Institutional report - Coronary

Anatomical and functional assessment of single left internal mammary artery versus arterial T-grafts 12 years after surgery


*Department of Cardiothoracic Surgery, Thoraxcentre, Bd 575, Erasmus Medical Center Rotterdam, P.O. Box 2040, 3000 CA, Rotterdam, The Netherlands
bDepartment of Cardiology, Thoraxcentre, Erasmus Medical Center Rotterdam, P.O. Box 2040, 3000 CA, Rotterdam, The Netherlands
cDepartment of Radiology, Erasmus Medical Center Rotterdam, P.O. Box 2040, 3000 CA, Rotterdam, The Netherlands

Received 29 November 2008; received in revised form 29 April 2009; accepted 30 April 2009

Abstract

We determined whether ultrasonographic left internal mammary artery (LIMA) findings correspond with 64 multislice computed tomography (MSCT) in patients 12 years after coronary artery bypass grafting. We included 34 patients (63.2 ± 9.2 years), 16 with conventional single LIMA (group I) and 18 arterial T-grafts (group II), in a cross-sectional study. Patients underwent transthoracic proximal LIMA ultrasonography at rest and during the Azoulay maneuver, transthoracic echocardiography of the left ventricle and 64-MSCT. MSCT scans showed three string sign LIMA grafts (19%) in group I and three distal string sign LIMA grafts (17%) and 16 occluded T-graft anastomoses (22%) in group II. LIMA diameters and areas are significantly larger in group II in the origin, 3.5 ± 0.7 vs. 2.5 ± 0.5 mm, P = 0.00007 and 0.09 ± 0.04 vs. 0.05 ± 0.02 cm², P = 0.00019 and in the third intercostal space, 3.4 ± 0.7 vs. 2.5 ± 0.5 mm, P = 0.00009 and 0.09 ± 0.03 vs. 0.05 ± 0.02 cm², P = 0.000047. Most ultrasonographic LIMA findings do not differ between the groups. Thus, proximal LIMA diameters and areas are significantly larger in T-grafts and ultrasonographic variables equalize between the groups at rest and during the Azoulay maneuver 12 years after surgery.

© 2009 Published by European Association for Cardio-Thoracic Surgery. All rights reserved.

Keywords: Ultrasound; Coronary artery bypass grafting; Follow-up; Computed tomography

1. Introduction

The in situ left internal mammary artery (LIMA) is the first choice in coronary artery bypass grafting (CABG) to the left anterior descending artery (LAD) because of reduced cardiac events and superior graft patency [1, 2]. Due to these findings, composite arterial T-grafts are used in daily practice [3]. Questions remain whether the main stem of the LIMA of these T-grafts is able to supply sufficient blood at rest and during stress as well as the unknown long-term effects on arterial conduit luminal size [4, 5]. LIMA graft patency in patients with recurrent angina is usually assessed by angiography although other diagnostic techniques are very promising, for example multislice computed tomography (MSCT) [6].

To investigate the long-term outcome of single LIMA-LAD vs. arterial T-grafts, we compared anatomical and functional graft characteristics by 64-MSCT dual-source computed tomography (DSCT) scan at rest and transthoracic ultrasonography at rest and during the Azoulay maneuver 12 years after bypass surgery.

2. Materials and methods

2.1. Patients

Between September 2007 and January 2008, we included 34 patients in a cross-sectional study who were operated during the period of 1994 until 1997. Excluded were patients over 85 years of age, previous allergic reaction to contrast, serious co-morbidity, impaired renal function (creatinine ≥ 120 µmol/l) and irregular cardiac rhythm.

The Institutional Review Board of the Erasmus MC Rotterdam approved this study (NL 13011-078-06). Written informed consent was obtained from all patients.

All patients underwent a DSCT scan, transthoracic duplex scanning of the proximal LIMA, transthoracic echocardiography (TTE) of the left ventricle, an electrocardiogram and a short questionnaire within 1 day.

The DSCT scans were performed to assess the anatomical function (patency) of the arterial grafts and were classified into patent or (distal) string sign grafts. Grafts larger or equal to 2 mm in diameter with good contrast run-off were classified as patent grafts and with a diameter smaller than 2 mm as string sign grafts.

