Evaluation of Flow in the Left Anterior Descending Coronary Artery But Not in the Left Internal Mammary Artery Graft Predicts Significant Stenosis of the Arterial Conduit

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OBJECTIVES The purpose of this study was to evaluate which Doppler-derived flow index best predicts new distal left anterior descending coronary artery (LAD) stenosis in patients with left internal mammary artery (LIMA) graft.

BACKGROUND The LIMA flow measurement has been proposed to assess graft function, but it may be misleading in case of new distal LAD stenosis and/or competitive flow from native LAD. Distal LAD coronary flow reserve (CFR: hyperemic/baseline peak flow velocity ratio) may be more appropriate.

METHODS The LIMA and distal LAD flow was measured by transthoracic Doppler echocardiography in 96 patients undergoing diagnostic/therapeutic coronary angiography, 7 ± 4 years after cardiac bypass surgery. The LIMA flow indexes (systolic-to-diastolic peak velocity ratio [SDPVr] >1, diastolic time velocity integral fraction [DTVIf] <0.5, and CFR <2) and LAD CFR <2 were used to predict ≥70% new LAD stenosis.

RESULTS The LAD CFR <2 predicted new LAD stenosis, found in 21 of 77 patients without competitive flow from native LAD, with significantly higher diagnostic accuracy (98%) than LIMA flow indexes (SDPVr >1 61%, DTVIf <0.5 = 69%, and CFR <2 = 72%). The LIMA flow indexes were abnormal in 17 of 19 patients with competitive graft flow, but only 5 had graft restriction, and none had significant LAD stenosis. In a multivariate model of new distal LAD stenosis prediction, competitive flow from native LAD reduced the predictive role of LIMA but not of LAD CFR.

CONCLUSIONS In patients without competitive flow from native LAD, LAD CFR is more accurate for the detection of LAD stenosis than LIMA CFR. In patients with competitive graft flow, abnormal LIMA flow patterns and blunted LIMA CFR do not reflect downstream LAD flow as LAD CFR does. (J Am Coll Cardiol 2005;45:424–32) © 2005 by the American College of Cardiology Foundation

Myocardial revascularization with the left internal mammary artery (LIMA) over the left anterior descending coronary artery (LAD) is the most used surgical strategy in patients with coronary artery disease, owing to an excellent long-term patency profile (1).

Transthoracic Doppler ultrasound has been proposed to study the LIMA-LAD conduit (2–8). In the early 1990s, the available technology allowed one to measure flow in the LIMA only from a mid-left parasternal (2) or a supraclavicular approach (3–5,7,8), at its take-off from the left subclavian artery, but not in the distal LAD. Either resting flow or coronary flow velocity reserve (CFR) in the LIMA were used to assess graft function. However, sampling the graft may be misleading, because: 1) graft flow may not predict a new distal LAD stenosis, because proximal to the stenosis the flow may be preserved (9); and 2) competitive flow from the native LAD may impair mammary flow and blunt mammary flow reserve, even in the absence of any graft stenosis. Recent advances in transthoracic color-Doppler ultrasound technology allowed imaging of the distal LAD (10,11) for the noninvasive detection of recanalization in acute anterior myocardial infarction (12), diagnosis of LAD disease by measurement of CFR (13,14), monitoring of changes in CFR after stenting (15,16), and the study of microcirculation in coronary artery disease (17).

Sampling the distal LAD in patients with LIMA graft may overcome the aforementioned limitation of sampling only the LIMA. We have therefore compared several flow-derived indexes of the LIMA graft and distal LAD to find which parameter best predicts the function of the LIMA-LAD conduit, with particular regard to a new distal LAD stenosis.

METHODS

Study patients. One hundred consecutive patients with LIMA-LAD graft, referred for coronary angiography, were
evaluated with transthoracic Doppler echocardiography for noninvasive assessment of LIMA-LAD conduit function. Ninety-six patients (82 males, 14 females, age 62 ± 8 years, range 35 to 77 years), 15 with isolated LIMA graft and 81 with associated saphenous vein grafts, had adequate assessment of CFR in the LIMA and distal LAD. One patient had a normally functioning prosthetic aortic valve. Transthoracic Doppler echocardiography was performed 7 ± 4 years (range 0.8 to 18 years) after successful cardiac surgery and 24 to 48 h before coronary angiography. Exclusion criteria were: acute coronary syndrome, previous myocardial infarction, left ventricular hypertrophy, congestive heart failure, significant valvular heart disease, and contraindications to adenosine administration. All patients were in sinus rhythm and fasting state, and provided written informed consent. All coronary active medications were withdrawn the day before the Doppler study.

