Intravascular physiologic evaluation of the left anterior small thoracotomy operation: a novel approach to left anterior descending artery revascularization

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Key words:
Coronary angiography; Intracoronary Doppler; Minimally invasive coronary artery bypass.

Background. **Efficacy and long-term patency rate of the left internal mammary artery (LIMA) conduits for revascularization of the left anterior descending coronary artery (LAD) has been demonstrated, with improved results as compared to the saphenous vein graft operation. Novel approaches to LAD revascularization including the use of the left anterior small thoracotomy (LAST) operation with persistence of the intercostal arteries compared to the traditional LIMA operation have not been reported. This study evaluated flow characteristics of LAST operation.**

Methods. **Phasic blood flow velocity in the proximal and distal arterial conduit segments was measured in 30 patients by intravascular Doppler flow wire after surgical revascularization of the LAD: 15 patients were revascularized by conventional operation using the LIMA (Group A), and 15 patients were submitted to the LAST operation (Group B). All patients underwent coronary angiography and ventriculography at 116 – 111 days after operation. Only angiographically normal grafts with normal left ventricular wall motion and coronary arteries free from significant distal stenosis were included for coronary flow velocity and reserve measurements.**

Results. **The diastolic/systolic velocity ratio in the proximal portion of the internal mammary artery was similar in the two groups (Group A 0.8 – 0.2 vs Group B 0.7 – 0.3, p = NS). Distal diastolic/systolic velocity ratio in Group A (1.7 – 0.1) was higher than Group B (0.9 – 0.3, p < 0.001). There were no differences in basal average peak velocity or coronary flow reserve between the proximal and distal segments for either groups.**

Conclusions. **Although proximal phasic coronary flow patterns between the two groups were similar, distal diastolic/systolic velocity ratio was higher in the LIMA than in the LAST. This difference may be related to the persistence of the intercostal artery in the LAST operation. These data confirm the continued patency and similar functional flow patterns compared to the conventional LIMA operation, supporting further investigation and application of this novel approach to LAD revascularization.**

(Ital Heart J 2000; 1 (8): 549-554)

Received May 15, 2000; accepted June 15, 2000.

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Introduction

The left internal mammary artery (LIMA) is today considered the graft of choice for the surgical bypass of the left anterior descending coronary artery (LAD) because of the superior long-term patency rates compared to the saphenous vein graft[1,2]. Accordingly, there has been an increased use of alternative arterial coronary bypass conduits like the right gastroepiploic artery[3], the inferior epigastric artery[4], and the radial artery[5] employed alone as free graft or in complex arterial conduits arranged like an inverted Y with *in situ* LIMA[6]. Moreover the recent use of LIMA distal anastomosis performed by means of the left anterior small thoracotomy (LAST) operation without cardiopulmonary bypass has extended the applications of the arterial coronary bypass conduits[7]. However the flow patterns of these heterogeneous arterial conduits are not completely characterized[8]. In particular at present there is no physiologic data on the LAST operation compared to the conventional LIMA operation. Accurate measurement of intravascular phasic blood flow velocities during a routine cardiac catheterization can be evaluated by a Doppler-tipped angioplasty guidewire[9,10]. While differences in phasic blood flow characteristics of the LIMA and saphenous vein graft on the LAD have been described by Bach et al.[11], and the functional evaluation of the LIMA on the LAD in the early and late postoperative periods has been performed by Akasaka et al.[12] and by Gurne et al.[13], the LAST operation has not been previously studied. Therefore, the aim of this study was to analyze the flow characteristics of the LAST operation compared to the conventional LIMA operation performed by median sternotomy and cardiopulmonary bypass. The hypothesis was that the LAST operation is a revascularization technique with similar or superior functional results when compared to the conventional LIMA operation.