2.2. Transthoracic ultrasonography protocol

The IE 33 208 ultrasound system (Philips, Best, The Netherlands), which combined 2-D imaging and pulsed Doppler ultrasound to evaluate blood velocity variables of the LIMA as well as left ventricular function, was used. TTE evaluation in the second or third intercostal space of the single LIMA and the main stem of the T-graft were performed in all patients with a 9-MHz linear array vascular probe (Philips, Bothell, WA, USA). LIMA duplex recordings were...
electrocardiographically controlled during 3–5 cardiac cycles. The ultrasonographic LIMA variables analyzed were: systolic and diastolic peak velocity (SPV and DPV), systolic, diastolic and total velocity integral (SVI, DVI and TVI), diastolic/systolic velocity integral ratio (DSVIR), diastolic/total (diastolic-systolic) velocity integral ratio (DTVIR) and peak diastolic/peak systolic velocity ratio (DSPVR).

Echocardiographic standard views, using the 55-1 broadband phased array transducer (Philips, Bothell, WA, USA), were obtained in order to classify left ventricular function and left ventricular ejection fraction (LVEF).

We performed the Azoulay maneuver [7] at the end and measured ultrasonographic LIMA variables.

We analyzed different (sub) groups: (a) distal string sign LIMA grafts vs. patent LIMA grafts in group II (b) LVEF smaller than 50% (n=6) vs. LVEF >50% (n=25) (c) proximal string sign LIMA grafts (n=3 in group I) vs. all proximal patent grafts (n=31) (d) all patients in group I vs. group II.

### 2.3. DSCT scan

Neither beta-blockers nor nitroglycerin were administered prior to the scan. All patients were scanned using a Somatom Definition DSCT scanner (Siemens Medical Solutions, Forchheim, Germany). The system is equipped with two X-ray tubes and two corresponding detectors mounted on a single gantry with an angular offset of 90° and a gantry rotation time of 330 ms. Datasets were reconstructed using a single-segmental reconstruction algorithm: slice thickness 0.75 mm; increment 0.4 mm; medium-to-smooth convolution kernel (B26); resulting in a spatial resolution of 0.6–0.7 mm in-plane and 0.5 mm through-plane.

### 2.4. Statistical analysis

Statistical analysis was performed with Epi Info 6.04c (CDC, Atlanta, GA, USA). Continuous variables are displayed as means ± S.D. Discrete variables are displayed as counts or proportions. Data within and between the groups were tested by paired and unpaired t-tests. A P-value of 0.05 or less was considered statistically significant. Sample size calculation showed that at least 10–11 patients in each group are necessary to detect a significant difference in DPV between the two groups, assuming that DPV in single LIMA to LAD grafts is on average 22 cm/s (range 15–30 cm/s) [8] vs. 35 cm/s (range 25–45) [9] in T-grafts (assuming equal variances, S.D. = 10, α = 0.05, power = 0.80).

### 3. Results

In group I, 16 LIMA-LAD anastomoses were constructed with a total of 66 distal anastomoses, 4.1 ± 1.1/patient. Four patients suffered from left main stenosis. In group II, 31 LIMA anastomoses, 43 FRIMA anastomoses, six gastroepiploic artery anastomoses and one additional venous anastomoses were constructed, 4.5 ± 1.1/patient, P = 0.26 between the groups.

In group II, six patients suffered from left main stenosis. The mean age of the 34 patients at the time of surgery differed significantly between the groups: P = 0.034. The time interval between operation and late follow-up is not significant (Table 1).

#### 3.1. DSCT scan

In all patients the DSCT scans were of diagnostic value. Examples are shown in Figs. 1–3.

DSCT scans showed three string sign LIMA grafts (19%) and six occluded venous anastomoses (12%) in group I and three distal (downstream from the T graft) string sign LIMA grafts (17%), two string sign FRIMA grafts (11%), seven occluded LIMA anastomoses (23%), nine occluded FRIMA anastomoses (21%), one string sign GEA graft (17%) and one occluded GEA anastomosis (17%) in group II.

Diameters and cross-sectional areas of the proximal LIMA grafts in group I are shown in Table 2 and of the proximal T-grafts in group II in Table 3.

DSCT showed no proximal string sign or occluded LIMA grafts in the T-graft main stem.