**Transthoracic Doppler ultrasound.** The LIMA and LAD were imaged as previously described (2,6,10,15–17), in the left lateral decubitus, by a small multi-hertz transducer connected to an ultrasound system (Sequoia C256; Siemens-Acuson, Mountain View, California), allowing independent change of frequency between two-dimensional (3.5 to 7.0 MHz) and color Doppler ultrasound (3.5 to 6.0 MHz). The LIMA and LAD flow velocities were measured by pulsed Doppler ultrasound under color-coding guide. Briefly, to image the LIMA, the left parasternal area between the second and fourth intercostal space was scanned. The LIMA graft was identified as a tubular structure with color flow directed from base to apex, and blood flow velocity was recorded by pulsed Doppler ultrasound. The distal LAD was imaged from the fourth to fifth left intercostal space in the interventricular groove, using a modified two-chamber view (13). Care was taken to visualize the most distal tract of the artery in the periapical area. The best long-axis view in color Doppler flow imaging was obtained to maintain a <30° angle between flow and Doppler ultrasound beam. The LAD flow velocity was measured by pulsed Doppler ultrasound. All studies were continuously recorded on a half-inch S-VHS videotape, and still-frames were digitally acquired and stored in a magnetic-optical disk for off-line analysis. Systolic and diastolic peak mean velocities were measured in the LIMA and LAD, and two resting LIMA flow parameters were derived (2): systolic-to-diastolic peak velocity (SDPV) ratio, and diastolic velocity time integral (DVTI) fraction (DVTI divided by the diastolic plus the systolic velocity time integral). The CFR was measured in the LIMA and distal LAD by 90-s venous adenosine infusion (140 mcg/kg/min) as the ratio between hyperemic and baseline peak flow velocities. For each test, three baseline and three hyperemic Doppler velocities were computed and averaged. All patients had continuous heart rate and electrocardiographic monitoring. Blood pressure was recorded at baseline, during adenosine infusion, and at recovery, for each test. An SDPV ratio >1 in the LIMA (2), DVTI fraction <0.5 in the LIMA (2), and CFR <2 in the LIMA and distal LAD were used to predict significant (≥70%) stenosis along the graft-to-LAD conduit (13,16,18,19). Flow parameters were measured blind to clinical and angiographic results.

**Coronary angiography.** Cardiac catheterization was performed by the percutaneous femoral approach. The LIMA, aortocoronary grafts, and native coronary arteries were selectively visualized. Vessel lumen diameters were measured online by electronic calipers, by two expert operators, blind to the Doppler results. The outer diameter of the fluid-filled diagnostic/therapeutic catheter, centered, was used as a scaling device to obtain absolute arterial dimensions. Two orthogonal projections of the graft and/or the coronary artery lesion at end-diastole were used to measure percent lumen narrowing, if present. A graft and/or distal LAD stenosis ≥70% was considered significant.

**Reproducibility of coronary flow reserve.** Inter- and intra-observer variability of coronary Doppler ultrasound measurements in our laboratory are 3.2% and 2%, respectively (13), whereas intra-individual variability never exceeds 2 cm/s, providing a maximal ±6% difference in relative terms (15).

**Statistical analysis.** Data are expressed as mean ± SD. The BMDP software (University of California Press, Berkeley, California, 1990) was used. When data expressed proportions, average values were used in most cases. Intergroup differences were assessed by *t* tests with separate variance (BMDP-7D). Sensitivity, specificity and diagnostic accuracy were calculated and compared using chi-square results (BMDP-4F). Cutoff values were determined selecting points of potential clinical value based on literature data, namely <2 versus ≥2 for CFRs (13,16,18,19), >1 versus ≤1 for SDPV ratio (2), and <0.5 versus ≥0.5 for DVTI fraction (2). Chi-square test was also used to test significance for proportions. All possible subsets analysis (BMDP-9R) was used to predict multivariately (20), by using a linear model, the presence of new distal LAD stenosis. A series of 10 basal covariates was considered, and four different models were run to compare the role of either CFR in the LAD or LIMA and the respective contribution of LIMA flow type in the presence of either CFR in the LAD or LIMA as independent covariates. F-statistics and standard parameters produced by BMDP-9R were used to compare the four models. A comprehensive evaluation of all these parameters enabled conclusions about significance of differences. A *p* value <0.05 was considered statistically significant.