Methods

Patient characteristics. The study population included 15 patients who underwent conventional internal mammary artery implanted to the LAD by means of median sternotomy (Group A) and 15 patients with the LAST operation (Group B). All patients had control of cardiac catheterization at 4 – 4 months postoperatively. Group A was studied 159 – 112 days after surgery (range 5-300 days with 5 patients studied at hospital discharge). Group B was studied 77 – 99 days after surgery (range 5-250 days with 10 patients studied at hospital discharge). The study was performed as part of routine postoperative follow-up. All patients were asymptomatic at the time of the study. Study inclusion criteria were patent grafts at the time of restudy with native coronary arteries free from significant distal stenoses and the absence of severe wall motion abnormalities in the LAD distribution on ventriculography.

All patients received diazepam (2 to 4 mg i.v.) as precatheterization medication and 3000 to 5000 IU heparin prior to the introduction of the Doppler guidewire and flow velocity measurements. All patients gave their informed written consent to the study. The study was approved by the Hospital Investigation Review Board.

Cardiac catheterization and angiography. Selective coronary angiography was performed with the Judkins technique using hand injection of low osmolar radiographic contrast media. Vessel diameter was quantitated at the sites of flow velocity measurement from the cineangiograms using an electronic digital caliper and the on-line analysis system (ACA-DCI-TM, Philips, Eindhoven, The Netherlands)[14]. Vessel shear rate was calculated using the formula 4(APV)/r, where APV is the average peak velocity in cm/s and r is the vessel radius in cm; units are expressed in s^{-1}[15]. Left ventriculography was performed by the biplane technique.

Intravascular flow velocity measurement (Figs. 1 and 2). The Doppler-tipped wire is a 0.018 in (diameter 0.46 mm), 175-cm long, flexible and steerable guidewire with a floppy distal end mounting a 12-MHz piezoelectric transducer at the tip[9] (Flowire Cardiometrics, Mountain View, CA, USA). The sample volume is positioned at a distance of 5.2 mm from the transducer. At this distance the sample volume has a width of approximately 2 mm due to the divergent ultrasound beam, 27 arc from the long axis, so that a large part of the flow velocity profile is included in the sample volume. The

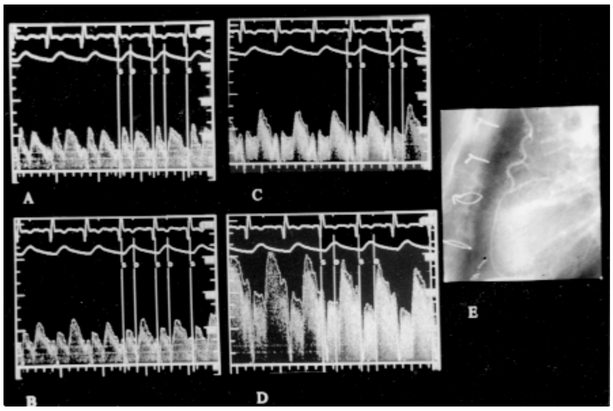

Figure 1. *Conventional internal mammary artery anastomosed on the left anterior descending artery.* A: *phasic blood flow velocity of the proximal internal mammary artery. It is present the typical diastolic/systolic pattern: average peak velocity (APV) 28 cm/s, diastolic/systolic velocity ratio 0.9.* B: *phasic blood flow velocity of the distal internal mammary artery. The diastolic flow velocity is prevalent, APV 24 cm/s, diastolic/systolic velocity ratio 1.6.* C: *phasic blood flow velocity of the left anterior descending coronary artery distal to the internal mammary artery anastomosis. There is a typical coronary flow pattern: AVP 27 cm/s, diastolic/systolic velocity ratio 2.0.* D: *phasic blood flow velocity of the left anterior descending coronary artery after adenosine hyperemia induction. AVP 81 cm/s, diastolic/systolic velocity ratio 2.0, coronary flow reserve 3.0.* E: *lateral angiographic projection of the distal anastomosis.*