### Table 1

<table>
<thead>
<tr>
<th>Variables</th>
<th>Group I</th>
<th>Group II</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>13</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>Diabetes</td>
<td>4</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Age at operation</td>
<td>55.4 ± 11.5</td>
<td>48.5 ± 6.3</td>
<td>0.03</td>
</tr>
<tr>
<td>Follow-up period (years)</td>
<td>11.5 ± 1.7</td>
<td>11.5 ± 1.1</td>
<td>0.9</td>
</tr>
<tr>
<td>Hypertension</td>
<td>10</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Familiar coronary disease</td>
<td>6</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Smoking history</td>
<td>4</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Postoperative PCI (LAD)</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Length (m)</td>
<td>1.8 ± 0.1</td>
<td>1.8 ± 0.1</td>
<td>0.6</td>
</tr>
<tr>
<td>Weight</td>
<td>86 ± 12</td>
<td>88.8 ± 11</td>
<td>0.4</td>
</tr>
<tr>
<td>Preoperative left main stenosis</td>
<td>4</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Statins</td>
<td>12</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Aspirin</td>
<td>14</td>
<td>17</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 1. Late follow-up main stem transthoracic ultrasonography (a) and DSCT coronary angiography of a patent composite arterial T-graft from the transverse (b) and anterolateral view (c). (A) Main stem of the T-graft; (B) LIMA branch of the T-graft; (C) too large, not kinking, patent FRIMA branch of the T-graft. DSCT, Dual-source computed tomography; LIMA, left internal mammary artery; FRIMA, free right internal mammary artery; SPV, systolic peak velocity (cm/s); DPV, diastolic peak velocity (cm/s).
3.2. Ultrasonographic findings

Doppler profiles could be obtained from all patients. Examples are shown in Figs. 1a, 2a and 3a. In one patient TTE and the Azoulay maneuver could not be performed due to time constraints.

No differences could be obtained between the string sign and patent LIMA grafts within group I at rest or during the Azoulay maneuver (Table 4). Proximal string sign LIMA grafts were only observed in group I.

When only patent grafts in both groups were selected, only DPV at rest and total velocity integral values differs. Nevertheless, all variables are more pronounced in T-grafts at rest and during the Azoulay maneuver (Table 5).

Remarkably, ultrasonographic LIMA findings do not differ between and within the subgroups at rest and during the Azoulay maneuver.

3.3. Echocardiography

All but one patient underwent TTE to determine LVEF. In two patients, no adequate window could be obtained. In group I, the overall EF was 57±16 vs. 59±9% in group II, \( P=0.71 \).

3.4. Questionnaire

All but six patients (82%) remained free of recurrent angina in the postoperative period until these late follow-up investigations. Four patients in group I and two patients in group II have suffered recurrent angina during exercise within the last 6 months.

4. Discussion

The intrinsic properties of internal mammary arteries explain the long-term survival of these bypass grafts [10] which results in the statement that arterial composite T-grafts also would have a good long-term graft patency. Coronary angiography (CA) is an invasive procedure which in patients with T-grafts may result in serious events (hypoperfusion) due to induced spasm of the main stem. Therefore, we performed two different control methods in order to determine functional and anatomical patency of T-grafts.

Cardiac CT scan sensitivity and specificity above 90% have been reported for coronary artery stenosis compared to CA [11]. However, cardiac CT scans are essentially a morphologic and not a functional diagnostic method in coronary artery bypass control. Thus, we performed additionally ultrasonography at rest and during the Azoulay maneuver to assess functionality of single LIMA grafts and the main stem of T-grafts. One of the aims of the study was to determine whether TTE can play a role in the assessment of different LIMA perfusion areas, whereas TTE of T-grafts have not been described over a follow-up period over 10 years.

No overall ultrasonographically significant differences were obtained between the groups nor between subgroups at rest or during the Azoulay maneuver. With regard to the larger perfusion area of the T-grafts, one should expect higher ultrasonographic values in these grafts compared to single LIMA grafts.
The Azoulay maneuver did not have any influence on Doppler profiles. An explanation may be related to physiological exercise that does not appear to be as complete as pharmacological inducement.

Prifti et al. [12] stated in a short follow-up study that peak systolic and diastolic velocity ratios are good variables for demonstrating functional T-graft status. Ratios of greater than 0.85 demonstrated good flow through both distal branches of the T-graft. This means that systolic and diastolic peak velocities equalize in contrast to preoperative values. In spite of the in situ RIMA graft in their study, our findings in the in situ LIMA grafts are different. We found in both patent single LIMA and T-grafts values of 0.3 ± 0.1. Thus, these values are not discriminative in our long-term follow-up study.