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**Abbreviations and Acronyms**

CFR = coronary flow velocity reserve

DVTI = diastolic velocity time integral

LAD = left anterior descending coronary artery

LIMA = left internal mammary artery

SDPV = systolic-to-diastolic peak velocity

CFR = coronary flow velocity reserve

DVTI = diastolic velocity time integral

LAD = left anterior descending coronary artery

LIMA = left internal mammary artery

SDPV = systolic-to-diastolic peak velocity

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RESULTS

Coronary angiography. Seventy-seven patients had proximal occlusion of the LAD that was distally supplied only by the graft (non-competitive LIMA flow from the native LAD, Group A). Nineteen patients had an open proximal LAD with competitive flow between the graft and the native LAD (Group B); in 14 of 19 patients the graft was patent, and injection of dye in the graft or in the LAD alternatively produced at the joining tract (watershed area) a wash-in and washout effect (Figs. 1A and 1B); in 5 of 19 patients the distal LIMA was diffusely restricted (≥70% stenosis) (Figs. 1C and D) (21). In Group A, 21 patients (27.3%) had a significant (≥70%) new stenosis of the LAD after the anastomosis, whereas in Group B, none of 19 patients had significant LAD narrowing (percent diameter stenosis 40 ± 14%, range 20% to 60%). None of the patients had collateral vessels from the LAD to other coronary arteries and vice versa.

Transsthoracic Doppler ultrasound. Groups were not statistically different regarding risk factors, demographic and clinical variables, but had different Doppler-derived flow dynamics (Table 1). Baseline LIMA flow was predominantly diastolic in Group A (Fig. 2A), whereas it was balanced (n = 6) or predominantly systolic (n = 13) in Group B (Figs. 2E and 2G). These flow patterns produced significantly higher SDPV ratio and lower DVTI fraction in Group B than in Group A (Table 1), indicating restricted graft flow in Group B.

Table 1. Study Population

<table>
<thead>
<tr>
<th>Demographic variables</th>
<th>Group A: Non-Competitive (n = 77)</th>
<th>Group B: Competitive (n = 19)</th>
<th>T (Separate Variance)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender (male/female = 1/0)</td>
<td>0.896</td>
<td>0.789</td>
<td>1.04</td>
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<td>Age (yrs)</td>
<td>62 ± 9</td>
<td>63 ± 7</td>
<td>-0.36</td>
<td>NS</td>
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<tr>
<td>Body surface area (m²)</td>
<td>1.86 ± 0.12</td>
<td>1.88 ± 0.18</td>
<td>-0.31</td>
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<tr>
<td>Clinical variables</td>
<td></td>
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<tr>
<td>LVEDP (mm Hg)</td>
<td>13 ± 3</td>
<td>13 ± 4</td>
<td>-0.19</td>
<td>NS</td>
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<td>Left ventricular ejection fraction (%)</td>
<td>56 ± 6</td>
<td>56 ± 5</td>
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<td>Left ventricular wall motion score index</td>
<td>1.15 ± 0.21</td>
<td>1.20 ± 0.26</td>
<td>-0.83</td>
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<td>Left ventricular hypertrophy (yes/no 1/0)</td>
<td>0.351</td>
<td>0.421</td>
<td>-0.55</td>
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<td>Previous acute myocardial infarction (yes/no 1/0)</td>
<td>0.325</td>
<td>0.368</td>
<td>-0.35</td>
<td>NS</td>
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<tr>
<td>Distal LAD stenosis ≥70% (%)</td>
<td>27.3</td>
<td>0</td>
<td>6.63†</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>LIMA stenosis ≥70% (%)</td>
<td>0</td>
<td>26.3</td>
<td>21.38†</td>
<td>&lt;0.0001</td>
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<td>Risk factors (yes/no 1/0)</td>
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<td>Cholesterol</td>
<td>0.766</td>
<td>0.632</td>
<td>1.09</td>
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<td>Diabetes mellitus</td>
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<td>0.211</td>
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<td>NS</td>
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<td>Hypertension</td>
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<td>0.526</td>
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<td>NS</td>
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<td>Smoker</td>
<td>0.610</td>
<td>0.684</td>
<td>-0.60</td>
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<td>Doppler ultrasound flow-derived variables</td>
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<tr>
<td>SDPV LIMA ratio</td>
<td>0.81 ± 0.32</td>
<td>1.68 ± 0.81</td>
<td>-4.57</td>
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<tr>
<td>DVTI LIMA fraction</td>
<td>0.70 ± 0.08</td>
<td>0.55 ± 0.12</td>
<td>5.05</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>CFR LIMA (peak velocity)</td>
<td>2.45 ± 0.86</td>
<td>1.40 ± 0.34</td>
<td>8.40</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>CFR LAD (peak velocity)</td>
<td>2.45 ± 0.99</td>
<td>2.95 ± 0.38*</td>
<td>-3.50</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Absolute difference between LIMA and LAD peak CFR</td>
<td>0.004 ± 0.73</td>
<td>-1.55 ± 0.47</td>
<td>11.36</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

