Original articles

Noninvasive assessment of left and right internal mammary artery graft patency using transthoracic color Doppler echocardiography

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Key words:
Coronary artery bypass graft; Dipyridamole; Echocardiography.

Background. **The aim of this study was to evaluate the patency of left and right internal mammary artery grafts respectively on the left anterior descending and right coronary artery by noninvasive transthoracic color Doppler echocardiography.**

Methods. **Thirty eight patients (34 males, 4 females, mean age 59 ± 2 years), with a history of coronary artery bypass grafting for a total of 42 mammary artery grafts, were studied by means of color Doppler echocardiography at baseline and after vasodilation with dipyridamole infusion (0.56 mg/kg i.v. over 4 min). The evaluated echocardiographic parameters included: systolic (SPV) and diastolic peak velocities (DPV), systolic (SVI) and diastolic velocity-time integrals (DVI), and the DPV/SPV and DVI/SVI ratios. We also calculated the dipyridamole infusion to baseline ratio of the diastolic peak velocities ($DPV_{dip}/DPV_{baseline}$), the index of internal mammary artery graft blood flow reserve and the percent DPV increment as an index of graft stenosis.**

Results. **On the basis of coronary angiography, two groups were selected: group A (36 mammary grafts) with patent grafts and group B (6 mammary grafts) with moderate or severe stenosis of the grafts. Group A had a predominant diastolic pattern with a DPV of 0.24 ± 0.13 m/s, whereas group B had a predominant systolic pattern with a reduced DPV of 0.12 ± 0.03 m/s ($p < 0.01$). Dipyridamole induced an increase in the DPV respectively of 86.8 ± 64.4% in group A and 13.8 ± 15.9% in group B ($p < 0.001$). Statistical analysis (Mann-Whitney test) revealed a significant difference between the two groups for the baseline DPV ($p < 0.01$), DVI ($p < 0.05$), DPV/SPV ratio ($p < 0.005$), DVI/SVI ratio ($p < 0.05$), and for the after dipyridamole infusion values: DPV ($p < 0.0001$), DVI ($p < 0.005$), DPV/SPV ratio ($p < 0.001$), and DVI/SVI ratio ($p < 0.05$). Multivariate analysis showed that the percent DPV increment, the $DPV_{dip}/DPV_{baseline}$ ratio and the baseline DPV were independent determinants of the stenosis as evaluated at angiography ($\beta = -0.38$, $p < 0.01$; $\beta = -0.37$, $p < 0.01$, and $\beta = -0.33$, $p < 0.05$, respectively; cumulative $r^2 = 0.25$, standard error 0.30 m/s, $p < 0.005$).**

Conclusions. **The echocardiographic evaluation of the mammary grafts is a simple, noninvasive method for the assessment of the graft patency and of the functional status of the vessel. The percent DPV increment and baseline DPV were independent determinants of mammary graft stenosis.**

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Introduction

The evaluation of chest pain in patients with recurrence of anginal symptoms after coronary artery bypass surgery may represent a problem because symptoms are often atypical and the results of provocative tests may be dubious or non-diagnostic. Cardiac catheterization is the method of choice for the assessment of the patency of internal mammary artery grafts (MG)[1,2]. Recent studies have shown that measurements of the MG velocity profile using transthoracic color Doppler echocardiography are feasible[3-5]. After pharmacological vasodilation, a lack of an increase in blood flow could be suggestive of the presence of significant MG stenosis[6]. In view of this, it is reasonable to suggest that a noninvasive, easily reproducible method for the assessment of left and right internal MG blood velocities and of the flow reserve with a high diagnostic power would be useful.

The aim of this study was to evaluate, by echocardiography, the patency of the left and right internal MG on the left anterior descending and right coronary arteries respectively, at baseline and after dipyridamole infusion.

