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Graft revision after transit time flow measurement in off-pump coronary artery bypass grafting ☆

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Abstract

Objective: To determine whether coronary graft patency can be predicted by transit time flow measurement (TTFM). **Methods**: From May 1 1997 to December 31 1998, TTFM was prospectively evaluated in 409 patients undergoing coronary artery bypass grafting (CABG) without cardiopulmonary bypass (CPB). All grafts (1145) were tested with TTFM. **Results**: Thirty-seven out of 1145 grafts (3.2%) were revised in 33 patients (7.6%). In six cases (18.1%) use of CPB was necessary during revision due to hemodynamic instability. The remaining patients underwent revision off-pump. Thirty-four grafts (91.9%) were revised for both low flow and abnormal flow curve patterns. Findings at revision included: thrombosis of the anastomosis ($n = 6$), stenosis at the toe or heel of the anastomosis ($n = 8$), coronary flap or dissection ($n = 5$), dissection of the internal mammary artery ($n = 5$), graft kinking ($n = 4$), flap at proximal anastomosis ($n = 1$), coronary stenosis distal to the graft ($n = 3$), and no findings ($n = 2$). After revision all flow values and flow patterns improved. Although three additional grafts (8.1%) were revised for low flow (<7 ml/min) despite normal flow patterns, there were no findings at revision and flow values and curves remained unchanged after revision. Postoperatively, one patient developed a stroke (3%), one had an acute myocardial infarction (MI) (3%), one had a sternal wound infection (3%), and one required prolonged ventilatory support (3%). **Conclusion**: Evaluation of TTFM is valuable in determining the status of a coronary graft after CABG. Correct interpretation of flow patterns allows for correction of abnormalities prior to chest closure. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Transit time flow measurement; Off-coronary pulmonary bypass; Graft; Revision

1. Introduction

The increasing popularity of coronary artery bypass grafting (CABG) performed on a beating heart without cardiopulmonary bypass (CPB), has raised interests and concerns about intraoperative evaluation of graft patency. In the past, a wide variety of flow measurement techniques have been used to assess intraoperatively the quality of the anastomoses after traditional CABG performed under CPB conditions [1,2].

Transit time flow measurement (TTFM) has recently been introduced as an effective and reliable mean for intraoperative evaluation of coronary grafts. This technology allows for flow determination independently of vessel size, shape and Doppler angle used [3]. Exact interpretation of transit time flow patterns is essential to correctly use this technology in both off-CPB and traditional CABG [4,5].

The objective of this study was to assess the clinical applicability of TTFM in detecting anastomotic imperfections following myocardial revascularization in off-CPB coronary artery surgery.

2. Materials and patients

From May 1997 to December 1998, TTFMs were evaluated in 409 patients undergoing off-CPB coronary artery surgery via median sternotomy. A total of 1145 grafts were tested with TTFM.

2.1. Surgical technique

After median sternotomy and conduit harvesting, the pericardium was opened and pericardial stay sutures were placed. Exposure of the different coronary branches was obtained placing the 'single' suture in the oblique sinus of the pericardium [6]. Coronary stabilization was achieved

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with the CTS stabilizer (CTS, Cupertino, CA). Systematical proximal snaring (4-0 pledgetted suture) and intracoronary shunting of the involved coronary artery branches were used.

The distal anastomoses were performed with 7-0 prolene running suture. The proximal anastomoses were performed with 6-0 prolene running suture on a partially excluded ascending aorta.

2.2. TTFM technique

At the end of every single anastomosis, flow values and flow curves were obtained using the TTFM device (Medistim BF 2004, Medistim, Oslo, Norway).

The TTFM probe was perfectly fitted around the graft. Different probe sizes were available to avoid distortion or compression of the graft. Skeletonization of a small segment of the mammary artery was necessary to reduce the quantity of tissue interposed between the vessel and the probe. Aqueous gel was used to improve probe contact.

TTFM was evaluated both with and without proximal snaring of the native coronary artery to detect any possible imperfection localized at the toe of the anastomosis and to exclude flow competition from the native vessel. Before making any measurement, adequate deairing of the grafts was performed, adequate systemic blood pressure was maintained, traction on the pericardium was released and the stabilizer was removed from the epicardial surface to allow for the heart to return to its anatomical position. TTFM was repeated before chest closure to confirm graft patency and to detect any possible graft kinking or compression.

2.3. Curve interpretation

During our clinical experience we developed a progressive expertise in TTFM findings interpretation. To correctly address the TTFM findings, flow curves, pulsatile index (PI) and mean flow values are evaluated.

