The comparison of the graft patency after coronary artery bypass grafting using coronary angiography and multi-slice computed tomography

Kyung-Jong Yooa,*, Donghoon Choib, Byoung Woock Choi, Sang-Hyun Lima, Byung-Chul Chang

a Department of Thoracic and Cardiovascular Surgery, Yonsei Cardiovascular Hospital, Yonsei University College of Medicine, Seoul, South Korea
b Department of Cardiology, Yonsei Cardiovascular Hospital, Yonsei University College of Medicine, Seoul, South Korea

Received 12 September 2002; received in revised form 21 February 2003; accepted 17 March 2003

Abstract

Objective: Coronary angiography (CAG) is the gold standard method in evaluating graft patency following coronary artery bypass grafting (CABG), even though there are several kinds of non-invasive methods. Recently developed multi-slice CT (m-CT), having effective scan times up to 0.25 s and multi-row detector array systems, enable rapid imaging of cardiac structures, including coronary arteries during one breath-hold. We compared m-CT with CAG for the evaluation of graft patency following CABG.

Methods: Forty-two patients having undergone m-CT and CAG within 3 months of CABG were studied. Twenty-three patients underwent conventional CABG and 19 off-pump CABG. A total of 125 grafts were used, including 42 left internal mammary arteries (LIMA), 25 radial arteries (RA), 3 right internal mammary arteries (RIMA) and 55 vein grafts.

Results: CAG showed a 96% (120/125) patency rate (1 LIMA, 2 RA and 2 vein grafts were occluded). m-CT showed a 98% (122/125) correct positive ratio with a sensitivity and specificity of 98 and 100%, respectively. The sensitivity in LIMA, RA, RIMA and vein grafts was 98, 91, 100 and 100%, respectively, with 100% specificity for all. There was an equivocal result in the competitive grafts with native coronary artery that were patent in the CAG, but faint opacification with no significant flow in the m-CT.

Conclusions: This study showed that m-CT was very simple, useful and accurate in evaluating graft patency during the early post-operative period following CABG, even though there was an equivocal result in the competitive grafts with a native coronary artery.

© 2003 Elsevier Science B.V. All rights reserved.

Keywords: Coronary artery bypass grafting; Coronary angiography; Multi-slice CT

1. Introduction

Coronary artery angiography (CAG) is the gold standard method in evaluating graft patency following coronary artery bypass grafting (CABG). However, it is a stressful invasive procedure for the patients, and increases hospital cost. CAG especially, has risks of morbidities, such as acute myocardial infarction, stroke and ventricular arrhythmias [1]. Since 1986, several kinds of non-invasive methods, like electron-beam tomography [2–11] and helical scan computed tomography [12], have been attempted for evaluating graft patency, but they have shown limited results due to artifacts caused by the necessity of holding a long breath, and the limited value concerning the evaluation of mammary artery grafts using a high number of metallic clips. Other minimally invasive approaches, including transcutaneous Doppler echocardiography [13,14], digital subtraction angiography [15], nuclear magnetic resonance imaging [16,17] and conventional computed tomography [18,19], to visualize or detect flow in bypass grafts have also been studied. However, none of these approaches has resulted in an accurate diagnostic procedure that is widely accepted. The recently developed multi-slice CT (m-CT), having effective scan times up to 0.25 s and multi-row detector array systems, enable rapid imaging of cardiac structures, including coronary arteries, covering the ascending aorta and whole heart during the short period of time of one breath-hold.
In our present study, we compared the effect of m-CT with CAG to determine graft patency, including small sized grafts, such as mammary and radial artery (RA) following CABG.

2. Materials and methods

2.1. Data collection

Forty-two patients (32 men and 10 women) were investigated by m-CT within 3 months of CAG following bypass grafts. The patients’ ages ranged from 44 to 74 years, with a mean age of 61 years. Twenty-three patients underwent conventional CABG with 70 bypass grafts and 19 underwent off-pump CABG (OPCAB) with 55 bypass grafts. Forty-two patients had a total of the 125 coronary artery bypass grafts, including 42 left internal mammary artery (LIMA), 25 RA, 3 right internal mammary artery (RIMA) and 55 vein grafts. There were ten sequential artery (LIMA), and 55 vein grafts. There were ten sequential bypasses. All radial arteries were used as a Y or T grafts with LIMA. The grafts were anastomosed to the left anterior descending artery (n = 42), the diagonal branch (n = 14), the left circumflex branch (n = 33) and the right coronary branch (n = 36).

