Computed tomographic assessment of coronary artery bypass grafts

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SUMMARY Twenty four patients with 65 coronary artery bypass grafts were studied by computed tomography and angiography within a 10 day period in order to assess graft patency and graft flow. In the assessment of graft patency computed tomography had an accuracy of 93% and in that of graft flow one of 91%. These results indicate that computed tomography is an accurate method for assessing graft patency and flow and is useful in the investigation of certain groups of patients who have had coronary artery bypass graft surgery.

Coronary artery bypass grafting is now a common operation in the United Kingdom,1 and in the United States is probably the commonest elective operation performed. Information on the patency and function of these grafts is important for assessing current and new surgical techniques and also in managing patients with continuing angina or recurrent angina.

The generally accepted technique for assessing graft patency is selective angiography. Recent studies, however, have indicated that computed tomography can be as accurate as angiography in assessing graft patency.2–4 Since computed tomography shows only a small portion of the graft within a single thin transverse section and provides no information about coronary arteries it is not possible to comment on the state of the graft or grafted coronary artery. There is, however, information to suggest that dynamic computed tomography can be used to assess graft flow by studying iodine transit.2,5 We report our experience in assessing graft patency and flow using this technique.

Patients and methods

Twenty four patients with 65 grafts were studied. Thirteen were investigated because of a recurrence of angina, and 11 consecutive patients who agreed to undergo both angiography and computed tomography were studied in the postoperative period. Computed tomography and angiography were performed within a 10 day period in all patients and were reported blind by experienced independent observers.

COMPUTED TOMOGRAPHY

Computed tomography was performed using an International General Electric CT/T 8800 scanner with dynamic scan facilities. All scans were performed during suspended deep inspiration. A scanned projection radiograph of the chest was first performed to identify graft markers (if used) and to select the approximate levels to be scanned. To identify the level of the aortic root and base of the left ventricle a dynamic incremental series of 1 cm thick scans at 1 cm intervals was performed before the administration of contrast. From these sections an anatomical level was selected for scanning during intravenous contrast injection. In the first five patients one level just above the aortic valve was selected. In later patients two series of scans were performed, when graft markers were identified, one just below the lowest marker and one at the level of the aortic valve. In those patients without markers one series of scans was performed at the level of the left ventricular outflow tract and the other 2 cm above this.

Four scans with a 5-6 s scan time and 1-4 s interscan time were performed at the selected levels after an intravenous injection of iodinated contrast medium. Thirty millilitres of contrast were injected at 10 ml/s into an antecubital vein using a Medrad Mk4 power injector. The injection and first scan were started simultaneously. Using this timing the left heart was opacified during the second and third scans allowing the first scan to be used as a control (Fig. 1). Where necessary for technical reasons further series of scans were performed. A graft was considered to be patent

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Fig. 1 Sequential computed tomograms at one transverse level showing passage of contrast through the heart: (a) contrast in superior vena cava (SVC) and pulmonary artery (PA); (b) and (c) contrast in ascending aorta (Ao) and grafts to the left anterior descending (LAD), diagonal (Dg), and obtuse marginal (OM) arteries (arrowed); and (d) heart clear of contrast. DA, descending aorta.

Fig. 2 Computed tomogram showing patent grafts (arrowed) to the right coronary artery (RCA), left anterior descending (LAD), obtuse marginal (OM), and diagonal (Dg) artery.

when opacification occurred at the site of the graft during the passage of contrast through the aorta (Fig. 2).

To assess graft flow, time density curves were produced for each graft from each series of scans and compared with a curve from the aorta. The density of each graft and the ascending aorta was measured on each scan using commercially available computer software which allows a region of interest of variable size to be positioned by a tracking ball and measures the mean density within the region. The size of the region was set to include as much as possible of the graft without including any surrounding tissue. The density was then plotted against the scan numbers from 1–4—that is, time.

CARDIAC CATHETERISATION

Left heart catheterisation was performed with the
femoral approach in all patients. Where grafts were selectively entered angiography was performed in at least two views. When grafts could not be selectively catheterised aortograms were performed in the 60° left anterior oblique and the 30° right anterior oblique projection, and the grafts were considered to be occluded if an appropriately positioned dimple was seen. Only those cases in which grafts were fully visualised by angiography were included in the analysis.

Where the graft was patent, graft flow was assessed as good or bad on the rate of clearance of contrast, and whether this was due to graft disease or poor run off in the grafted vessel was recorded.

