Non-invasive evaluation of mammary artery flow reserve and adequacy to increased myocardial oxygen demand

Mario Gaudino, Michele Serricchio, Paolo Tondi, Franco Glièca, Alessandro Giordano, Carlo Trani, Paolo Pola, Gianfederico Possati

Abstract

Objective: To evaluate the flow reserve and adequacy to meet myocardial requests in stress conditions of mammary artery-left anterior descending (IMA-LAD) grafts using a non-invasive method. Methods: Patients (20) with angiographic evidence of normofunctioning left IMA-LAD grafts were submitted to dipyridamole Tl201 myocardial scintigraphy and concomitant transthoracic echo-Doppler evaluation of the IMA flow at a mean interval of 32.5 months after surgery. Results: Under basal conditions, the mean peak and end flow velocities in systole were 0.39 and 0.06 m/s, respectively. In diastole, the mean peak and end flow velocities were 0.27 and 0.02 m/s and mean tele-diastolic flow velocity was 0.14 m/s, with a mean systolic/diastolic ratio of 1.51. After dipyridamole infusion, mean systolic velocities were 0.47 (peak) and 0.23 (end) m/s, respectively (+20 and +283%), whereas mean diastolic velocities were 0.56 (peak) and 0.06 (end) m/s, +107 and +200%, respectively. Mean tele-diastolic flow velocity increased to 0.32 m/s (+128%) and the systolic-diastolic index changed to 0.85. In all cases no significant scintigraphic evidence of induced ischemia was demonstrated in the LAD region. Conclusions: Transthoracic echo-Doppler evaluation combined with Tl201 myocardial scintigraphy is a useful tool for the assessment of IMA flow reserve and adequacy to stress conditions. In the late postoperative period, the IMA shows the possibility of increasing the flow velocity, almost 2-fold; the increase in flow is prevalently diastolic and leads to a complete reversal of the physiological systolic/diastolic flow ratio. The flow reserve of IMA is always able to meet the augmented myocardial oxygen demand after dipyridamole infusion. © 1998 Elsevier Science B.V. All rights reserved.

Keywords: Internal mammary artery; Echo-Doppler; Tl201 myocardial scintigraphy; Flow reserve
ing both the hemodynamic characteristics of the increase of IMA flow under stress conditions and the adequacy of this flow to an augmented myocardial O_2 request.

2. Materials and methods

2.1. Patient population

This study protocol involves 20 patients who underwent single IMA-LAD grafting at our institution and in whom post-operative angiography revealed a normo-functioning IMA graft. These twenty cases were selected among the 194 patients who underwent postoperative angiography at our Institution from January to December 1996; selection was based on a perfect postoperative angiography (all graft widely patent) and the willingness of the patient to undergo the dipyridamole study.

Main clinical and angiographic data of the patients are shown in Table 1. Each patient gave his/her informed consent before either the post-operative angiography and the scintigraphic, echo-Doppler evaluation.

2.2. Echo-Doppler evaluation

All echo-Doppler measurements were performed using a computerised system (Acuson 128 XP/10 ART; Acuson, USA) equipped with a 7 MHz linear probe with 40-mm opening and 5 MHz pulsed Doppler. Patients were studied in supine position, with the trunk elevated by 30°, after an adaptation period of 5 min in a room kept at constant temperature (26°C).

The left IMA was usually detected in the third intercostal space in parasternal position; in 4 patients the IMA could be detected only in the supraclavicular position. In 3 of these patients, endovenous infusion of an echo-contrast medium (suspension of microparticles of galactose and palmitic acid 300 mg/ml; Levovist, Schering AG, Germany) was also necessary in order to ameliorate the vascular imaging. The artery could be visualized in all our cases.

The following parameters were calculated: Peak systolic velocity (m/s) (PSV); end systolic velocity (m/s) (ESV); peak diastolic velocity (m/s) (PDV); end diastolic velocity (m/s) (EDV); tele-diastolic velocity (TDV), time average mean velocity (m/s) (TAMV); resistance index, (PSV-EDV)/PSV (RI); pulsatility index, (PSV-EDV)/TAMV (PI); systolic-diastolic peak velocity ratio (SDR). The TAMV was defined as the area between the line traced on the Doppler wave and the base line, and represents the mean velocity corrected for the duration of the velocity curve, electronically calculated by the computer by tracing the area of the curve. The diameter of the IMA was calculated using internal electronic calipers on frozen frame images from the B-mode recording.

Flow (F) was obtained using the formula: F (ml/min) = TAMV (cm/s) × (πr² × 60) where r is half the internal diameter of the IMA expressed in cm.

2.3. Vasodilatory protocol

The left IMA flow was evaluated in all patients at rest and after e.v. administration of dipyridamole 0.84 mg/kg (Persantin, Boehringer Mannheim, Germany).