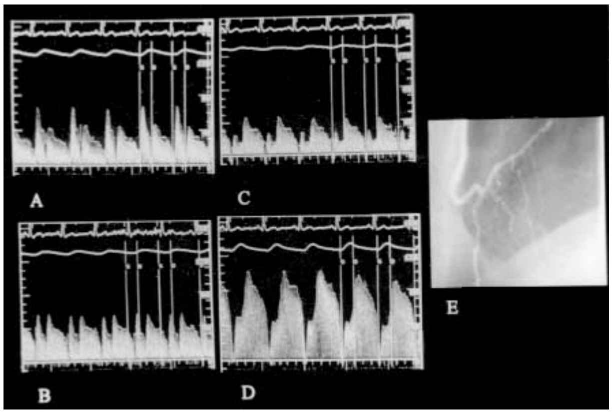

Figure 2. *Left anterior small thoracotomy operation.* A: *phasic blood flow velocity of the proximal internal mammary artery. It is present a diastolic/systolic pattern: average peak velocity (APV) 28 cm/s, diastolic/systolic velocity ratio 0.7.* B: *phasic blood flow velocity of the distal internal mammary artery (distal to the last intercostal artery). There is a diastolic/systolic pattern: APV 27 cm/s, diastolic/systolic velocity ratio 1.0.* C: *phasic blood flow velocity of the left anterior descending coronary artery distal to the internal mammary artery anastomosis. There is a typical coronary flow pattern: APV: 25 cm/s, diastolic/systolic velocity ratio 2.0.* D: *phasic blood flow velocity of the left anterior descending coronary artery after adenosine hyperemia induction. APV 75 cm/s, diastolic/systolic velocity ratio 1.9, coronary flow reserve 3.0.* E: *enlargement of the lateral angiographic projection of the distal anastomosis, note the internal mammary artery course near to the sternum and the U shape of the artery before the anastomosis.*

pulse repetition frequency (17-96 KHz) varies with the velocity range selected (50-600 cm/s) so that flow velocities up to 6 m/s can be recorded without frequency aliasing. A real time fast Fourier transform algorithm is used for the analysis of the Doppler signal, to increase the reliability of the measurements[16]. The frequency response of the system calculates approximately 90 spectra per second. Simultaneous electrocardiogram and arterial pressure signals are also input to the video display. Digitized spectral velocity from three cardiac cycles was averaged to compute the following data: APV and diastolic/systolic peak velocity ratio. The Doppler guidewire has been validated for accurately measuring phasic flow velocity patterns[9,10]. Flow velocity data were acquired in the proximal and distal one third of the arterial conduits. For the LAST group the distal velocity was obtained beyond the last intercostal vessel. The data were acquired only after acquisition of a stable flow velocity signal.

In both groups blood flow velocity in the native LAD, distal to the graft anastomosis, was also measured. Basal blood flow velocity was acquired 3-5 min from the last contrast injection.

Coronary flow reserve was calculated as the ratio of peak blood flow velocity after adenosine intravessel bolus administration (12-14 µg) to the blood flow at rest[17-20].

Statistical analysis. Results are expressed as mean value – SD unless otherwise indicated. Statistical analysis comparing the two groups was performed with unpaired two-tailed Student s t testing. One-way analysis of variance was used to compare results of angiographic and phasic flow data at the proximal and distal segment. Differences in time from surgery to angiography in each group were analyzed by the χ^2 test. A p value of < 0.05 was considered statistically significant.

Results

Demographic data (Table I). Group A (LIMA) included 11 men and 4 women. Group B had 14 men and 1 woman. There was no difference in patient age. Group A was studied 159 – 112 days postoperatively, while Group B was examined 77 – 99 days after surgery (p = 0.04).

Catheterization and angiographic data (Tables I-IV). There was no difference in heart rate, mean blood pressure, left ventricular end-diastolic pressure, or left ventricular ejection fraction. The angiographic percent LAD proximal stenosis and proximal and distal internal mammary artery vessel diameter were also similar between groups. A significantly higher diameter was observed in patients studied for > 6 months vs those studied in the immediate postoperative period (68% proximal; 72% distal).