Methods

From June 1998 to September 1999, 38 consecutive patients (34 males, 4 females, mean age 59 ± 2 years), with a history of

coronary artery bypass surgery for a total of 42 MG, undergoing coronary angiography because of the recurrence of anginal symptoms, were studied after their informed consent and approval of the Ethics Committee of the Monaldi Hospital were obtained. The criteria used to define the pain as "typical" or "atypical" were subjective, because the definition of "atypical chest pain" is largely ill defined. In our study population, 14 patients (37%) presented with pain definable as "typical angina" on the grounds of its thoracic location, duration and radiation; 10/14 patients reported the onset of chest pain during physical activity. Twenty-four patients (63%) presented with pain definable as "atypical": 11/24 patients referred chest wall tenderness, spontaneous in 7 and precipitated by neck or back movements in 4 patients; intermittent dysphagia was present in 8 other patients; the other 5 patients presented with short lasting and spontaneous breathlessness.

An ischemic provocative test was performed in all patients: an exercise test (treadmill test according to the modified Bruce protocol) in 27 patients and a stress-echo (dobutamine stress echocardiography) in 11. During the treadmill test, both blood pressure and 12-lead ECG monitoring was performed. The treadmill test was considered positive for ischemia if there was a horizontal or downsloping ST-segment depression ≥ 1 mm at 80 ms after the J-point. Dobutamine stress echocardiography was performed according to a standard protocol. A 12-lead ECG was recorded at baseline and at each stage, and echocardiographic imaging was performed continuously. The regional wall motion was semiquantitatively assessed by an echocardiographer who was unaware of the patients' clinical history. The wall motion at rest and at each step was scored 1 through 5 according to a 16-segment model. The development of new or worsening wall motion abnormalities was considered indicative of myocardial ischemia. The treadmill test was considered positive in 8 patients (7 with "typical" and only one with "atypical" angina), whereas dobutamine stress echocardiography was positive only in 3 patients (all with "typical angina"). The clinical characteristics of the patients are shown in table I.

Echocardiography was performed using a Sequoia ultrasound machine (Acuson Corporation, Mountain View, CA, USA) equipped with a small transthoracic multiHertz vector transducer (3.5-7 MHz), easily adaptable to narrow intercostal spaces. Both internal mammary vessels were localized by means of low non-directional color flow mapping. Patients were examined in the left lateral position using a left parasternal window and the long-axis sections were adjusted in order to identify the left and right internal MG, in color Doppler and in two-dimensional echocardiography[7], from their origin from the subclavian artery to their anastomosis to the coronary artery. Once the position of the mammary artery was identified, intraluminal flow signals were obtained using the pulsed Doppler method. The sampling volume was located within the vessel lumen with the probe placed as parallel as possible to the long axis of the artery.

Table I. Clinical characteristics of the patients.

No. patients	38
Sex (M/F)	34/4
Age (years)	59 ± 2
Previous myocardial infarction	18
Anterior	12
Inferior	6
Previous unstable angina	20
Time from CABG (years)	5 ± 2
Bypass mammary artery graft	
Isolated LIMA to DA	14
LIMA to DA + saphenous vein graft	22
LIMA to DA + RIMA to RCA	6
Typical chest pain	14 (37%)
Atypical chest pain	24 (63%)
Positive provocative tests	11 (29%)

CABG = coronary artery bypass graft; DA = descending anterior coronary artery; LIMA = left internal mammary artery; RCA = right coronary artery; RIMA = right internal mammary artery.

In all cases, in the analyzed artery a biphasic pattern of blood flow corresponding to the systolic and diastolic waves was detected. MG flow shows a gradual transition in its pattern from a predominant systolic velocity proximally (at the origin from the subclavian artery) to a predominant diastolic velocity distally (next to the anastomosis with the coronary artery)[8]. Therefore, in our assessment of the MG flow velocities we chose to use a parasternal window close to the anastomosis, instead of a subclavicular approach, in order to avoid artifacts due to the influence of the subclavian artery flow velocity (Fig. 1). It is essential to localize the best transthoracic window in order to minimize the angle between the Doppler beam and the long axis of the artery. Furthermore, this approach allows for a correct post-stenotic flow velocity assessment by avoiding the possible influence of the residual mammary artery collateral flow after vasodilation.

