Detection of coronary artery bypass graft patency by contrast enhanced magnetic resonance angiography

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Received 20 September 1998; received in revised form 18 January 1999; accepted 27 January 1999

Abstract

Objective: The subject and purpose of the prospective study was to delineate coronary artery bypass graft (CABG) course and to determine patency of aortocoronary venous bypass grafts (ACVB) compared with internal mammary artery bypass grafts (IMA) in the early postoperative follow-up, by contrast enhanced magnetic resonance angiography (MRA). For control, patients were examined with X-ray angiography and spiral-computed tomography (CT).

Methods: Eighty-five patients (74 male/11 female) with a mean age of 63.7 years underwent MRA examination, applying contrast enhanced gradient-echo sequence after an average distance of 7 days from CABG surgery. A 1.5 Tesla magnetom vision (Siemens, Erlangen, Germany) with phased array coil technology was used. Overall, 247 bypass grafts (160 ACVB/87 IMA) were studied with a 3D (three dimensional) ultrashort TE gradient-echo sequence (TR/TE/a:5 ms/2 ms/40°) with 512*512 matrix and 500 mm FoV in single breath-hold technique after Gd-DTPA bolus injection. CABGs were judged in three different parts, including the course of CABG and both anastomoses. CABGs were controlled by angiography and spiral-CT to examine sensitivity, specificity and efficiency of MRA examination. Additional measurement of bypass graft flow velocity of arterial and venous grafts was performed with 2D phase contrast technique in breath-hold technique with ECG triggering.

Results: One hundred and thirty-nine of 160 (86.9%) ACVB grafts and 83 of 87 (95.4%) IMA grafts could be visualized. Suspected occlusions of 10 CABGs were confirmed in 80% with a second modality. Five CABGs were false positive in MRA. MRA proved a high specificity (93.8%), sensitivity (89.9%) and efficiency (1.73), especially in detection of IMA to LAD and ACVB to LAD and RCA (Table 1). 3D maximum intensity projection (MIP) reconstruction was helpful in delineating CABG course and in several cases in detecting stenosis of coronary arteries. Results of flow velocity showed a significant higher mean systolic velocity in arterial bypasses than in venous grafts with a higher maximum velocity in systole than in diastole in both grafts. Bypass stenosis in distal anastomoses could not be verified with MRA and flow method.

Conclusion: Contrast enhanced 3D ultrashort TE gradient-echo magnetic resonance angiography has the potential for being a reliable method for CABG visualization and CABG patency determination in the early postoperative period. MR flow measurement was not qualified for detection of a bypass stenosis. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Magnetic resonance angiography; Flow measurement; Bypass graft patency; X-ray angiography

1. Introduction

Follow up of coronary artery bypass grafts (CABG) after coronary surgery is routinely performed by means of X-ray coronary angiography with the possibility of graft interventions like angioplasty or stenting. X-ray coronary angiography using ionizing radiation, is expensive, invasive and connected with the risk of severe complications. Contrast enhanced magnetic resonance angiography (MRA) is a recently implemented, non-invasive and fast imaging modality, although it requires a major technical equipment. The question arises, if contrast enhanced MR angiography in combination with MR flow quantification is suitable...
for postoperative follow-up with high sensitivity, specificity and reliability.

The purpose was to study prospectively the patency of aortocoronary venous bypass (ACVB) grafts and internal mammary artery (IMA) grafts using contrast enhanced MR angiography and to compare the results with those of X-ray angiography and/or spiral computed tomography.

2. Materials and methods

During a 1.5 years period, 85 patients (74 male/11 female) with a mean age of 63.7 ± 8.3 years were examined by MR angiography after CABG surgery. Mean distance from surgery was 7 days. Patients with cardiac pacemakers, ferromagnetic metallic implants like heart valve prosthesis, foreign bodies or external pacemaker wires were excluded from the study. All patients received an average number of 3.1 grafts. Seventy-four patients received at least one IMA graft together with venous grafts, 12 patients had a double sided IMA and venous grafts. Six patients received venous grafts only. A total of 247 grafts, including 170 venous grafts, 74 left sided IMA grafts and 13 right sided IMA grafts were examined. Ten of the 170 venous grafts resulted from earlier bypass surgery. Regarding the supplied vessel area the left anterior descending (LAD) artery was most commonly revascularized by IMA grafts (77 IMA grafts/43 ACVB), whereas the left circumflex artery (RCX) (13 IMA/73 ACVB) and the right coronary artery (RCA) (2 IMA/44 ACVB) were principally revascularized by venous grafts.