The curves should always be coupled with the EKG tracing to correctly differentiate the systolic from the diastolic flow. In a patent coronary graft, the hemodynamics are similar to those physiologically observed in the coronary circulation: blood flows mainly during diastole with minimal systolic peaks taking place during the isovolumetric ventricular contraction (QRS complex) (Fig. 1).

The PI, expressed as an absolute number, is a good indicator of the flow pattern and, consequently, of the quality of the anastomosis. This number is obtained by dividing the difference between the maximum and the minimum flow by the value of the mean flow. In our experience, the PI should be included between 1 and 5. The possibility of a technical error in the anastomosis increases for higher PI values.

The mean flow is expressed as ml/min and, being very dependent by the quality of the revascularized coronary artery, is not a good indicator of the quality of the anastomosis. Mean flow values should always be interpreted together with TTF curves and PI values.

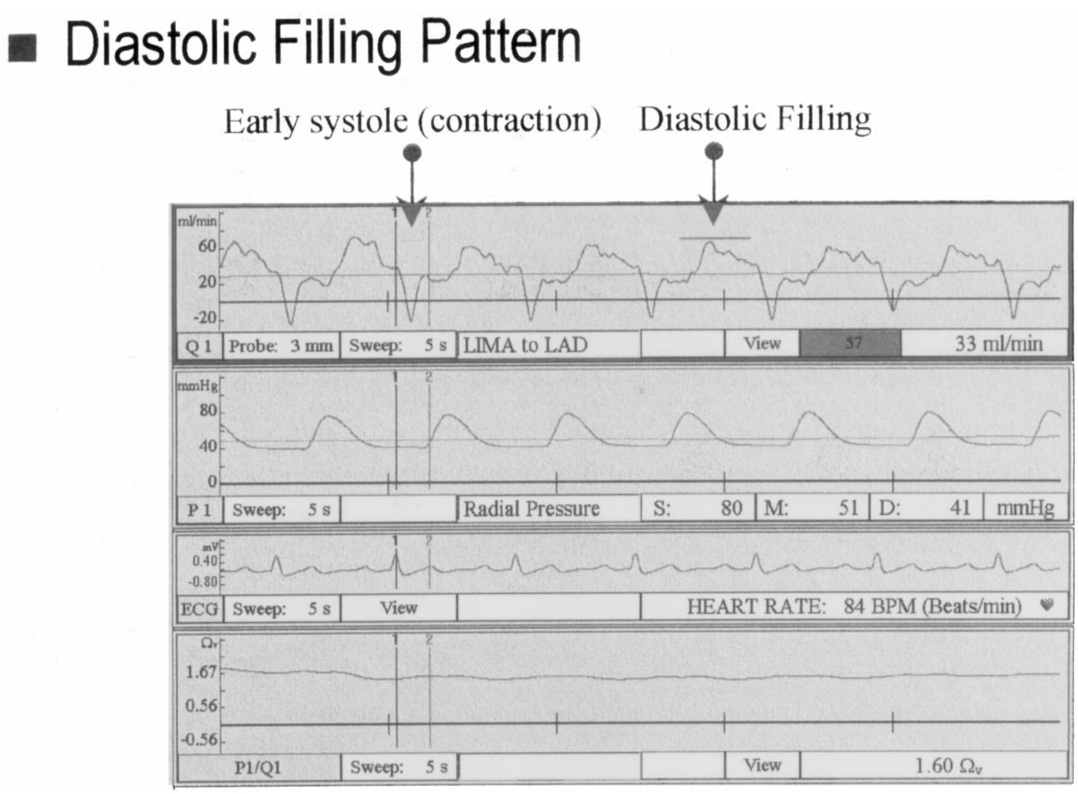

Fig. 1. TTF normal curve.

3. Results

Forty-one grafts (41/1145) were revised in 33 patients. In three patients, four flow curves and flow values were not properly stored in the TTFM device hardware and for this reason have not been included in this study.

A total of 37 grafts are included: 18 to the left anterior descending coronary (LAD) and diagonal branches, ten to the circumflex system and nine to the right coronary artery system (RCA) (Table 1).

A total of six patients (18.1%) underwent graft revision on CPB.

TTFM findings before revision are summarized in Table 1.