*The higher CFR in the LAD in patients with flow competition reflects the absence of significant (≥70%) distal LAD stenosis in this group; conversely 21 patients without competitive flow had significant LAD stenosis. †These values are chi-square. Data are mean ± SD (also for variables having % values); only mean for variables representing proportions.

CFR = coronary flow reserve; DVTI = diastolic velocity time integral; LAD = left anterior descending coronary artery; LIMA = left internal mammary artery; LVEDP = left ventricular end-diastolic pressure; SDPV = systolic/diastolic peak velocity.
In Group A, CFR was superposable in the LIMA and LAD (absolute difference 0.004 ± 0.73) (Table 1, Fig. 3). In 21 patients with significant distal LAD stenosis, CFR in the LIMA overestimated that in the LAD (1.64 ± 0.77 and 1.27 ± 0.30, respectively), being in 5 patients even >2 (Fig. 4). In Group B, CFR in the LIMA was lower than that in the LAD (absolute difference −1.55 ± 0.47) (Table 1, Fig. 5), but it could not predict whether the graft was restricted (n = 5, CFR = 1.46 ± 0.34) or full patent (n = 14, CFR = 1.23 ± 0.32). Of note, LIMA flow indexes were abnormal (higher SDPV ratio, lower DVTI fraction, and blunted CFR) in 17 of 19 patients with competitive graft flow, but only 5 had graft restriction, and none had significant LAD stenosis.

The univariate analysis showed that CFR in the LAD had a higher diagnostic accuracy to predict a significant new distal LAD stenosis compared with the other Doppler ultrasound parameters measured in the LIMA (Table 2).
Conversely, the Doppler-derived LIMA flow indexes (SDPV ratio >1, DVTI fraction <0.5, and CFR <2) had a low diagnostic accuracy in predicting graft restriction (Table 2). Finally, sensitivity, specificity, and diagnostic accuracy of LIMA CFR to predict LAD CFR were respectively 42.5%, 89.3%, and 69.8% (chi-square 12.94, p < 0.0003), which is in overall agreement with the results shown in Table 2, where LIMA and LAD CFR are assessed with regard to the respective predictive role of either LIMA or LAD stenoses.

The multivariate analysis showed that the best predictor of significant new LAD stenosis was CFR in the LAD (Table 3, model A). Moreover, CFR in the LIMA contributed less than one-third of CFR in the LAD to the prediction of distal LAD stenosis (Table 3, model B). Flow competition from the native LAD was the main confound-

**Figure 3.** Patient with occluded proximal left anterior coronary artery (LAD), without competitive left internal mammary artery (LIMA) flow. The flow velocity reserve (CFR) was similar when assessed either at the level of the LIMA (empty arrow), or at the level of the LAD (white arrow).

**Figure 4.** Patient without competitive left internal mammary artery (LIMA) flow, occluded proximal left anterior descending coronary artery (LAD), and 80% distal, post-anastomotic LAD stenosis. The coronary flow reserve (CFR) in the LIMA is 3.7, whereas in the distal LAD it is 1.5.
ing factor when LIMA flow parameters were used to predict distal LAD stenosis (Table 3, models C and D). Globally (Table 3), when CFR was measured in the LAD (with or without LIMA flow type consideration, i.e., presence or absence of competitive graft flow), prediction of distal LAD stenosis was good (taking $r^2$ into consideration). On the other hand, prediction of distal LAD stenosis was poor when CFR was measured in the LIMA, although LIMA flow type consideration greatly ameliorated its predictive capabilities. Finally, although statistically significant, LIMA flow type contributed very little to the prediction of distal LAD stenosis when CFR was measured in the LAD.