Results

Angiography fully visualised 60 of the 65 grafts (Fig. 3). Fifty six grafts were selectively catheterised, of which 46 were patent and 10 occluded. Aortography demonstrated a further patent graft and three occluded grafts. These three grafts, which were proximally occluded, showed some distal filling at coronary arteriography but no pulsatile flow. In the case of an internal mammary artery graft that was not selectively catheterised or visualised at arteriography, coronary arteriography showed pulsatile flow in the distal graft, which was, therefore, considered to be patent. It was not possible to catheterise selectively the remaining four grafts or to show any evidence of the graft at arteriography. Some distal filling was seen in one of these grafts at coronary arteriography; however, pulsatile flow and washout were poor, and it was not considered possible to comment on its patency. These five cases were, therefore, excluded from the analysis. One further graft was excluded from the analysis because the patient had chest pain and electrocardiographic changes between the two studies and it is possible that the graft had occluded. Computed tomography had shown that the graft was patent, and five days later it was found to be occluded at angiography.

Computed tomography showed as patent 45 of the 47 angiographically patent grafts (Fig. 3). Of the two grafts not visualised by computed tomography, one had many metallic clips causing artefact at all levels scanned, and one was the distal part of a sequential graft.

Two of the grafts that were considered to be occluded at angiography were demonstrated as patent by computed tomography. The first graft was occluded proximally and showed distal filling at coronary arteriography. We believe that we visualised the distal portion of the graft at computed tomography, and it was after this case that we started performing the two series of scans and have since correctly identified a similar situation. In the second graft there was no obvious reason for the discrepancy between the two techniques. Of the four grafts not visualised at angiography, computed tomography suggested two to be patent and two occluded. The distribution and patency of the grafts are shown in Table 1. The one graft with no explanation for incorrect assessment by computed tomography was a graft to the circumflex artery. Analysis of these results of graft patency give computed tomography compared with angiography a sensitivity ((grafts patent by computed tomography and angiography/grafts patent by angiography alone) \times 100) of 96%, a specificity ((grafts occluded by computed tomography and angiography/grafts occluded by angiography) \times 100) of 83%, and an overall accuracy (patent and occluded grafts diagnosed correctly by computed tomography/all studied grafts) \times 100) of 93%.

GRAFT FLOW

This was assessed in the 45 grafts demonstrated as patent by both techniques. Angiographic analysis was not possible in three grafts. One angiogram (three grafts) had been sent to another hospital. In nine grafts it was not possible to analyse the computed tomographic data: data were missing for three; in two patients with three grafts there was delayed venous

<table>
<thead>
<tr>
<th>Grafted artery</th>
<th>Total No of grafts</th>
<th>Patent</th>
<th>Occluded</th>
<th>Not visualised</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left anterior descending</td>
<td>22</td>
<td>18</td>
<td>4</td>
<td>—</td>
</tr>
<tr>
<td>Diagonal</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>—</td>
</tr>
<tr>
<td>Circumflex</td>
<td>12</td>
<td>8</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Marginal</td>
<td>10</td>
<td>7</td>
<td>3</td>
<td>—</td>
</tr>
<tr>
<td>Right coronary artery</td>
<td>18</td>
<td>13</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>65</td>
<td>48</td>
<td>13</td>
<td>4</td>
</tr>
</tbody>
</table>
Computed tomography of coronary artery bypass grafts

Table 2  Comparison of graft flow by computed tomography and angiography. Figures are numbers of grafts

<table>
<thead>
<tr>
<th>Angiography</th>
<th>Computed tomography</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good flow</td>
<td>Good flow</td>
</tr>
<tr>
<td>Poor flow</td>
<td>Poor flow</td>
</tr>
</tbody>
</table>

return and, therefore, no bolus effect; and in the remaining three the tomographic appearance of the graft was too small to make analysis possible, the small size being confirmed at angiography in two, and the third being a moderate sized graft with good flow. Of the 33 grafts that were analysed 25 had large grafts with good run off in the grafted artery (Table 2). In all of these the graft curve followed the same contour as the aortic curve (Fig. 4a), and the density in the graft fell to less than 50% of its peak value. One of these grafts had a 50% ostial stenosis but angiographically had good flow, and the stenosis was not regarded as significant; this graft had a normal curve at computed tomography. Eight grafts had poor run off in the grafted artery as assessed angiographically, and the graft curve compared with the aortic curve in six of these showed delayed clearance of contrast (Fig. 4b), the density within the graft remaining above 50% of the peak value. Two of these six also showed delayed appearance of contrast, the peak density in the graft occurring after the aortic peak. The remaining two grafts had normal curves. We found no relation between the peak density in the graft and the peak density in aorta in relation to angiographic assessment of graft flow. Analysis of these results for graft flow give a sensitivity of 100%, a specificity of 75%, and an overall accuracy of 91%.