Examination was performed with a 1.5 Tesla whole body scanner (Magnetom VisionÒ, Siemens Medical Systems, Erlangen, Germany) with high performance gradient systems and phased array body coil technology for improved signal detection. After multiplanar scout views contrast enhanced MR angiography was performed in a transversal, sagittal and coronal direction consecutively (Fig. 1a). Each MR angiography was enhanced with a 20 cc bolus of gadopentetate dimeglumine (Magnevist, Schering AG, Berlin, Germany). This paramagnetic contrast medium (in MRA clearly improving the results) was injected manually within 10 s. Data acquisition was performed for a period of 25–30 s. It covered a volume of 250–315 × 500 × 96 mm³ using a 512 × 512 point matrix size. Consecutively a 3D (three dimensional) maximum intensity projection (MIP) of the data sets was calculated. For correlation, data of MRA were compared with X-ray coronary angiography or spiral computed tomography in the same patient.

Additionally ECG-triggered MR graft flow was measured using the 3D MR angiography for slice orientation depending on the graft course. Phase contrast sequence technologies allow flow sensitive imaging, rating of flow direction, flow volume and flow velocities in cm/s (Fig. 1b). Since moving blood is contrasted in MRA, patent bypass grafts could be visualized, particularly after injection of a paramagnetic Gd-DTPA bolus. Within the same acquisition time, spatial resolution of the MRA could be improved by using a non-ECG-triggered technique with a pixel size of 1.4 × 1.0 mm. Due to the lack of blood flow, occluded grafts could not be visualized. Image evaluation was performed by contrast enhancement, pulsation and breathing artifacts and wrap around artifacts using a five step scale (from 1 = excellent to 5 = insufficient for diagnosis). For patency control grafts were divided into three different segments: proximal anastomosis, graft course and distal anastomosis.

The image quality revealed a mean score of 2.4 ± 0.9. All MR data sets were of sufficient image quality to verify bypass graft patency. Graft patency was assessed independently by two radiologists experienced in MRA. Subse-

![Fig. 1. (a) A transversal scout view with contrast enhanced MRA visualized ACVB and left mammary artery graft (LIMA) as well as a coronary artery (RCA). (b) Flow curves from IMA (1) and ACVB (2) bypass grafts demonstrate flow velocity in cm/s.](https://academic.oup.com/ejcts/article-abstract/15/4/389/522714/Detection-of-coronary-artery-bypass-graft-patency/522714?redirectedFrom=doi)
quently the grafts were assigned to different groups: ‘visible’ means patent, ‘non-visible’ means occluded. They were compared with data of the control group. This control group consisted of 20 patients with coronary angiography (15 IMA/37 ACVB) and additional five patients with spiral computed tomography (3 IMA/10 ACVB). In total, 65 grafts (18 IMA/47 ACVB) were monitored by correlation modalities. Using spiral CT as control for identifying arterial and venous coronary bypass graft patency, an adequate reliability similar to the X-ray angiography was achieved [1].

We calculated sensitivities (true patent/(true patent + false occluded)), specificities (true occluded/(true occluded + false patent)), positive (true patent/(true patent + false patent)) and negative (true occluded/(true occluded + false occluded)) predictive values and the test efficiency (sum of positive and negative predictive values). Differences between venous and arterial grafts as well as results of different supplied vessel areas were verified using the Mann–Whitney U test and the Kruskal–Wallis H test considering P-values, 0.05 as statistically significant.