Coronary angiography was performed in accordance with the standard Judkins technique. Multiple projections were used to evaluate the left and right internal MG and stenoses were classified on the basis of the visually determined percent narrowing as severe (> 70%), moderate (40 to 70%) and mild or trivial (< 40%).

On the basis of coronary angiography, two groups were selected: group A, which consisted of 36 patent MG and group B, formed by 6 MG with moderate or severe stenosis.

A low-dose dipyridamole infusion (0.56 mg/kg in 4 min) was performed during the determination of the blood flow velocities in both the left and right internal MG. The following parameters were obtained at baseline and after dipyridamole infusion: systolic (SPV) and diastolic peak velocities (DPV), systolic (SVI) and

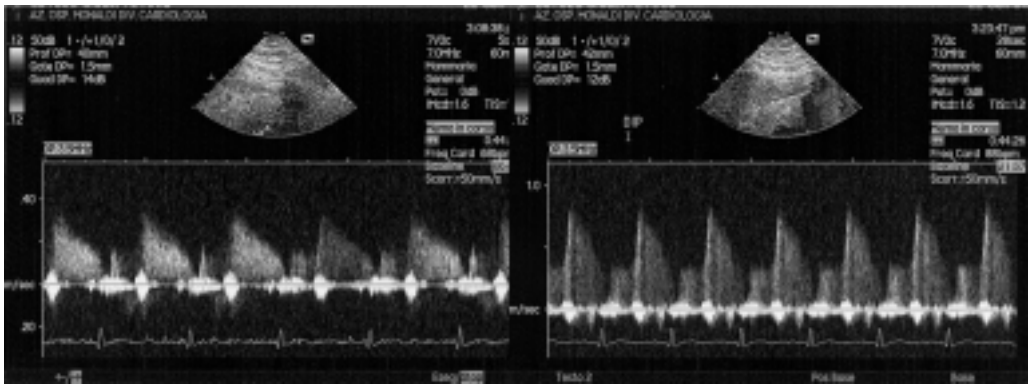

Figure 1. *A case of a mammary artery graft with a normally increased diastolic flow: following dipyridamole infusion the diastolic peak velocity is significantly increased with respect to baseline.*

diastolic velocity-time integrals (DVI), DPV/SPV and DVI/SVI ratios. The blood pressure and ECG were monitored throughout the entire protocol. We also calculated the dipyridamole infusion to baseline ratios of the diastolic peak velocities ($DPV_{dip}/DPV_{baseline}$), the index of the internal MG blood flow reserve and the percent DPV increment as an index of graft stenosis.

All images were recorded on a magneto-optical disk and later analyzed by two observers (LDS and SC), unaware of the angiographic result, and their measurements were averaged.

Statistical analysis. The analyses were performed using the SPSS for windows release 8.0 (SPSS Inc., Chicago, IL, USA). Data are presented as mean ± SD. Mann-Whitney's test for non-parametric data was used to assess intergroup differences. Linear regression analyses and the partial correlation test using Pearson's method were done to assess univariate relations. Stepwise forwards, multiple regression analyses were performed to weigh the independent effects of potential determinants, not obviously related to each other, on a dependent variable. Differences were considered significant at $p < 0.05$. We also calculated the sensitivity and specificity of the percent flow increase for graft stenosis using standard formulas, with coronary angiography as gold standard.

Results

Doppler echocardiographic analysis. The left and right internal MG were identified in all patients through a parasternal window. The analysis of the Doppler mammary artery flow measurements is reported in table II. At baseline, the systolic indexes (SPV and SVI) were not significantly different between the two groups. On the other hand, the diastolic indexes DPV ($p < 0.01$) and DVI ($p < 0.05$) were significantly reduced in group B with respect to group A. Consequently, even the DPV/SPV ratio ($p < 0.005$) and the DVI/SVI ratio ($p < 0.05$) were significantly impaired in group B.