The time required to complete a CFR test (time for the acquisition of an adequate spectral Doppler signal of baseline coronary flow velocity plus 90-s adenosine infusion) was 7 ± 5 min (range 3 to 18 min) for the LIMA and 12 ± 5 min (range 5 to 29 min) for distal LAD.

**Hemodynamic variables.** Adenosine infusion induced similar hemodynamic changes in both LIMA and LAD CFR assessments. A slight increase in heart rate (from 68 ±
stenosis in 25% of the cases (Fig. 4), because low pre-

in the distal LAD, failing to detect a significant LAD

distal LAD stenosis, CFR in the LIMA overestimated CFR

and stress (2–5,7,8), but previous reports were focused only

to image other grafts, but with the concept clear in mind

and Doppler sampling is less affected by wall motion artifact

LIMA-LAD graft can be easily studied. In particular,

and Doppler ultrasound

LIMA flow is very easy to obtain, because the vessel is still,

LAD stenosis or graft restriction (2,3,8,21). This flow

resistance to flow in the arterial conduit, owing to distal

systolic component, to coronary-like, with prominent dia-

over the LAD changes from arterial-like, with prominent

diastolic component. According to previous reports, a promi-

systolic component within the graft reflects increased

resting LIMA flow indexes are

reflect more the presence of flow competition than graft

restriction or coronary artery stenosis in the post-

anastomotic tract of the LAD. Conversely, in patients

without competitive graft flow from the native LAD and

new distal LAD stenosis, resting graft flow was often

preserved.

Limitations. With the available technology, only the

LIMA-LAD graft can be easily studied. In particular,

LIMA flow is very easy to obtain, because the vessel is still,

and Doppler sampling is less affected by wall motion artifact

than the LAD. Further technological advances are needed

to image other grafts, but with the concept clear in mind

that distal recipient artery flow should be always sampled.

Conclusions. In patients with a proximally occluded LAD

and patent LIMA, CFR in the distal LAD is more

accurate for the detection of distal LAD stenosis than

CFR in the LIMA. In patients with a proximally patent

LAD and competitive flow, resting graft flow indexes are

<table>
<thead>
<tr>
<th></th>
<th>≥70% LAD Stenosis</th>
<th>≥70% LIMA Stenosis</th>
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</thead>
<tbody>
<tr>
<td><strong>Sensitivity (%)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CFR LIMA (peak velocity)</td>
<td>42</td>
<td>12</td>
</tr>
<tr>
<td>CFR LAD (peak velocity)</td>
<td>91</td>
<td>0</td>
</tr>
<tr>
<td>SDPV LIMA ratio</td>
<td>21</td>
<td>0</td>
</tr>
<tr>
<td>DVTI LIMA fraction</td>
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<td>1</td>
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<tr>
<td><strong>Specificity (%)</strong></td>
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<tr>
<td>CFR LIMA (peak velocity)</td>
<td>93</td>
<td>100</td>
</tr>
<tr>
<td>CFR LAD (peak velocity)</td>
<td>100</td>
<td>93</td>
</tr>
<tr>
<td>SDPV LIMA ratio</td>
<td>78</td>
<td>82</td>
</tr>
<tr>
<td>DVTI LIMA fraction</td>
<td>97</td>
<td>56</td>
</tr>
<tr>
<td><strong>Diagnostic accuracy (%)</strong></td>
<td></td>
<td></td>
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<tr>
<td>CFR LIMA (peak velocity)</td>
<td>72 (17.068)</td>
<td>64 (7.385)*</td>
</tr>
<tr>
<td>CFR LAD (peak velocity)</td>
<td>98 (85.312)</td>
<td>71 (1.662)*</td>
</tr>
<tr>
<td>SDPV LIMA ratio</td>
<td>61 (0.005)</td>
<td>24 (12.810)*</td>
</tr>
<tr>
<td>DVTI LIMA fraction</td>
<td>69 (2.781)</td>
<td>6 (30.967)*</td>
</tr>
</tbody>
</table>

Cut off values were: <2 vs. ≥2 for CFRe (13,16,18,19); >1 vs. ≤1 for SDPV LIMA ratio (2), and <0.5 vs. ≥0.5 for DVTI LIMA fraction (2). Next to the values of the diagnostic accuracy the corresponding chi-square values are reported, in parentheses. Direct comparison of these chi-square values may be performed between the two groups: *Significance (p < 0.05) of the difference is concluded for absolute chi-square differences ≥3.84 (1 degree of freedom). A similar method is useful for comparison among diagnostic accuracies.

