients, and it is a group that is increasing the last time, having had a previous percutaneous angioplasty with positioning of metal stents. Do you consider it as a possibility to go farther with a CT scan?

Dr Simon: I took the slide out, but we have one patient who has a very nicely placed stent in the LAD, and with the technique available, the quality of the CT allows for using that in such cases. You don’t have this well known effect of metal, no; you don’t have that anymore. Actually, you see the stent in the CT.

Dr Bertolini: It doesn’t affect the quality?

Dr Simon: Exactly.

Dr R. Di Bartolomeo (Bologna, Italy): Do you think about the patient with surgical clips, pacemaker or defibrillator?

Dr Simon: There is a surgical clip right here (indicating). The surgical clips are no problem. We also use a CT scanner to do post-CABG controls of all arterial T-grafts we do in a study, and I have never seen a clip causing a problem.

Dr Di Bartolomeo: I use systematically this technique to study the coronaries in the patient that requires an operation for an aortic aneurysm, a redo operation, because sometimes the normal angiography is difficult. Do you have experience in this?

Dr Simon: Yes. We use a lot of CT scanning, and in many cases we do get, and I absolutely agree, additional results which may come in very handy. Every patient undergoing redo sternotomy, for example, also has a CT scan. But these are, of course, cardiac scans. They do not give you the field of view that you would get with a normal chest CT scan. This is a very reduced field of view. And actually you will not be able to look at the aortic arch with this technique because the field of view is too small. Now, with an electron beam scanner and fast advancement you may be able to do that, but this is something that we cannot do yet.