2.2. Coronary artery angiogram

CAG was performed with Jukins catheters via the femoral or radial artery using a digital angiographic system (Hicor, Simens, Erlangen, Germany). The grafts were selectively catheterized, with the exception of some of the LIMA, where left subclavian arteriography was performed in place of a LIMA angiography. The angiograms were assessed by two cardiologists with no knowledge of the m-CT findings. Coronary artery segments were classified as significantly stenosed if the luminal diameter reduction was more than 50%. In case of a failed cannulation of the proximal site of the vein graft to the ascending aorta, an aortogram was performed to confirm the occlusion of the graft.

2.3. Multi-slice computed tomography

m-CT was performed in a multi-detector row CT scanner (LightSpeed plus, GE medical systems, Milwaukee, WI) with a collimation of 1.25 mm, a rotation time of 0.5 s, at 120 kV and 300 mA. The circulation time was measured with a 15 ml bolus injection of the non-ionic contrast agent, iopamidol (Iopamiro 370 mg/ml, Bracco s.p.a., Milano, Italy), prior to the main scan. The total contrast dose for the main scan ranged from 120 to 150 ml depending on the total scan time, with an injection rate of 4 ml/s for the first half of the scan, plus a delayed period following the injection, and then 2 ml/s for the second half, through an 18-gauge needle into the antecubital vein. Each scan covered the whole heart from just above main pulmonary artery. The raw data were reconstructed routinely at 40 and 70% of the cardiac phase using retrospectively ECG-gated reconstruction at 25 cm of the displayed field of view. The reconstructed images were transferred to a workstation (Advanced workstation 4.0, GE medical systems, Milwaukee, WI) for post-processing. Axial, 3D volume-rendered, and multi-planar reconstructed images were analyzed for evaluation of the number, location and patency of bypass grafts. An occlusion of a graft was diagnosed if the graft was not visualized, or was shown as a stump-like structure along its course.

For evaluating stenosis of native coronary artery or patency of CABG, the protocol of CT angiography using m-CT should be different because of some limitations. Bypass grafts, because of their size and relative immobility, can be reliably imaged with less limitation of heart rate and without necessity of multiple selection of reconstruction windows or premedication to lower the heart rate like in native coronary artery. m-CT for evaluating native coronary artery requires strict selection of patients to constantly acquire assessable quality of images. The most important thing to consider is to maintain the heart rate at less than 70 bpm. As the heart rate increases, the number of arteries that could be evaluated decreases, and overall sensitivity for stenosis was reported as 62% when heart rate was less than 70 bpm compared with a sensitivity of 33% when heart rate was greater than 70 bpm [20]. We included patients who presented with heart rate greater than 70 bpm and we did not use premedication to lower heart rate, because the study was aimed to evaluate the patency of CABG. Therefore, evaluation of native coronary artery stenosis is not constantly possible with the protocol used in the study.

The patients in this study were randomly selected from those complying with our study. All patients gave their written informed consent after the methods and extra-cost of the m-CT investigation had been fully explained.

2.4. Data analysis

The sensitivity and specificity of m-CT for the assessment of bypass graft patency were calculated using the following definitions, and expressed as a percentage: sensitivity = [true positive/(true positive + false negative)] × 100, specificity = [true negative/(true negative + false positive)] × 100, correct positive ratio (predictive accuracy) = ([true positive + true negative]/total group).

3. Results

The CAG and m-CT investigation were completed in all patients without complications. The mean scanning times for the m-CT was 24 ± 3.5 s.

The CAG showed a 96% (120/125 grafts) patency rate (1 LIMA, 2 RA, 2 vein grafts were occluded), and the m-CT
showed a 98% (122/125 grafts) correct positive ratio, which matched the correct results from the CAG (Figs. 1–4). The sensitivity and specificity of m-CT for all grafts were 98 and 100%, respectively (Table 1).

With regard to the LIMA, 41 of the 42 grafts (98%) were patent in the CAG. Two were competitive, with native left anterior descending artery without stenosis, which were evaluated as a patent grafts on the CAG. m-CT revealed that 40 of the 42 grafts were patent. One of the two occluded grafts on the m-CT, which showed a severe competitive flow with the native coronary artery on the CAG, was shown as a very thin string with multiple metal clips. This was evaluated as an occluded graft. However, another case showing a faint opacification on the m-CT was evaluated as a patent graft. The sensitivity and specificity of m-CT for LIMA grafts were 98 and 100%, respectively.