Table II. Doppler echocardiographic data at baseline and after dipyridamole infusion.

	Group A (n=36)	Group B (n=6)	p
SPV (m/s)	0.24 ± 0.09	0.26 ± 0.05	NS
DPV (m/s)	0.24 ± 0.13	0.12 ± 0.03	< 0.01
DPV/SPV ratio	1.17 ± 0.78	0.46 ± 0.05	< 0.005
SVI (m)	0.05 ± 0.02	0.05 ± 0.02	NS
DVI (m)	0.9 ± 0.04	0.05 ± 0.03	< 0.05
DVI/SVI ratio	1.95 ± 1.3	0.94 ± 0.2	< 0.05
Dip-SPV (m/s)	0.37 ± 0.14	0.27 ± 0.04	< 0.05
Dip-DPV (m/s)	0.56 ± 18.9	0.13 ± 0.03	< 0.001
DPV increment (%)	86.8 ± 64.4	13.8 ± 15.9	< 0.001
Dip-DPV/SPV ratio	1.24 ± 0.63	0.47 ± 0.07	< 0.001
Dip-SVI (m)	0.10 ± 0.11	0.06 ± 0.02	< 0.05
$DPV_{dip}/DPV_{baseline}$ ratio	1.90 ± 0.68	1.07 ± 0.08	< 0.01
Dip-DVI (m)	0.17 ± 0.1	0.05 ± 0.02	< 0.005
Dip-DVI/SVI ratio	3.07 ± 5.2	0.93 ± 0.07	< 0.05

DPV = diastolic peak velocity; Dip = dipyridamole; DVI = diastolic velocity-time integral; SPV = systolic peak velocity; SVI = systolic velocity-time integral.

After dipyridamole infusion, DPV ($p < 0.001$), DPV/SPV ratio ($p < 0.001$), DVI ($p < 0.005$), SPV ($p < 0.05$), SVI ($p < 0.05$), and DVI/SVI ratio ($p < 0.05$) were significantly reduced in group B. Consequently, both the percent DPV increment and $DPV_{dip}/DPV_{baseline}$ ratio were severely impaired in group B with respect to group A ($p < 0.001$ and $p < 0.008$, respectively).

The assessment of the reproducibility of the MG flow in 10 randomly selected patients (6 of group A and 4 of group B) revealed an intraobserver mean error of 4 ± 1% and an interobserver mean error of 5 ± 1.5%.

Relationship between diastolic flow increase in percent and Doppler measurements. In the overall population, the percent DPV increment was not significantly related to age ($r = 0.10$) as well as to baseline DPV and SPV ($r = -0.07$ and $r = 0.14$, respectively). On the other hand, it was positively related to dipyridamole DPV ($r = 0.50$, $p < 0.001$) and dipyridamole SPV ($r = 0.57$, $p < 0.0002$).

On the grounds of these univariate relations, a stepwise forward multiple linear regression analysis was performed to weigh the independent associations of the presence of a significant angiographic stenosis and Doppler measurements, both at baseline and after dipyridamole infusion, in the overall population. Heart rate, age, baseline DPV and SPV, and baseline DVI and SVI were included in the first model as potential determinants. After adjusting for these variables, the baseline DPV was found to be the only independent determinant of the stenosis ($\beta = -0.31$, $p < 005$; cumulative $r^2 = 0.10$, standard error 0.32 m/s, $p = 0.04$). In a second multivariate analysis that also included DPV, SPV, DVI, SVI after dipyridamole infusion, only DPV after dipyridamole infusion was independently associated with the presence of stenosis ($\beta = -0.40$, $p < 0.01$; cumulative $r^2 = 0.16$, standard error 0.31 m/s, $p < 0.01$). Using this model, the correlation of baseline DPV versus the presence of an arterial graft stenosis was not significant.