Abbreviations as in Table 1.

13 to 76 ± 15 beats/min for LAD; and from 69 ± 14 to

77 ± 14 beats/min for LIMA) was counterbalanced by a

slight decrease in mean arterial pressure (from 97 ± 6 to 89

± 8 mm Hg for LAD; and from 97 ± 6 to 89 ± 4 mm Hg

for LIMA). Baseline rate-pressure product was also similar

and did not significantly change during adenosine infusion.

Adenosine infusion. Maximal increase in coronary flow

velocity was obtained within 60 s of drug infusion, and flow

returned to baseline within 30 s of discontinuing the drug.

No major adverse reactions occurred during or after aden-
osine infusion. All patients experienced some degree of

hyperventilation, which was marked in four and rapidly

disappeared at the end of the infusion.

**DISCUSSION**

Selective coronary angiography is the gold-standard tech-

nique to evaluate graft function, but it cannot be routinely or

serially used to assess modification in graft flow (22).

Transthoracic Doppler echocardiography has been sug-

gested as an alternative tool to explore LIMA flow at rest

and stress (2–5,7,8), but previous reports were focused only

on the diagnosis of LIMA obstruction, without taking into

consideration the impact of downstream distal LAD steno-
sis and the influence of competitive flow from the native

LAD.

In our patients with proximally occluded LAD and new
distal LAD stenosis, CFR in the LIMA overestimated CFR

in the distal LAD, failing to detect a significant LAD

stenosis in 25% of the cases (Fig. 4), because low pre-

lesional branch resistances might direct flow away from the

stenosis (branch steal) (9).

In patients with flow competition between the LIMA

and LAD, measurement of CFR in the distal LAD pre-
dicted the functional status of the LIMA-LAD conduit

better than measurement in the graft alone, because compe-
titive graft flow, irrespective of the presence of graft

obstruction, blunts CFR in the LIMA but not in the LAD.

The possible causes of blunted CFR in the LIMA in case of

competitive flow with the native LAD are not known, but

we may hypothesize that the angle between the graft and the

LAD may facilitate flow in the native vessel. Competitive

graft flow from the native LAD has been considered deleterious to the function of the LIMA-LAD conduit, as it may produce diffuse narrowing of the distal LIMA in approximately 10% of the patients (23,24). This belief has been subsequently revised, because it has been experimentally and clinically observed an adequate perfusion of the distal vessel, despite competitive flow and/or graft restriction (25,26). Our results confirm these findings. In fact, in our patients with competitive flow from the native LAD, a full-patent graft was more frequent (14 of 19 patients) than a diffusely narrowed graft (5 of 19 patients), and neither competitive flow from the native LAD nor graft obstruction affected CFR in the distal LAD.

Resting LIMA flow has been previously proposed for the

identification of graft restriction or distal LAD stenosis (2,3,8,21). The resting flow pattern of the LIMA grafted over the LAD changes from arterial-like, with prominent systolic component, to coronary-like, with prominent dia-
stolic component. According to previous reports, a promi-

nent systolic component within the graft reflects increased

resistance to flow in the arterial conduit, owing to distal

LAD stenosis or graft restriction (2,3,8,21). This flow

pattern was observed in most of our patients with graft flow

competition from the native LAD, but only 5 of 19 had

graft restriction and none had new distal LAD stenosis.