With regard to the RA grafts, 23 of the 25 grafts were patent by CAG. However, 21 of the 25 grafts were evaluated as patent grafts by m-CT. The sensitivity and specificity of m-CT for RA grafts were 91 and 100%, respectively. All three of the RIMA grafts were found patent by CAG, and were also evaluated as patent grafts by m-CT. Fifty-three of the 55 vein grafts were found patent by CAG and m-CT, it was a perfectly matched result with CAG. The sensitivity and specificity of m-CT for RIMA and vein grafts were both 100 and 100%, respectively. All sequential grafts were
Conventional CABG showed a 96% (67/70 grafts) patency rate (1 RA and 2 vein grafts were occluded). The m-CT showed a 97% (68/70 grafts) correct positive ratio, which matched the correct results with CAG. The sensitivity and specificity of conventional CABG were 97 and 100%, respectively. The OPCAB showed a 96% (53/55 grafts) patency by CAG, and were evaluated as patent grafts by m-CT.

Fig. 2. Fifty-three-year-old woman with bypass graft to left anterior descending artery (LAD) with left internal mammary artery (LIMA), obtuse marginal branch with radial artery, right coronary artery (RCA) with saphenous vein graft (SVG). RA was used as a Y graft with LIMA. Whitish vertical lines (arrow) were atrial and ventricular pacing wire. A. Multi-slice CT (m-CT) study showed patent LIMA and SVG. B. Coronary artery angiogram (CAG) showed patent SVG, and matched images compared with m-CT.

Fig. 3. Fifty-seven-year-old man with bypass graft to left anterior descending artery (LAD) with left internal mammary artery (LIMA), diagonal branch (Dx) with saphenous vein graft (SVG). Multi-slice CT (m-CT) study showed occluded LIMA and patent SVG. LIMA was not opacified and metal clips identified its course.

Fig. 4. Forty-four-year-old man with bypass graft to left anterior descending artery (LAD) with left internal mammary artery (LIMA), obtuse marginal branch (OM) with saphenous vein graft (SVG), right coronary artery (RCA) with SVG. Omega shape metal marked proximal site of saphenous vein graft for follow-up angiogram. Multi-slice CT (m-CT) study showed patent LIMA and SVG to OM. However, SVG to RCA was not opacified and metal clips identified its course.
Table 1
One hundred and twenty-five grafts in 42 patients shown as patent or occluded on m-CT and coronary angiography, and diagnostic accuracy according to grafts

<table>
<thead>
<tr>
<th></th>
<th>CAG</th>
<th>M-CT</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All grafts</td>
<td>120</td>
<td>118</td>
<td>98</td>
<td>100</td>
</tr>
<tr>
<td>LIMA (n = 42)</td>
<td>41</td>
<td>40</td>
<td>98</td>
<td>100</td>
</tr>
<tr>
<td>RA (n = 25)</td>
<td>23</td>
<td>21</td>
<td>91</td>
<td>100</td>
</tr>
<tr>
<td>RIMA (n = 3)</td>
<td>3</td>
<td>3</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Vein (n = 55)</td>
<td>53</td>
<td>53</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

CAG, coronary artery angiogram; m-CT, multi-slice computed tomography; LIMA, left internal mammary artery; RA, radial artery; RIMA, right internal mammary artery.

4. Discussion

Several kinds of non-invasive methods have been attempted to replace coronary artery angiography for the evaluation of graft patency following CABG [2–19], and from the results achieved so far, they proved that several non-invasive techniques such as an electron-beam tomography [2–11] and helical scan computed tomography [12] could evaluate graft patency. However, these techniques have shown limited usefulness and benefits, when compared to CAG. Although CAG gives the most accurate information on the status of grafts, it is invasive, costly, and carries potential procedure-related risks [1]. It also requires hospitalization, and is emotionally and physically stressful to patients, and therefore not suitable as a tool for outpatients or long-term follow-up. Electron-beam tomography and helical scan computed tomography have little risks by themselves compared to CAG, but they have many drawbacks. Arterial grafts, such as LIMA are usually smaller and have more metal clips along their course than vein grafts, which make artifacts, and therefore the accuracy for arterial grafts is not as good as for venous grafts when evaluation is possible. Other important drawbacks are breathing artifact and incorrect positioning of the image volume, due to both non-invasive methods requiring long time breath-holds, which reduce the image quality [2–12].