3. Results

The overall patency rate was 95% for the IMA grafts and 87% for the venous grafts. Comparing the results of MRA to 20 X-ray angiographies and five spiral CTs, five grafts were judged falsely patent in MR angiography and one was considered falsely occluded. This resulted in a sensitivity of 90% and a specificity of 94%. Positive and negative predictive values were calculated as 97 and 75%, respectively, and the test efficiency was 1.73. Comparing the results of venous and arterial grafts, sensitivity was highest among the IMA grafts, whereas specificity, positive and negative predictive values as well as the test efficiency were higher among the venous grafts (Table 1). Regarding the different supplied coronary vessel areas, MR angiography was most reliable for LAD grafts. The negative predictive value was the lowest for RCA grafts. The test efficiency was highest for LAD grafts. Efficiency in detection of CX grafts was worse and the worst was for RCA grafts. 3D MIP reconstruction with a spatial display of whole graft course was helpful in assessing severe proximal coronary artery stenosis in individual cases. The evaluation of stenosis of the distal anastomosis of ACVB and IMA grafts was not able in MRA due to blurring caused by cardiac motion. Additional ECG triggering cannot improve identification of distal anastomosis because of the data acquisition window, which is too long to freeze cardiac motion [2].

The bypass flow examination of arterial and venous grafts showed in all coronary arteries no typical flow performance like in coronary arteries. With the breath-hold technique, only 65% of patient data could be evaluated because of artifacts, e.g. of vessel clips in mammary arteries. There were only minimal differences in flow velocity of venous and arterial bypasses and between different coronary vessel areas. No concurrent flow in bypass grafts could be mea-

Table 1
Patency control of ACVB and IMA bypass grafts by MRA demonstrates high sensitivity assessing patent IMA grafts and high specificity in detecting venous LAD and RCA grafts

<table>
<thead>
<tr>
<th></th>
<th>ACVB</th>
<th>IMA</th>
<th>LAD</th>
<th>RCX</th>
<th>RCA</th>
<th>All CABG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity (%)</td>
<td>87.9</td>
<td>93.8</td>
<td>95.7</td>
<td>82.2</td>
<td>88.9</td>
<td>89.8</td>
</tr>
<tr>
<td>Specificity (%)</td>
<td>100</td>
<td>50</td>
<td>100</td>
<td>85.7</td>
<td>100</td>
<td>93.8</td>
</tr>
<tr>
<td>Positive predictive value (%)</td>
<td>100</td>
<td>93.8</td>
<td>100</td>
<td>93.3</td>
<td>100</td>
<td>97.8</td>
</tr>
<tr>
<td>Negative predictive value (%)</td>
<td>77.8</td>
<td>50.0</td>
<td>88.9</td>
<td>66.7</td>
<td>50.0</td>
<td>75.0</td>
</tr>
<tr>
<td>Efficiency</td>
<td>1.78</td>
<td>1.44</td>
<td>1.89</td>
<td>1.6</td>
<td>1.5</td>
<td>1.73</td>
</tr>
</tbody>
</table>

The highest test efficiency was calculated for venous LAD grafts.

Table 2
Other studies for visualization of coronary bypass grafts in MRT (most techniques had an insufficient specificity for reliable clinical use)

<table>
<thead>
<tr>
<th>Group</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>Specialties</th>
<th>Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rubinstein et al. [3]</td>
<td>92</td>
<td>85</td>
<td>Only ACVB</td>
<td>SE</td>
</tr>
<tr>
<td>Theissen et al. [4]</td>
<td>83</td>
<td>56</td>
<td>Only axial SD</td>
<td>SE</td>
</tr>
<tr>
<td>Jenkins et al. [5]</td>
<td>89</td>
<td>73</td>
<td>Rotative SE</td>
<td>SE</td>
</tr>
<tr>
<td>White et al. [6]</td>
<td>86</td>
<td>59</td>
<td>Detection IMA: 94%</td>
<td>SE</td>
</tr>
<tr>
<td>Wicke et al. [7]</td>
<td>73</td>
<td>73</td>
<td>Flow measurement</td>
<td>GE</td>
</tr>
<tr>
<td>Knoll et al. [8]</td>
<td>94</td>
<td>81</td>
<td>cine-GE</td>
<td>GE</td>
</tr>
<tr>
<td>Hoogendorn et al. [9]</td>
<td>100</td>
<td>88</td>
<td>GE</td>
<td>GE</td>
</tr>
<tr>
<td>White et al. [10]</td>
<td>93</td>
<td>86</td>
<td>cine-GE</td>
<td>GE</td>
</tr>
<tr>
<td>Aantgenima et al. [11]</td>
<td>100</td>
<td>88</td>
<td>GE</td>
<td>GE</td>
</tr>
</tbody>
</table>