Phasic flow velocity data (Tables II-IV). In the proximal and distal vessel segments, APV and shear rate were not significantly different (Table II). The proximal diastolic/systolic peak velocity ratio was similar between groups (Group A 0.8 – 0.2 vs Group B 0.7 – 0.3, p = NS). The distal diastolic/systolic peak velocity ratio of Group A was significantly greater than Group B (Group A 1.7 – 0.1 vs Group B 0.9 – 0.3, p < 0.001).

In patients studied early postoperatively (< 15 days) and late postoperatively (> 6 months), APV and shear rate were higher in patients studied early in both groups (Table IV). A significant difference was noted in coronary flow reserve in both groups in patients studied < 15

Table I. Clinical characteristics and cardiac catheterization data.

	LIMA (n=15)	LAST (n=15)
Demographic data		
Age (years)	62 – 11	62 – 10
Sex (M/F)	11/4	14/1
Early and late postoperative evaluation	3/12	10/5
Catheterization data		
Heart rate (b/min)	68 – 6	75 – 10
Mean blood pressure (mmHg)	96 – 5	98 – 9
LVEDP (mmHg)	12 – 3	10 – 4
Angiographic data		
% stenosis LAD	98 – 3	97 – 3
LVEF (%)	60 – 5	58 – 6
Vessel diameter (mm)		
Proximal	3.5 – 0.7	3.4 – 0.8
Distal	2.6 – 0.5	2.6 – 0.6

Values are expressed as mean – SD. LIMA = left internal mammary artery; LAST = left anterior small thoracotomy; LVEDP = left ventricular end-diastolic pressure; LVEF = left ventricular ejection fraction.

Table II. Phasic flow characteristics.

	LIMA (n=15)	LAST (n=15)
Bypass graft at rest		
APV (cm/s)		
Proximal	25 – 7	27 – 5
Distal	26 – 5	25 – 5
Distal LDA	24 – 9	25 – 9
Shear rate		
Proximal	667 – 303	684 – 250
Distal	760 – 285	829 – 288
DSVR		
Proximal	0.8 – 0.2	0.7 – 0.3
Distal	1.7 – 0.1*	0.9 – 0.3*
Distal LAD	2.4 – 0.6	2.5 – 0.5
Bypass graft flow reserve		
Proximal	2.6 – 0.7	2.6 – 0.6
Distal	2.5 – 0.7	2.6 – 0.6

Value are expressed as mean – SD. APV = average peak velocity; DSVR = diastolic/systolic velocity ratio. Other abbreviations as in table I. Shear rate is defined as 4(APV)/r (see text for details)[14]. * p < 0.001.

Table III. Angiographic and phasic flow data: individual patients of groups A and B.