In contrast to other non-invasive methods, m-CT has good image quality due to the short scanning time and thin (1.25 mm) slice thickness, even though it covers the entire ascending aorta. It is faster, and has a lesser thickness than any other non-invasive methods. Therefore m-CT could reduce artifacts and improve the image quality. We also used no drugs to control heart rate or pre-oxygenation for an increased breath-hold. However, all studies were finished in one breath-hold with no difficulties. With regard to the arterial grafts, including composite grafts, m-CT showed the proximal course of the arterial grafts without any artifacts, even though it had many metallic clips and small sized lumen. It showed perfectly matched images compared with CAG for both course and view. For vein grafts, including sequential grafts, m-CT was able to visualize the entire course of vein grafts and distal native coronary artery irrespective of the site even with the small sized native coronary artery lumen.

In this study, we analyzed several kinds of grafts, sequential anastomoses, composite arterial grafts (Y or T grafts of LIMA–RA) and OPCAB grafts. The arterial and sequential grafts were not completely evaluated by other non-invasive methods. Composite arterial and OPCAB grafts were not also studied. We studied all combination of grafts, irrespective of the site even with the small sized native coronary artery lumen.

In our early study, we had confusion with the competitive flow of grafts, which were shown as faint opacification on the m-CT, and were evaluated as occluded or patent grafts. From our experiences, these are now known to be patent grafts. In our study, there was a 3-month interval between CAG and m-CT in maximum, which might misunderstand a true negative as a false negative. Although this study gave encouraging results, we think with two studies over a shorter period, we would be able to get better results.

In our early study, we had confusion with the competitive flow of grafts, which were shown as faint opacification on the m-CT, and were evaluated as occluded or patent grafts. From our experiences, these are now known to be patent grafts.

This study has developed m-CT as a highly accurate tool for the evaluation of graft patency following conventional CABG or OPCAB. Compared with other non-invasive methods, m-CT depicts almost the same image as CAG, and can evaluate all kinds of grafts such as small arterial grafts without artifacts, and also reduces the cost.

With our experience, we are now able to use m-CT, not only for the evaluation of early graft patency, but also for stenosis of stent and old bypass grafts in outpatients. The correct positive ratio of this technique is now nearly 100% for the evaluation of graft patency following coronary
bypass surgery. We think that m-CT could be a very useful and accurate technique for screening test in outpatient follow-up, and could replace CAG for the evaluation of graft patency following coronary artery bypass graft.

References


Appendix A. Conference discussion

Dr T. Acuff (Denton, TX, USA): We have a very limited experience in Dallas using this, and we have found that it will tell whether the grafts are patent but we can’t tell whether they are stenotic or not. Can you comment on that?

Dr Yoo: Actually this study was performed immediate postoperatively and we expected to find some stenosis. However, we could not find any stenosis in this study.

Dr P. Sergeant (Leuven, Belgium): This was a study, Have you transferred that into the actual routine or do you at this moment still continue in the usual fashion?

Dr Yoo: Actually we performed this study last year. At that time we had some difficulty to persuade the patient to undergo coronary angiogram and multi-slice CT, so we have performed it only in 42 patients. However, now we know with our experience that this study shows more than 99% accuracy. So we do not use coronary angiogram to evaluate graft patency, and just use multi-slice CT for the evaluation of graft patency.

Dr T. Wahlers (Jena, Germany): I have got a question concerning the breath-hold. Most of the patients are beyond 65 years, so how does breath holding influence the accuracy of the pictures?

Dr Yoo: There is a big difference from other non-invasive methods. Other methods usually take longer time for scanning, and it takes at least 40 seconds causing some problems to scan in one breath leading to poor imaging. However, in this scan, as I have shown before, the mean time was 24 seconds and most patients can endure in one breath.

Dr F. Mohr (Leipzig, Germany): If you look into the literature about patencies, and many studies have been done in terms of MIDCABs, etc., there was an incidence of early anastomotic stenosis, even graft stenosis, about 5 to 6%, which is accepted. Did you see no stenosis in your experience? Also, there was an incidence of early anastomotic stenosis, even graft stenosis, about 5 to 6%, which is accepted. Did you see no stenosis in your experience?