ACVB, aorto coronary venous bypass; IMA, internal mammary artery bypass; SD, section direction; SE, spin echo technique; GE, gradient echo technique; cine-GE, GE with different phases in one layer.
sured. Partially in the beginning of systole a backward flow was observed (Fig. 1b, with a negative velocity value in flow curve 2). Results of flow velocity showed a significant higher mean systolic velocity in arterial bypasses than in venous grafts with a higher maximum velocity in systole (3.6 ± 3.1 cm/s) than in diastole (4.3 ± 2.3 cm/s, P < 0.01). However, mean diastolic velocity (2.4 ± 2.0 cm/s) and minimum diastolic values (0.6 ± 2.7 cm/s) in both graft types exceeded mean systolic (1.7 ± 1.3 cm/s, n.s.) and minimum systolic values (~2.1 ± 2.1 cm/s, P < 0.01) significantly. Maximum systolic and diastolic velocity was significantly (P < 0.001) higher than minimum flow values.

4. Discussion

In the last 15 years MRT was used in different modifications for visualization of coronary bypass grafts. Other groups applied different techniques like spin echo and gradient echo sequences (Table 2). So far only 2D applications without intravascular contrast medium were used.

First visualization of venous bypass grafts by means of MR imaging was reported in 1983 [12]. Studies for visualization of IMA grafts were performed in 1987, however, without comparing the results with established modalities [13]. MR imaging studies of coronary arteries using breath-hold sequence techniques were investigated by Manning et al. in 1993 [14] first. MR flow of coronary artery bypass grafts with evaluation of the cyclic flow profile were studied by Hoogendorn et al. [9] in 1995 using phase contrast MR techniques. However, this group investigated only venous bypass grafts to LAD and RCA. This examination had high sensitivity (100%) and specificity (88%). In a retrospective examination, Aurigemma et al. [11] achieved a very high sensitivity (100%) and sensitivity (88%) by using retrospective ECG triggering and data acquisition in several ECG segments. Special flow characteristics of left internal thoracic artery grafts were postoperatively examined by Galjee and Nasi [15,16].

We are the first to demonstrate a contrast enhanced MR angiography technique with a high sensitivity in providing patent IMA grafts, as well as high specificity in assessing venous LAD and RCA grafts. The highest test efficiency was obtained among the venous LAD grafts. In our study, the flow velocity measurement was not qualified for exact classification of bypass stenoses, but in 3D pictures coronary and bypass stenoses sometimes could be found. In future, therefore, a further shortening of repetition and echo time (for higher resolution of details) is necessary for detection and classification of bypass stenoses and examination of distal anastomoses of bypass grafts. So far invasive, intravascular Doppler-sonographical methods have higher quality than magnetic resonance tomography, especially in mammmary artery grafts [15]. MRA can be proposed as a useful screening procedure for postoperative assessment of graft patency, especially in patients with recurrent chest pain after bypass surgery.

The advantage of MRA is a very short time exposure of commonly 20–25 min. An expensive ECG-triggering is not necessary for a simple bypass visualization and for a 3D dataset. There are a lot of possibilities of postprocessing for visualization of total bypass course.

The disadvantage of MRA is the use of expensive paramagnetic contrast medium (with less side effects compared with jodine contrast medium in X-ray angiography). The evaluation of the distal anastomosis of ACVB and IMA was not possible. MRA examination is decisively depending on the collaboration between patient and radiologist to avoid artifacts in breath-hold technique. Today, MR-angiography is only available in few medical centers with MRT equipment and additional expensive high-performance gradient coil systems.

5. Conclusion

Contrast enhanced MRA with a sensitivity of 93.8% and high specificity of 89.8% seems to be superior to other MRT techniques. Thus contrast enhanced 3D magnetic resonance angiography has the potential for being a reliable method for CABG visualization and CABG patency assessment in the early postoperative period. For further evaluation of occluded bypasses for intervention, an X-ray angiography is necessary. 3D postprocessing is helpful in delineating graft courses. Conventional X-ray angiography is invasive and can be associated with minor and major complications such as arrhythmia, myocardial infarction, stroke or bleeding. Compared with coronary angiography contrast enhanced MR angiography is a non-invasive examination modality without iodine contrast medium and ionizing radiation. It is applicable within 20–30 min with minimal risks.

References