	APVp	APVd	DSVRp	DSVRd	Proximal diameter (mm)	Distal diameter (mm)	CFRp	CFRd	Postop.
Group A									
1	25	26	0.78	1.70	3.50	2.40	2.80	2.70	190
2	32	30	1.01	1.90	2.50	2.20	1.60	1.50	10
3	19	21	0.49	1.60	4.50	2.80	3.50	2.90	250
4	23	23	0.95	1.80	3.40	3.20	3.00	3.20	190
5	26	26	0.60	1.70	3.70	3.20	2.80	2.90	230
6	34	30	0.75	1.60	3.00	2.10	2.00	1.90	15
7	20	23	0.88	1.80	3.20	2.20	2.50	2.80	211
8	17	19	0.90	1.80	4.50	3.20	3.50	3.20	300
9	18	18	0.94	1.95	4.10	3.10	2.90	2.90	231
10	22	21	0.54	1.70	3.60	2.80	3.00	2.90	211
11	34	30	0.74	1.90	2.60	2.00	1.50	1.60	5
12	32	31	0.85	1.60	2.70	2.10	1.80	1.80	12
13	18	17	0.90	1.60	4.50	3.00	3.20	3.00	268
14	20	21	0.69	1.70	3.80	2.80	3.00	3.50	210
15	34	33	0.75	1.80	2.30	2.10	1.40	1.30	12
Mean – SD	25 – 7	26 – 5	0.78 – 0.2	1.7 – 0.1	3.5 – 0.7	2.6 – 0.5	2.6 – 0.7	2.5 – 0.7	159 – 112
Group B									
1	27	25	0.69	0.90	3.40	2.40	2.60	2.10	10
2	24	23	0.93	1.20	3.80	2.70	2.90	2.70	182
3	32	30	0.30	0.46	2.50	2.10	1.70	1.80	5
4	30	27	0.40	0.57	2.70	2.00	2.50	2.50	10
5	20	18	0.51	0.69	4.30	3.50	3.60	3.40	250
6	19	17	0.89	0.88	4.60	3.60	3.30	3.20	221
7	18	19	0.80	0.99	4.70	3.50	3.10	2.90	210
8	24	21	0.60	0.80	3.80	2.70	3.60	3.50	190
9	30	29	0.98	0.98	2.60	2.10	2.00	1.90	6
10	28	26	1.03	1.02	3.40	2.40	2.40	2.30	15
11	29	27	0.61	0.89	3.30	2.50	1.90	1.70	11
12	29	27	1.01	1.30	3.20	2.50	2.40	2.30	12
13	28	25	0.42	0.63	3.40	2.50	1.90	1.90	12
14	30	30	0.32	0.50	2.30	2.00	2.90	2.30	7
15	31	32	0.79	0.92	2.50	2.10	2.10	2.00	9
Mean – SD	27 – 5	25 – 5	0.7 – 0.3	0.9 – 0.3	3.4 – 0.8	2.6 – 0.6	2.6 – 0.6	2.6 – 0.6	77 – 99

APVp, APVd = proximal and distal average peak velocity; CFRp, CFRd = proximal and distal coronary flow reserve; DSVRp, DSVRd = proximal and distal diastolic/systolic velocity ratio; Postop. = postoperative evaluation.

Table IV. Data differences in the study groups between postoperative times.

	Group A		Group B	
	< 15 days	> 6 months	< 15 days	> 6 months
No. patients	5	10	5	10
Proximal vessel diameter	2.6 – 0.3*	3.9 – 0.5*	2.9 – 0.5*	4.2 – 0.4*
Distal vessel diameter	2.1 – 0.07*	2.9 – 0.3*	2.3 – 0.2*	3.2 – 0.5*
Proximal APV	33 – 12**	21 – 3**	29 – 2*	21 – 3*
Distal APV	31 – 13**	21 – 3**	28 – 2	20 – 2
Proximal shear rate	1021 – 106*	490 – 182*	825 – 165*	405 – 126*
Distal shear rate	1084 – 196*	599 – 150*	997 – 40*	493 – 126*
Proximal CFR	1.7 – 0.2*	3.0 – 0.3*	2.2 – 0.4*	3.3 – 0.3*
Distal CFR	1.6 – 0.2*	3.0 – 0.2*	1.9 – 0.7*	3.1 – 0.3*

Abbreviations as in table III. Statistical analysis about the patients data of the same group evaluated at early (< 15 days) and late postoperatively (> 6 months). * $p < 0.001$; ** $p < 0.05$.

days postoperatively and those evaluated after 6 months (Group A proximal 1.7 – 0.2 vs 3.0 – 0.3, distal 1.6 – 0.2 vs 3.0 – 0.2, respectively, $p < 0.001$; Group B proximal 2.2 – 0.4 vs 3.3 – 0.3, distal 1.9 – 0.7 vs 3.1 – 0.3, respectively, $p < 0.001$) (Table IV).