Furthermore, in the last stepwise, diastolic and systolic variables, both the peak velocity and velocity-time integral, the percent DPV increment and the $DPV_{dip}/DPV_{baseline}$ ratio were included in the model; after adjusting for these measurements, the percent DPV increment ($\beta = -0.38$, $p < 0.01$), the $DPV_{dip}/DPV_{baseline}$ ratio ($\beta = -0.37$, $p < 0.01$) and the baseline DPV ($\beta = -0.33$, $p < 0.05$) were independent determinants of the stenosis at angiography.

Discussion

Echocardiography can be a useful tool in the clinical evaluation and follow-up of patients submitted to bypass surgery; this technique has a wide range of indications, particularly in the evaluation of the global and regional systolic and diastolic function, risk stratification and clinical management decision. After bypass surgery, when symptoms persist or recur, the stress test can be helpful. After cardiac surgery, many patients have abnormal baseline ECG findings and abnormal responses to the standard treadmill test. In these patients, stress echocardiography may be helpful for the evaluation of residual ischemia, but not to be excluded the likelihood of graft closure.

In the present study, we assessed the value of MG flow measurement using echocardiography for the detection of coronary artery bypass conduits derived from the internal mammary arteries.

In our previous study[6], we reported the rate of visualization of both right and left MG as 100%. This datum has again been confirmed in this study: the use of a small transthoracic multiHertz transducer and the application of echocardiographic software, which permits analysis of the vessel Doppler flow intensity and also reveals low velocities and a reduced blood volume independent of the direction of flow, allowed the visualization of both the left and right internal MG in all the patients. This high success rate in the visualization of the internal MG suggests that in the clinical setting the MG flow can be routinely and noninvasively assessed at echocardiography.

In this study, the DPV/SPV ratio was not found to be a predictor of MG stenosis, as proposed by Crowley and Shapiro[3] and by Takagi et al.[9], owing to the flow characteristics of MG. In fact, the MG systolic flow is elevated near its subclavian artery origin and progressively decreases distally. On the other hand, the diastolic flow is elevated throughout its course. For this reason, the DPV/SPV ratio could vary depending on whether we measure it proximally or distally and should be interpreted with respect to the MG sampling site[10]. We prefer to use a parasternal approach, close to the anastomosis, in order to obtain an intraluminal MG Doppler flow with a predominant diastolic pattern and thus evaluate a pattern of flow similar to that occurring in the native coronary artery.

In this study we did not measure blood flow but blood velocity. The absolute value of the blood flow within the MG was not calculated because it was difficult to visualize the cross-sectional area of the MG, particularly the right internal MG, and hence accurately measure the vessel's diameter. However, a previous study[11] showed a close correlation between flow velocities and blood flow.

A predominant diastolic flow velocity, similar to the pattern of flow in the native coronary artery, with a DPV greater than the SPV, is seen in MG without significant stenosis[3-6,9,12] (Fig. 1), whereas a predominant systolic flow velocity has been shown to be indicative of graft dysfunction (Fig. 2). In all these cases, the administration of a vasodilator agent such as dipyridamole or adenosine does not provide new information on the graft patency. In addition to graft stenosis, MG flow may be abnormal, with a predomi-