Lemma et al. [13] described in a short-term follow-up study their angiographic- and guide wire findings in the proximal and distal arterial composite T-grafts using radial arteries vs. single LIMA-LAD grafts. They found significant differences between the groups for proximal time-average peak velocities. We did not calculate this variable but in patent grafts DPV at rest significant also appeared with higher values in the T-grafts (P=0.03), while SPV did not (P=0.07). The ratio of these variables remains equal in our study, 0.3 ± 0.1 in both groups, while significant differences appear in their study: 0.9 ± 0.4 for single LIMA grafts.
Table 5

<table>
<thead>
<tr>
<th>Variables</th>
<th>Group I</th>
<th>Group II</th>
<th>P</th>
<th>Group I</th>
<th>Group II</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>at rest</td>
<td>at rest</td>
<td></td>
<td>Azoulay</td>
<td>Azoulay</td>
<td></td>
</tr>
<tr>
<td>n = 13</td>
<td>n = 13</td>
<td>n = 13</td>
<td></td>
<td>n = 13</td>
<td>n = 13</td>
<td></td>
</tr>
<tr>
<td>DPV (cm/s)</td>
<td>16.5±3.0</td>
<td>23.5±8.8</td>
<td>0.03</td>
<td>17.2±9.2</td>
<td>25.4±13.1</td>
<td>0.08</td>
</tr>
<tr>
<td>SPV (cm/s)</td>
<td>56.2±15.2</td>
<td>76.8±36.2</td>
<td>0.07</td>
<td>57.6±13.9</td>
<td>97.7±75.2</td>
<td>0.07</td>
</tr>
<tr>
<td>DVI (cm²)</td>
<td>6.3±3.5</td>
<td>9.0±4.1</td>
<td>0.09</td>
<td>6.3±3.9</td>
<td>9.3±4.4</td>
<td>0.09</td>
</tr>
<tr>
<td>SVI (cm²)</td>
<td>11.7±3.8</td>
<td>14.2±5.8</td>
<td>0.20</td>
<td>12.0±3.1</td>
<td>18.7±11.8</td>
<td>0.06</td>
</tr>
<tr>
<td>TVI (cm²)</td>
<td>16.1±4.0</td>
<td>24.8±10.3</td>
<td>0.01</td>
<td>17.7±5.7</td>
<td>25.9±10.4</td>
<td>0.02</td>
</tr>
<tr>
<td>DSVIR</td>
<td>0.54±0.3</td>
<td>0.66±0.23</td>
<td>0.24</td>
<td>0.53±0.28</td>
<td>0.56±0.21</td>
<td>0.77</td>
</tr>
<tr>
<td>DTIR</td>
<td>0.35±0.13</td>
<td>0.37±0.1</td>
<td>0.58</td>
<td>0.34±0.12</td>
<td>0.34±0.1</td>
<td>0.87</td>
</tr>
<tr>
<td>DSPVR</td>
<td>0.3±0.1</td>
<td>0.34±0.1</td>
<td>0.33</td>
<td>0.3±0.1</td>
<td>0.3±0.1</td>
<td>0.97</td>
</tr>
</tbody>
</table>

Group I, patients with single LIMA grafts to the LAD and additional vein grafts; group II, patients with LIMA-free RIMA composite T-grafts; P, unpaired value for only patent grafts between the groups. Abbreviations as described in Table 3. Data are ±5.D.

vs. 1.1±0.2 for T-grafts, (P = 0.03), suggesting a higher diastolic part in the cardiac cycle in T-grafts. Angiography showed significantly larger proximal LIMA diameters in T-grafts than in single LIMA grafts (2.8±0.4 vs. 2.4±0.5 mm, P = 0.019). Diameters in the T-graft group in our study appeared higher compared to the study of Lemma et al. (3.5±0.7 vs. 2.8±0.4 mm). An explanation can be the higher number of anastomoses with T-grafts per patient in our study. Gurné et al. [14] already described the ability of the IMA graft to adapt its dimension to flow demand in the late postoperative period.

The different diameters between the groups explain the equalization of the Doppler profiles.

The number of occluded T-graft anastomoses in our study seems relatively high [15]. According to Nakajima et al. [15], occluded bypass grafts can be the results of competitive flow. This should be a subject for further detailed analysis in comparison to the findings of sequential LIMA grafts.

4.1. Study limitations

We did not consider the severity of coronary stenosis. Especially in small coronary vessels, we did not succeed to measure the severity of coronary stenosis with high accuracy.

Cardioactive medication was continued during the study. This could affect ultrasonographic measurements during the Azoulay maneuver.

In conclusion, ultrasonography can detect adequate Doppler profiles in the proximal part of single LIMA bypass grafts as well as in T-grafts but can not distinguish between patent and string sign grafts.

Proximal LIMA diameters and areas are significantly larger in T-grafts compared to single LIMA grafts, probably due to larger perfusion areas, which can explain the equalization of ultrasonographic variables with no significant differences between and within both groups at rest and during the Azoulay maneuver 12 years after surgery.

Acknowledgments

Special thanks to M. Rengo for preparing the DSCT images and A. Weustink for her contribution both to the scanning protocol as well as the actual scanning.

References