Echo-Doppler evaluation of IMA flow was started immediately after administration of dipyridamole and continued without interruption for 15 minutes. Flow measurements were made when the vasodilator effect was judged to be maximal by the operator. All patients suspended all vasoactive medications two days before the test.

2.4. Scintigraphic evaluation

Tallium^{201} myocardial scintigraphy was performed in all patients immediately after the dipyridamole test (in
Fig. 2. Echo-Doppler evaluation of left IMA flow at rest (a) and after dipyridamole infusion (a): the increase of diastolic peak velocity (V3) is even superior to the increase in systolic peak velocity (V1) (V2, end-systolic velocity; V4, end-diastolic velocity).

In order to verify if the increase of left IMA blood flow was sufficient to meet the augmented myocardial oxygen demand, 370 MBq of Tc99m-Sestamibi was injected intravenously 2–3 min after completion of Dipyridamole infusion. Image acquisition was started 30–60 min later (DYP-SPET). After 3–4 h, 1110 MBq of Tc99m-Sestamibi was injected at rest (REST-SPET). Image acquisition was started 30–60 min later. Imaging was performed by a rotating rectangular single head gamma-camera (Starcam 3200i, General Electric, USA) equipped with a low-energy high resolution parallel hole collimator. Energy discrimination was achieved by a 20% window centred over the 140 KeV photopeak of 99mTc; zoom factor was 1.33. acquisition matrix was 64 × 64. The camera was rotated in 6° increments, collecting 32 views for 50 s each. Image reconstruction was accomplished by filtered back-projection with a Butterworth filter with a cut-off frequency of 0.35 cycles/pixel and a power factor of 5. No attenuation or scatter correction was performed. From transverse axial tomograms encompassing the whole heart, sagittal and oblique slices parallel to the long axis and short axis of the left ventricle were obtained. From the DYP-SPET
and REST-SPET studies of each patient three short axis slices (apical, mid-ventricular and basal) one horizontal long axis (mid-ventricular) and one vertical long axis slice (mid-ventricular) were selected. The tomograms were divided into 20 segments (Fig. 1). Eight segments (numbered 1, 2, 5, 6, 9, 10, 13 and 15) were attributed to the distribution territory of the LAD. Two experienced observers blinded to patients conditions and to each other assigned to each of these segments a score according to the local perfusion conditions: 0 = normal perfusion; 1 = mild defect; 2 = severe defect. Disagreements were resolved by consensus after a common reevaluation.

The sum of the scores, from 0 (normal LAD perfusion) to 16 (severe defect of all LAD segments) of DYP-SPET represented the LAD perfusion after dipyridamole, while the sum of the scores of REST-SPET represented the LAD perfusion at rest. The difference between DYP-SPET total score and REST-SPET total score represented the amount of ischemia scintigraphically detected (ischemia index).

3. Results

Detailed results of the echo-doppler measurement are shown in Table 2.

IMA flow after dipyridamole infusion was significantly superior than at baseline (+138%; \(P<0.01\)).

In general, due to the peculiar characteristics of the coronary circulation, dipyridamole administration led to a marked increase of the end-systolic and diastolic flow velocities and to a less evident increase of the systolic velocity and the IMA diameter (Fig. 2).

More specifically, after dipyridamole ESV, PDV, EDV, TDV and TAMV were all significantly superior than at baseline (\(P<0.01\) for all), whereas the PI and the SDR were significantly lower (again \(P<0.01\) for all). PDV and TAMV had the maximal absolute increase (+0.29 and +0.22 m/s, respectively); while ESV and EDV showed the maximal relative increase (+283 and +200%, respectively).

In four cases minimal scintigraphic evidence of induced ischemia was demonstrated in the LAD region (all the 4 patients had diseased diagonal or antero-lateral branches who were not grafted at surgery because of the poor quality and/or small diameter of the vessels); in the remaining 16 patients no inducible ischemia could be demonstrated (Fig. 3) and the mean ischemia index was 1.5 ± 0.5 (Table 3).

All patients with inducible ischemia had been operated traditionally (and not using minimally invasive techniques) and the increase of IMA flow after dipyridamole infusion in these patients was not significantly different from those of the others 16 cases.
The possibility of evaluating coronary artery bypass graft flow reserve and adequacy to meet augmented myocardial oxygen demands simultaneously would be of obvious interest in clinical research. However, until now a concomitant study of graft flow and myocardial perfusion has never been attempted and the two evaluations have always been performed in different settings. Moreover, flow studies have usually been possible only by mean of invasive, catheter-based methods and their extensive application has been limited by both economical and ethical reasons. The recent validation of transthoracic echo-Doppler for the study of IMA flow variations provided a new non-invasive tools for graft flow study [4,5].