Discussion

Information on coronary artery bypass graft patency is important both for the surgeon and for patient management. Although this can be provided by selective angiography, this is a highly invasive and time consuming investigation, especially in those cases in which graft markers have not been used. Where it is not possible selectively to catheterise the graft, aortic root angiography is often helpful. There are, however, a number of cases where no information can be obtained, and these grafts are not invariably occluded as repeat catheterisation at a later date can show patency.

A simpler less invasive technique of comparable accuracy would, therefore, be useful. The results from this study suggest that computed tomography fulfils these criteria. There are several problems that
can make the assessment of graft patency by tomography difficult or incorrect; most of these can be overcome. Proximally occluded grafts that are patent distally and the reverse situation of a distally occluded graft patent proximally can appear patent at computed tomography.\(^2\) Performing scans at two levels overcomes this problem. Metallic clips on grafts, calcified areas of pericardium, calcification or contrast in coronary arteries, and differentiation of the left atrial appendage from grafts to the circumflex artery or its branches make graft identification difficult or impossible.\(^6\) Knowledge of these possibilities and scanning at multiple levels allowed us to overcome these problems in most cases (Fig. 5). In our series there was only one graft with so many metallic clips that we were unable to find a level to scan. In the case of "\(y\)" grafts, first identifying the graft and then scanning at lower levels until the bifurcation of the graft is identified it is possible to demonstrate both grafts. In the case of sequential grafts, however, it is possible to comment only on the patency of the first grafted artery, as below this there is the possibility of incorrectly identifying the coronary artery as the graft.

Although we correctly identified only 10 of the 13 occluded grafts in one of these, it is possible that one graft occluded between the two studies, in one the distal portion of the graft was patent, and in one, which was a graft to the circumflex artery, we have no explanation, although it is possible that we were visualising a part of the left atrial appendage.

Although knowledge of graft patency is important, it gives no indication of the function of the graft or grafted coronary artery. Information on graft and grafted artery disease and flow is necessary for a full assessment to be made. Computed tomography can provide anatomical information on only a very small transverse section of the graft, and it is not possible to obtain useful information on coronary arteries. Using the ability of computed tomography to measure densities it has proved possible in most cases to obtain information on graft flow by studying iodine transit. In several grafts (15%) flow at computed tomography could not be assessed for two reasons. In two patients it was not possible to obtain a bolus effect of contrast, the position of the arm above the head causing holdup of the venous return, and, although patency could be visualised in these grafts, it was not possible to comment on flow. The remaining grafts were smaller than the region of interest area and therefore surrounding tissue was included making the density measurements meaningless.

In those grafts where flow could be assessed computed tomography was correct in all grafts with no disease and a good angiographic flow. Computed tomography identified a further three grafts having good flow, one of these angiographically had a 50% ostial stenosis, but this was not considered to be affecting flow; the graft was large and had good run off and therefore the computed tomographic assessment was probably correct. The other two grafts had poor run off angiographically, and we have no explanation for this discrepancy. In the remaining grafts with poor angiographic flow computed tomography showed either delayed appearance or clearance of contrast from the graft. It may be possible to distinguish between graft and grafted vessel disease as to the cause of poor flow since delayed appearance of contrast should indicate proximal graft disease and delayed clearance distal graft disease or grafted vessel diseases. In view of the small number of grafts with disease or poor run off in this series we are not able to comment on this.

Computed tomography provides no information about coronary artery disease. Its role is, therefore, limited in patients with a recurrence of angina as this is often due to progression of native coronary artery disease. Information about the coronary arteries is, however, available from the preoperative angiograms. In patients with no relief of symptoms after surgery, and in patients in whom no further vessels are graftable the only information necessary is that of graft patency and flow which may be provided by computed tomography.

This study suggests that computed tomography is an accurate technique for demonstrating graft patency, although occasionally grafts to the circumflex artery may be confused with the left atrial appendage. When graft flow is considered, computed tomography was reliable only when this was good; nevertheless, the number of grafts with poor flow in this study was low. Presumably this is because some patients were studied in the early postoperative period when most grafts will be patent and have good flow.

These results indicate that computed tomography is useful in the investigation of early surgical results, and in those cases in which angiography has been unsuccessful. Until large numbers of grafts with poor flow have been studied it is not possible to say whether computed tomography would be useful in those patients with a recurrence of angina.

References
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