Based on our results, abnormal resting LIMA flow indexes

reflect more the presence of flow competition than graft

restriction or coronary artery stenosis in the post-
anastomotic tract of the LAD. Conversely, in patients

without competitive graft flow from the native LAD and

new distal LAD stenosis, resting graft flow was often

preserved.
Table 3. Variables Included in Multivariate Analysis to Predict Significant (≥70%) De Novo Stenosis in the Distal Left Anterior Descending Coronary Artery (Best Fit Linear Models: BMDP-9R)

<table>
<thead>
<tr>
<th>Basal Covariates</th>
<th>Mean ± SD</th>
<th>Covariates Added to Basal Ones in Models A to D</th>
<th>Mean ± SD</th>
</tr>
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<tbody>
<tr>
<td>Gender (male/female = 1/0)</td>
<td>0.875</td>
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<tr>
<td>Age (yrs)</td>
<td>62 ± 8</td>
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<tr>
<td>Body surface area (m²)</td>
<td>1.86 ± 0.14</td>
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<td>LVEDP (mm Hg)</td>
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<tr>
<td>Left ventricular ejection fraction (%)</td>
<td>56 ± 6</td>
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<td>Left ventricular wall motions score index</td>
<td>1.16 ± 0.22</td>
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<tr>
<td>Baseline pressure-rate product</td>
<td>6690 ± 1372</td>
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<tr>
<td>Risk factors (present/absent = 1/0)</td>
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</tr>
<tr>
<td>SDPV LIMA ratio</td>
<td>0.99 ± 0.57</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DVTI LIMA fraction</td>
<td>0.67 ± 0.11</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Model A | Model B | Model C | Model D
---|---|---|---
Multiple r² | 0.552 | 0.207 | 0.564 | 0.395 |
F-statistics | 57.24 | 8.02 | 39.69 | 70.09 |
DF₀ | 2 | 3 | 3 | 3 |
DF₁ | 93 | 92 | 92 | 92 |
Significance (p<) | 0.0000 | 0.0001 | 0.0000 | |
Intercept ± SE | 0.704 ± 0.23 (t = 3.06) | 0.556 ± 0.220 (t = 2.53) | 0.686 ± 0.228 (t = 3.00) | 1.162 ± 0.145 (t = 7.98) |

Entering Covariates | Age | LAD CFR | LVEDP | SDPV | LIMA CFR | Age | LAD CFR | LIMA Flow Type | Gender | LIMA CFR | LIMA Flow Type |
---|---|---|---|---|---|---|---|---|---|---|---|
Coefficient | 0.0056 | −0.327 | 0.021 | −0.180 | −0.194 | 0.0058 | −0.316 | −0.118 | −0.189 | −0.293 | −0.602 |
SE | 0.0034 | 0.031 | 0.012 | 0.070 | 0.045 | 0.0033 | 0.031 | 0.073 | 0.102 | 0.042 | 0.096 |
Stand. coeff. | 0.114 | −0.731 | 0.158 | −0.248 | −0.416 | 0.118 | −0.706 | −0.114 | −0.152 | −0.629 | −0.580 |
T | 1.64 | −10.53 | 1.69 | −2.56 | −4.28 | 1.72 | −10.01 | −1.62 | −1.85 | −6.84 | −6.26 |
χ² | 0.104 | 0.000 | 0.094 | 0.012 | 0.000 | 0.089 | 0.000 | 0.110 | 0.067 | 0.000 | 0.000 |
Tolerance | 0.999 | 0.999 | 0.985 | 0.915 | 0.912 | 0.997 | 0.952 | 0.951 | 0.983 | 0.775 | 0.764 |
Contribution to r² | 0.013 | 0.533 | 0.024 | 0.056 | 0.158 | 0.014 | 0.474 | 0.012 | 0.022 | 0.307 | 0.257 |

Model A: Basal covariates plus LAD CFR; Model B: Basal covariates plus LIMA CFR; Model C: Basal covariates plus LAD CFR and LIMA flow type consideration; Model D: Basal covariates plus LAD CFR and LIMA flow type consideration. Models A to D are different in that each one has a set of 10 basal covariates and either LAD or LIMA CFR, without (models A and B) or with (models C and D) LIMA flow type consideration. Thus models A and B have 11 covariates, whereas models C and D have 12 covariates. Direct comparison among models (taking DF₀ and DF₁ into account) may be performed considering that F-values must be adjusted for numerator degrees of freedom (DF₀) and denominator degrees of freedom (DF₁).

REFERENCES

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abnormal and CFR in the LIMA is blunted, but do not reflect downstream LAD flow, whereas CFR in the distal LAD does. Therefore, the non-invasive investigation of LIMA-LAD conduit by transthoracic Doppler ultrasound should be performed by measuring CFR in the distal LAD, whereas measurement in the graft alone may be misleading.

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