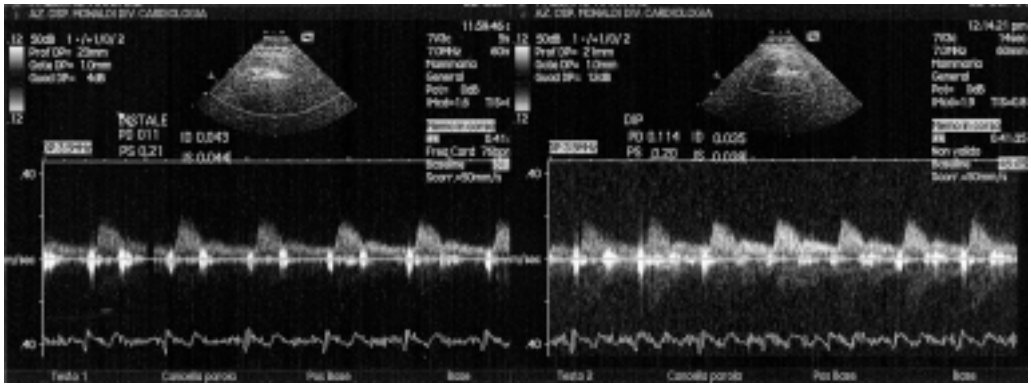

Figure 2. *A mammary artery graft with an impaired increase in diastolic flow: following dipyridamole infusion the diastolic peak velocity is only minimally increased with respect to baseline.*

nant systolic pattern, in other conditions including: 1) a partially occluded recipient artery distal to the graft anastomosis; 2) residual mammary artery side branches; 3) the presence of collateral flow; 4) a MG supplying scarred myocardium as a consequence of previous infarction. In all these cases, it is possible to evaluate the graft function after the administration of a vasodilator agent such as dipyridamole or adenosine. A significant increase in flow velocity after dipyridamole infusion accurately identifies non-stenotic grafts. In fact, the percent DPV increment and the $DPV_{dip}/DPV_{baseline}$ ratio may be used as indicators of the functional status of the MG just as the coronary flow reserve of the left anterior descending coronary artery is an index for the assessment of the pathophysiologic status of the native coronary artery in case of stenosis. Among several parameters examined at rest and after hyperemia, using multivariate analysis, the percent DPV increment, the $DPV_{dip}/DPV_{baseline}$ ratio, the DPV and the DPV after dipyridamole were independent determinants of stenosis at angiography. In our experience, an increase < 30% or a $DPV_{dip}/DPV_{baseline}$ ratio < 1.2 was associated with graft stenosis. Of interest, Chirillo et al.[12] and Voudris et al.[13] found similar results when using a supraclavicular approach; in particular, Chirillo et al. found a flow reserve of 1.1 and Voudris et al. a flow reserve of 1.3 in stenotic MG. Because of the greater diagnostic value of the flow changes after hyperemia, this noninvasive technique offers further insight into the assessment of MG patency, particularly in all cases with a dubious or non-diagnostic basal flow such as all those cases with a DPV/SPV ratio ≤ 1 or with a predominant systolic flow.

Even for the determination of the $DPV_{dip}/DPV_{baseline}$ ratio, we evaluated the changes in MG flow velocity, not the variations in MG blood flow. However, with regard to the coronary circulation it has been reported that changes in coronary flow velocities induced by coronary vasodilation closely reflect changes in coronary blood flow[11].

Study limitations. The first limitation of this study was that we did not measure blood flow but blood velocities. The absolute value of blood flow within MG (particularly in the right internal MG) was not calculated because the cross-sectional area of MG was not clearly visible. However, it has to be taken into account that a previous study showed a close correlation between flow velocities and blood flow[11]. The second limitation was that comparative, invasive data on the $DPV_{dip}/DPV_{baseline}$ ratio using Doppler sensor-tipped angioplasty guide wires were not obtained. Nevertheless, it has been reported that data regarding the coronary flow reserve concur with those obtainable by means of invasive measurements (Doppler flow wire)[14,15]. The third limitation was that, in our study, we chose intravenous dipyridamole rather than adenosine to induce hyperemia. Although dipyridamole infusion usually induces a lesser increase in flow velocities than adenosine, the vasodilator effect is more persistent[16]. This prolonged vasodilation allowed an accurate determination of MG flow velocities in all patients.

In conclusion, noninvasive Doppler echocardiographic assessment of MG, being noninvasive, rapid and easily reproducible, has a potential clinical application in the assessment of the functional status of MG. In particular, it can be used in the follow-up of patients with previous bypass, thus permitting us to avoid invasive evaluation when symptoms recur. Moreover, combined with segmental wall motion analysis after dipyridamole infusion, this method can simultaneously provide information on both the MG flow reserve and inducible ischemia. In fact, the echocardiographic evaluation of MG provides further data in addition to those obtainable at clinical evaluation and from the stress test: the major finding of this study is that echocardiography permits the identification of MG graft stenosis. The clinical impact is important, because all patients with MG stenosis, identified also on the grounds of the echocardiographic results, were submitted to percutaneous angioplasty of the graft.