Discussion

This study demonstrates that patients undergoing the LAST operation, compared to the conventional LIMA, have similar angiogarphic characteristics, phasic velocity flow patterns, coronary flow reserve and shear rates. A difference was observed in a lower diastolic/systolic velocity ratio in the distal internal mammary artery in patients with the LAST operation.

Anatomic variations. The LIMA average vessel diameter was similar between groups. In the present study patients examined early postoperatively had a narrower proximal and distal diameter than those evaluated > 6 months later, likely related to the increase in flow capacity and flow-mediated vasodilation of these vessels after 6 months[11].

Physiologic differences. Normally the LAD phasic peak velocity ratio has a diastolic predominance with a normal diastolic/systolic peak velocity ratio value > 1.5[9]. The phasic blood flow velocity of the conventional LIMA anastomosed to the LAD (Group A) presents a transition of phasic flow patterns from the proximal to the distal segments. The phasic blood flow displays a transition from proximal systolic-phasic velocity to distal diastolic-phasic flow[10-12]. The present study demonstrates that the phasic peak blood flow of Group B was attenuated representing a modulation of systolic/diastolic flow peak velocity ratio in the distal segment to the typical diastolic coronary pattern of the LAD. Our data, moreover, provide unique information about the normal flow velocity data of the LAST operation which may be used as reference for the correlation with noninvasive transthoracic Doppler echocardiography, when performed along the left parasternal border[21].

Coronary flow reserve and bypass conduits. As expected, there was no difference in coronary flow reserve at the proximal and distal graft segments between the two study groups. We observed a significant difference between the *in situ* internal mammary artery origin groups studied early postoperatively and those evaluated > 6 months later probably due to an increase in flow conduits. Since no difference in the determinants of myocardial oxygen consumption[16] (heart rate, mean blood pressure and left ventricular end-diastolic pressure) was present during the study, the evaluation of graft flow reserve may be reproducible in the different types of bypass studied.

Left anterior small thoracotomy operation and coronary steal. No difference was observed in the measurement of coronary flow reserve at the vessel segment distal to the last intercostal artery in the LAST operation compared to the conventional LIMA. In our model, adenosine produces myocardial hyperemia[17-20] distal to the origin of intercostal arteries allowing quantitation of the coronary flow and the coronary flow reserve. The results reveal a different type of basal phasic peak velocity blood flow in the LAST operation compared to the conventional LIMA, possibly due to the preserved patency of the intercostal arteries.

Intercostal arteries do not generally cause coronary steal in this type of arterial conduit for two reasons: 1) the coronary flow reserve is normal in comparison with that of the conventional LIMA operation, and 2) blood supply to the chest wall and the sternum is systolic while myocardial flow is diastolic, and thus out of phase to produce a coronary steal. In fact, since flow will be preferentially directed toward the region of lesser resistance, in our model of the LAST operation, the predominant diastolic perfusion will be to the LAD as shown by decreased diastolic/systolic peak velocity ratio with diastolic flow predominance. The present data, however, are not able to exclude the existence of other types of steal syndromes reported[22].

Study limitations. The intravessel Doppler measurements obtained in our study present the intrinsic technical limitation previously described[8-10]. The coronary flow reserve evaluation was measured by intravessel adenosine bolus, performed by hand injection, with the same technique previously described[18,19]. The presence of native antegrade flow through the LAD may influence the results of the distal anastomotic flow but it does not influence distal maximal hyperemic flow. Proximal LAD stenoses in our study had various degrees of significant narrowing, but none < 92% by an electronic caliper.

In conclusion, these data indicated similar blood flow patterns in the LIMA/LAST groups, with the exception of the lower diastolic/systolic velocity ratio at the distal internal mammary artery portion of the LAST. The phasic blood flow differences may be related to the persistence of the intercostal arteries in the LAST operation, a result which does not influence the shear rate or the flow reserve. These data confirm the similar patency and physiology of the LAST operation compared to the open-chest internal mammary artery operation. These findings have important clinical implications for future indications and performance of this novel approach to LAD revascularization.

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