Value and Limitations of Computed Tomography in Assessing Aortocoronary Bypass Graft Patency

WERNER G. DANIEL, M.D., WILFRIED DÖHRING, M.D., HANS-STEPHAN STENDER, M.D., AND PAUL R. LICHTLEN, M.D.

SUMMARY To determine the value of nondynamic computed tomography (CT) in assessing aortocoronary bypass graft patency, we studied 67 patients with 125 grafts by CT and by coronary angiography at close time intervals. CT scans were performed before and after one to three (average 1.98 ± 0.65) 50-ml i.v. bolus injections of contrast material. Eighty-four of 92 grafts patent at angiography were also visualized by CT (sensitivity 91.3%); 29 of 33 grafts closed at angiography were considered to be occluded by CT (specificity 87.9%). Eleven of 13 grafts demonstrating one or more severe obstructions at angiography were considered to be patent by CT. Interobserver disagreement existed in four of 125 grafts (3.2%) and intraobserver variability was 1.6%. Although nondynamic CT allows a correct assessment of graft patency in many cases, it does not provide sufficient information on graft stenosis and function to replace angiography in patients who are symptomatic after surgery.

ACCURATE determination of aortocoronary bypass graft patency requires angiography. Noninvasive methods for analyzing bypass graft function, such as the directional Doppler flow technique, thallium-201 myocardial perfusion scintigraphy and echocardiographic analysis of regional ventricular function, are of limited value because they indirectly assess bypass graft patency. A noninvasive method easily performed, repeatable and without special risks, visualizing the anatomy and providing direct information on graft patency, would be very useful in the postoperative evaluation of patients after bypass graft surgery. Computed tomography (CT) provides a high-resolution, cross-sectional image of the chest and may be an ideal tool for noninvasive evaluation of aortocoronary bypass grafts. However, the merits and limitations of this method need to be defined. In the studies so far published, the number of investigated grafts are often small, angiographic controls of the results are not always available, and clinical correlations are often lacking.

Therefore, in a consecutive series of patients who underwent postoperative coronary angiography for persistent or recurrent angina pectoris, CT scanning was also performed to assess bypass graft patency in close temporal relation to angiography. A conventional nondynamic scanner was used because it is the type most commonly available.

Materials and Methods

Patients and Angiography

From October 1979 to February 1981, 67 consecutive patients (65 males and two females), ages 40–67 years, who underwent angiographic assessment of graft patency because of recurrent postoperative chest pain were entered into the study. All patients gave written, informed consent for CT investigation and coronary angiography. One hundred twenty-five grafts...
(one to four grafts per patient; average 1.87 grafts) were studied. During angiography, performed 1 week to 8 years after surgery, all patent grafts were selectively opacified in at least two projections. Grafts were considered to be occluded if cannulation of the proximal anastomosis was not possible or only a "dimple" could be demonstrated. All patients with occluded grafts underwent aortic root angiography to confirm the diagnosis.

Computed Tomography

In 27 patients with 54 grafts, CT was performed 1–126 days before angiography (average 35 days); in 40 patients with 71 grafts, CT was performed 1–41 days (average 7 days) after angiography. CT examinations were performed during suspended inspiration using a Somatom total body scanner (Siemens AG) without additional equipment for dynamic scanning or gating of the cardiac cycle. The scan duration for one section (x-ray beam rotation of 360°) was 5 seconds and the tomographic sections were 8 mm thick. Scans could be repeated after an interval of 6 seconds.

A metal clip attached to the proximal anastomosis of each bypass graft during operation served as a marker for the search of the ideal scan level, just below the proximal anastomosis yet still above the origin of the coronary arteries. In addition, Polaroid photographs taken intraoperatively to show the exact position of the graft were available in most of the patients.

CT scans were obtained before and after one to three bolus injections (by hand or infusion pump; flow approximately 8–15 ml/sec) of 50 ml megluminoiglicinate (Rayvist 300) into an antecubital vein. Each patient received an average of 1.98 ± 0.65 injections of contrast material. Scanning started 5–8 seconds after the bolus injection, and two to three scans were made after injection. Grafts were visualized at the typical anatomic position and patency was judged qualitatively by two independent observers. In the 27 patients (54 grafts) studied by CT before angiography, both observers, and in the remaining 40 patients (71 grafts) studied after angiography, at least one of the two observers had no knowledge of the angiographic results. Grafts were considered to be patent when clear contrast enhancement associated with an increase of the attenuation values could be observed, indicating that the graft was perfused by contrast material. Grafts that were not enhanced when contrast appeared in the aorta were considered to be occluded. When grafts were not visualized at any time, CT studies were repeated at two or three different scan levels.