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References

1. Fitzgibbon GB, Leach AJ, Kafka HP, Keon WJ. Coronary bypass graft fate: long-term angiographic study. J Am Coll Cardiol 1991; 17: 1075-80.
2. Kyo S, Matsumura N, Yokote Y, Takamoto S, Omoto R. Evaluation of patency of internal mammary artery grafts: a comparison of two-dimensional Doppler echocardiography with coronary angiography. J Cardiol 1990; 20: 607-16.
3. Crowley JJ, Shapiro LM. Noninvasive assessment of left internal mammary artery graft patency using transthoracic echocardiography. Circulation 1995; 92 (Suppl): II25-II30.
4. Rombaut E, Vantrimpont P, Gurne O, et al. Noninvasive functional assessment of left internal mammary artery grafts by transcutaneous Doppler echocardiography. J Am Soc Echocardiogr 1998; 11: 403-8.
5. Pezzano A, Fusco R, Child M, et al. Assessment of left internal mammary artery grafts using dipyridamole Doppler echocardiography. Am J Cardiol 1997; 80: 1603-6.
6. De Simone L, Caso P, Severino S, et al. Noninvasive assessment of left and right internal mammary artery graft patency with high-frequency transthoracic echocardiography. J Am Soc Echocardiogr 1999; 12: 841-9.
7. Ehrsam JE, Spittell PC, Seward JB. Internal mammary artery: 100% visualization with new ultrasound technology. J Am Soc Echocardiogr 1998; 11: 10-2.
8. Krijne R, Lyttwin RM, Holtgen R, Heinrich KW. Doppler sonographic examination of the internal mammary artery graft: comparison of supraclavicular and high intercostal signals. Cardiology 1993; 82: 48-50.
9. Takagi T, Yoshikawa J, Yoshida K, Akasaka T. Noninvasive assessment of left internal mammary artery graft patency using duplex Doppler echocardiography from supraclavicular fossa. J Am Coll Cardiol 1993; 22: 1647-52.
10. Katz WE, Zenati M, Mandarino WA, Cohen HA, Gorcsan J III. Assessment of left internal mammary artery graft patency and flow reserve after minimally invasive direct coronary artery bypass. Am J Cardiol 1999; 84: 795-801.
11. Wilson RF, Laughlin DE, Ackell PH, et al. Transluminal, subselective measurement of coronary artery blood flow velocity and vasodilator reserve in man. Circulation 1985; 72: 82-92.
12. Chirillo F, Bruni A, Balestra C, et al. Assessment of internal mammary artery and saphenous vein graft patency and flow reserve using transthoracic Doppler echocardiography. Heart 2001; 86: 424-31.
13. Voudris V, Athanassopoulos G, Vassilikos V, et al. Usefulness of flow reserve in the left internal mammary artery to determine graft patency to the left anterior descending coronary artery. Am J Cardiol 1999; 83: 1157-63.
14. Hozumi T, Yoshida K, Akasaka T, et al. Noninvasive assessment of coronary flow velocity and coronary flow velocity reserve in the left anterior descending coronary artery by Doppler echocardiography: comparison with invasive technique. J Am Coll Cardiol 1998; 32: 1251-9.
15. Caiati C, Montaldo C, Zedda N, Bina A, Iliceto S. New noninvasive method for coronary flow reserve assessment: contrast-enhanced transthoracic second harmonic echo Doppler. Circulation 1999; 99: 771-8.
16. Rossen JD, Quillen JE, Lopez AG, Stenberg RG, Talman CL, Winniford MD. Comparison of coronary vasodilation with intravenous dipyridamole and adenosine. J Am Coll Cardiol 1991; 18: 485-91.