Our experience extends the application of transthoracic echo-Doppler studies and, by combining this method with dipyridamole Tl201 myocardial scintigraphy, allows a concomitant evaluation of the increase in mammary artery flow and the adequacy of this flow to meet augmented myocardial oxygen demand.

The fact that our results are concordant with those obtained using intravascular flow measurements and implantable Doppler probes [6,7] confirms the reliability of our echo-Doppler technique. On the other hand, the sensitivity and specificity of dipyridamole Tl201 myocardial scintigraphy in detecting myocardial ischemia has been proven to be extremely high [8,9].

In our experience, the systolic/diastolic peak velocity ratio was consistently higher than that reported by Crowley and Shapiro in 1995 [3]. However, these authors used an echocardiographical method and detected the IMA in close proximity to the anastomosis, whereas we evaluated IMA flow at a considerably more proximal level (III intercostal space or even more proximal in the patients in whom a supraclavicular approach had to be used). Luise and colleagues, and Kern and co-authors, using intravascular Doppler have reported that the systolic/diastolic flow ratio varies along the course of the IMA graft, showing a predominant systolic component in the proximal part and a superior diastolic flow in proximity of the anastomosis [6,10]. Moreover, Luise and colleagues found that the systolic/diastolic ratio is higher in a IMA graft with patent collaterals (i.e. in mammary arteries harvested without the use of specific devices through a minithoracotomy). As seven of our patients received a minimally invasive revascularization, it is obvious that the mean systo/diastolic peak velocity ratio in our series was higher than that reported by Crowley and Shapiro. In view of that, a systo/diastolic index > 1 cannot be considered an absolute predictor of IMA malfunction (as suggested by Crowley and Shapiro) but should always be related to the level where the IMA graft was detected and flow measurements performed and to the type of graft studied.

Our method is likely to have extensive future application in clinical research: its use will probably be particularly useful in the evaluation of the questioned adequacy of composite grafts to stress conditions, in the assessment of the variations of gastroepiploic grafts flow according to the gastrointestinal status and, more in general, in the study of the flow reserve and adequacy to myocardial requests of pedicled grafts in different physiological and pathological conditions.

### Acknowledgements

The authors wish to acknowledge Mr Domenico Costantini for his technical assistance in editing the photographic material.

### Table 2

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Rest</th>
<th>Dipyridamole</th>
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<tbody>
<tr>
<td>PSV (m/s)</td>
<td>0.39 ± 0.09</td>
<td>0.47 ± 0.15</td>
</tr>
<tr>
<td>ESV (m/s)</td>
<td>0.06 ± 0.03</td>
<td>0.23 ± 0.06</td>
</tr>
<tr>
<td>PDV (m/s)</td>
<td>0.27 ± 0.09</td>
<td>0.56 ± 0.23</td>
</tr>
<tr>
<td>EDV (m/s)</td>
<td>0.02 ± 0.01</td>
<td>0.06 ± 0.11</td>
</tr>
<tr>
<td>TDV (m/s)</td>
<td>0.14 ± 0.05</td>
<td>0.32 ± 0.03</td>
</tr>
<tr>
<td>TAMV (m/s)</td>
<td>0.41 ± 0.15</td>
<td>0.54 ± 0.32</td>
</tr>
<tr>
<td>PI</td>
<td>0.85 ± 0.13</td>
<td>0.79 ± 0.16</td>
</tr>
<tr>
<td>RI</td>
<td>1.51 ± 0.33</td>
<td>0.85 ± 0.28</td>
</tr>
<tr>
<td>SDR</td>
<td>2.00 ± 1.06</td>
<td>185.3 ± 67.8</td>
</tr>
<tr>
<td>Flow (ml/min)</td>
<td>77.7 ± 20.4</td>
<td>3.12 ± 0.29</td>
</tr>
<tr>
<td>Ø (mm)</td>
<td>2.98 ± 0.31</td>
<td></td>
</tr>
</tbody>
</table>

EDV, end diastolic velocity; ESV, end systolic velocity; PDV, peak diastolic velocity; PSV, peak systolic velocity; TAMV, time average mean velocity; TDV, tele-diastolic velocity; PI, pulsatility index; RI, resistance index; SDR, systolic-diastolic peak velocity ratio.

### Table 3

<table>
<thead>
<tr>
<th>Scintigraphic results</th>
<th>DYP-SPET total score</th>
<th>REST-SPET total score</th>
<th>Ischemia index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean ± S.D.</td>
<td>1.21 ± 2.89</td>
<td>0.94 ± 2.27</td>
<td>0.26 ± 0.65</td>
</tr>
</tbody>
</table>
References