Results

Angiography

Angiography revealed that 92 of 125 grafts (73.6%) were patent and 33 were occluded. Patency was found in 45 of 60 grafts to the left anterior descending coronary artery (LAD) (75%), in 19 of 25 grafts to the right coronary artery (RCA) (76%), in 20 of 31 grafts to an obtuse marginal branch (OMB) of the left circumflex coronary artery (LCx) (64.5%), and in five of six grafts to a diagonal branch (DB) (83.3%). All three internal mammary grafts were patent. Seventy-nine grafts appeared unobstructed both with regard to the proximal and distal anastomoses as well as the veins themselves. Thirteen grafts showed a severe narrowing (i.e., a stenosis of 75% or higher) of the graft itself or of one of the anastomoses: five grafts to an OMB of the LCx, four to the LAD, three to the RCA, and one to a DB. In nine cases the stenosis was localized in the proximal half and in four cases in the distal half of the bypass vein or in the region of the corresponding anastomosis.

Computed Tomography

Eighty-four of the 92 angiographically patent grafts were also visualized by CT (table 1): 44 of 45 patent grafts to the LAD (97.7%), 16 of 19 patent grafts to the RCA (84.2%), 17 of 20 patent grafts to an OMB of the LCx (85%), four of five patent grafts to a DB (80%), and all three internal mammary artery grafts. Typical CT examples are shown in figures 1 to 5. The sensitivity of CT scan detection of graft patent [(grafts patent by CT and angiography/grafts patent by angiography alone] × 100) was 91.3%.

After injection of contrast material in patent grafts, an increase of the attenuation values was measured that ranged from 40 to 180 Hounsfield units (HU). When compared with the corresponding values in the aortic root, there was always a difference between graft and aortic attenuation of 30–160 HU.

Of the 33 grafts occluded at angiography, 29

<table>
<thead>
<tr>
<th>Grafted vessel</th>
<th>Angiographically patent grafts</th>
<th>Angiographically occluded grafts</th>
<th>All grafts CT correct</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAD</td>
<td>CT + 44</td>
<td>CT - 1</td>
<td>CT + 1</td>
<td>CT - 14</td>
</tr>
<tr>
<td>RCA</td>
<td>CT + 16</td>
<td>CT - 3</td>
<td>CT + 1</td>
<td>CT - 5</td>
</tr>
<tr>
<td>Oblique marginal branch</td>
<td>CT + 17</td>
<td>CT - 3</td>
<td>CT + 2</td>
<td>CT - 9</td>
</tr>
<tr>
<td>Diagonal branch</td>
<td>CT + 4</td>
<td>CT - 1</td>
<td>CT + 1</td>
<td>CT - 1</td>
</tr>
<tr>
<td>Internal mammary</td>
<td>CT + 3</td>
<td>CT -</td>
<td>CT + 2</td>
<td>CT - 1</td>
</tr>
<tr>
<td>Total</td>
<td>84</td>
<td>8</td>
<td>36</td>
<td>29</td>
</tr>
</tbody>
</table>

Abbreviations: CT + and − = grafts patent and occluded by computed tomography; LAD = left anterior descending coronary artery; RCA = right coronary artery; Diagonal branch = diagonal branch of the LAD.
(87.9%) were considered to be occluded by CT: 14 of 15 occluded grafts to the LAD (93.3%), five of six occluded grafts to the RCA (83.3%), nine of 11 occluded grafts to an OMB of the LCx (81.8%) and one graft to a DB of the LAD. Hence, four grafts found occluded at angiography were considered to be patent by CT (one to the LAD, one to the RCA and two to an OMB of the LCx). In these four false-positive cases, the CT study was performed 9–32 days before angiography. Thus, some of these four grafts might have become occluded between CT and angiography, especially because all four patients were studied because of recent onset of chest pain. Accordingly, the study revealed a specificity ([grafts occluded by CT and angiography/grafts occluded by angiography] × 100) of 87.9%.

The accuracy of CT for assessment of bypass graft patency ([patent and occluded grafts diagnosed correctly by CT/all studied grafts] × 100) was 90.4%.

Because one of the two observers had knowledge of the angiographic results in some cases, the interpretation of the CT scans might have been biased; therefore, the 54 grafts (27 patients) studied by CT before angiography were evaluated separately. In these cases, both observers could not have any knowledge of the angiographic graft status. This subgroup includes 26 grafts to the LAD, 12 grafts to the RCA, 12 grafts to an OMB of the LCx, three grafts to a DB and one internal mammary artery graft. Thirty-seven of these grafts were patent at subsequent angiography. Thirty-five of them were considered to be patent by CT, resulting in a sensitivity of 94.6%. Seventeen grafts in this subgroup were occluded at angiography, but only 13 of them had been considered to be occluded on CT (specificity 76.5%). Accordingly, for this subgroup of 54 grafts studied by CT before angiography, the accuracy of CT was 88.9% (48 of 54 grafts).

Partial Graft Occlusion

In 13 grafts, angiography demonstrated one or more significant stenoses, either of the graft itself or of one of the anastomoses. Eleven (84.6%) of these partially obstructed bypass grafts were considered to be patent by CT (fig. 6).

Interobserver Disagreement

Interobserver disagreement existed with regard to the evaluation of four grafts (3.2%) — two angiographically patent grafts (one to a DB and one to an OMB) and two occluded grafts (one to the LAD and one to an OMB).

Intraobserver Variability

Fifteen months after the last patient was investigated by CT, all scans were reevaluated by one of the two observers. Reevaluation differed from the initial scan interpretation in only two cases (two grafts to an OMB of the LCx). Thus, the intraobserver variability was 1.6%.

Discussion

This study demonstrates that patency of aortocoronary bypass grafts can be documented by nondynamic

![Figure 1. CT scan of a single left anterior descending coronary artery bypass graft (arrow) before (A) and after (B) administration of contrast material. The patient was studied in the early postoperative period; a retrosternal hematoma (H) can still be seen. A = ascending aorta; P = pulmonary artery.](image)

![Figure 2. CT scan of a single left anterior descending coronary artery bypass graft (arrow) after administration of contrast material. The graft is seen in a course running parallel to the scan level. A = ascending aorta; P = pulmonary artery.](image)
CT with a clinically acceptable sensitivity and specificity when compared with angiography. This was particularly true for the grafts to the LAD, where sensitivity was 97.7%. In general, this study is in good agreement with other studies with angiographic control reporting a sensitivity ranging between 47.7% and 100%. These relatively large differences can, at least in part, be explained by the various types of scanners and study protocols used as well as by the scanning method itself. In our experience it is of considerable help in determining the optimal scan level to have had the aortic anastomosis of the graft marked during operation by a metal clip, which can be easily identified on CT by typical "streak" artifacts. In addition, as much information as possible concerning the exact location and course of each graft is important, e.g., Polaroid pictures taken during surgery documenting graft topography. Thus, in contrast to the findings of Guthaner al., we could visualize posteriorly positioned grafts to an OMB of the LCx with an acceptable accuracy (83.9%).

Radiation exposure associated with the CT studies is relatively low. The dosage calculated for the center of the thorax was as much as 1 R when the maximum of 20 CT scans was necessary (including multiple projections until the optimal scan level is found as well as the scans taken after three contrast medium injections). In contrast, the average x-ray dosage of our laboratories associated with a complete heart catheterization (including right- and left-heart catheterization, fluoroscopy, and filming of coronary arteries and bypass grafts in various projections) is approximately 10 R. However, CT and cardiac catheterization including coronary angiography provide completely different levels of information and should therefore not be compared.

We did not attempt to define the minimum amount of contrast medium necessary for adequate graft enhancement; therefore, 50-ml bolus injections were used in all patients. This led to a sufficient increase of the attenuation values within the bypass vein. Other authors have used lower and higher dosages in their studies, ranging from 20 ml or 30 ml per bolus injection to 110 ml or 140 ml.

Our patients had a relatively low patency rate (73.6%) at angiography, probably because they had recurrent angina pectoris postoperatively.

Four of the 33 angiographically occluded grafts were considered to be patent by CT and classified as false-positives; all were studied 9–32 days before angiography. Hence, in these four symptomatic patients, the grafts might have become occluded in the time between CT and angiography. False-positive CT scans have been reported with the use of both dynamic and nondynamic CT. Misinterpretations are especially common with the native right coronary artery. Other sources of error are occluded grafts with a residual diverticulum or some degree of retrograde flow. The problem with a graft diverticulum and
sometimes also with native coronary arteries may be avoided when scans are repeated on at least two levels.

Thirteen grafts of our series were markedly stenosed at angiography; 11 of them were clearly visualized by CT and judged to be patent. Positive CT results of partially occluded grafts have also been reported by other investigators. Because the CT slices were only about 1 cm thick, it is unlikely that focal graft stenoses will be reliably detected by current commercial scanners. Whether dynamic scanners with increased scan rate and shorter exposure time that allow construction of density-time curves of grafts will provide reliable information on graft function is not known. Initial work assessing graft flow has been promising.

Current CT scanning technique permits reasonably accurate noninvasive assessment of aortocoronary bypass graft patency. Thus, in postoperatively asymptomatic or markedly improved patients, CT scans demonstrating one or more patent grafts may provide sufficient anatomic documentation of the success of bypass graft surgery. Because current CT scanning does not provide definite information on partial graft obstruction or graft function, this method cannot replace angiography in patients who are symptomatic after bypass graft surgery.

References
Value and limitations of computed tomography in assessing aortocoronary bypass graft patency.
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