Curve patterns, flow and PI values remained unchanged after topical use of vasodilators (papaverine and nitrates). Twenty-nine grafts (78.37 %) were revised for abnormal (systolic) flow patterns, high PIs and low flow values. In five cases (13.51%), despite abnormal flow curves (systolic spikes) and high PIs, flow values were on average greater than 15 ml/min. Findings at revision of these 34 grafts included: thrombosis of the anastomosis (six patients), stenosis at the toe or heel of the anastomosis (eight patients), intimal flap or dissection in the native coronary artery (five patients), dissection of the internal mammary artery (five patients), graft kinking (four patients), flap at proximal anastomosis (one patient), coronary stenosis distal to the graft (three patients) and no findings (two patients). After revision, all flow patterns improved (diastolic flows) and mean flow values increased from a mean value of 3.85 ± 4.63 to 32.47 ± 28.59 ml/min with proximal snare

Table 1
TTFM findings in 37 grafts before revision[a,b]

Graft	% Coronary stenoses	Size coronary (mm)	Mean flow w/wo snare (ml/min)	PI w/wo snare	Resistance w/wo snare (Ω)	Flow pattern
SVG ⇒ RCA	*90*	*1.5*	*12/12*	*49/49*	*7.08/7.08*	*Systolic*
LIMA ⇒ LAD	100	2	5/5	6.6/6	12/12	Systolic
SVG ⇒ RCA	70	2.5	3/3	55/50	25.6/25.6	Systolic
SVG ⇒ D	85	2.0	6/12	10.8/4.2	9/7.83	Systolic
LIMA ⇒ LAD	90	2.5	0/1	7/7	60/60	Systolic
SVG ⇒ RCA	**100**	**1.5**	**5/5**	**0/3.3**	**11/11**	**Diastolic**
LIMA ⇒ LAD	85	2	0/4	4.2/3.2	80/23.24	Systolic
LIMA ⇒ LAD	*90*	*2.5*	*8/19*	*4.5/1*	*10.25/4.31*	*Systolic*
LIMA ⇒ D	90	2	12/7	3/3	6.5/11.42	Systolic
RIMA ⇒ RCA	100	2.5	0/15	48/4.3	62/3.86	Systolic
SVG ⇒ CX	50	1.5	0/1	12.7/12.6	51/51	Systolic
SVG ⇒ OM	90	2.0	0/0	45.7/45.7	83/83	Systolic
LIMA ⇒ LAD	90	1.5	1/1	34.6/34.6	87/87	Systolic
SVG ⇒ CX	90	1.5	0/0	22.1/22.1	67/67	Systolic
LIMA ⇒ LAD	**85**	**1.5**	**10/6**	**4.3/4.6**	**9.3/13.5**	**Diastolic**
SVG ⇒ RCA	80	2.0	0/14	10.4/2	73/5.7	Systolic
LIMA ⇒ LAD	90	2.0	1/4	14/4.9	69/17.5	Systolic
SVG ⇒ RCA	*95*	*2.0*	*13/13*	*8.2/8.2*	*7.3/7.3*	*Systolic*
LIMA ⇒ LAD	100	1.5	6/12	5.8/3.5	11.83/6.16	Systolic
LIMA ⇒ LAD	80	2.0	6/5	10/10	68/70	Systolic
SVG ⇒ OM	80	2.5	3/1	13.9/22	21.5/71	Systolic
SVG ⇒ OM2	90	2	0/10	225/6.5	70/7	Systolic
SVG ⇒ RCA	100	1.0	3/5	12/12	25.3/15.2	Systolic
SVG ⇒ D	90	1.5	0/0	52.8/52.8	67/67	Systolic
SVG ⇒ OM2	100	2.5	6/6	11.7/11.7	9/9	Systolic
SVG ⇒ LAD	90	1.5	0/11	58.4/2	86/8.3	Systolic
LIMA ⇒ LAD	**50**	**1.5**	**7/7**	**1.3/1.3**	**16.57/16.57**	**Diastolic**
LIMA ⇒ LAD	90	2.0	2/13	30.9/4.3	34/5.38	Systolic
SVG ⇒ LAD	60	1.5	0/0	265/265	89/89	Systolic
SVG ⇒ CX	60	1.5	1/1	67.1/67.1	57/57	Systolic
SVG ⇒ RCA	70	2.0	11/11	10/10	60/60	Systolic
SVG ⇒ OM1	*75*	*2.0*	*9/12*	*33.5/5*	*6.5/4.9*	*Systolic*
SVG ⇒ D	75	2.0	0/0	70.5/11	74/74	Systolic
SVG ⇒ RCA	95	2.5	8/4	14/14	8/16.25	Systolic
SVG ⇒ OM2	100	1.5	0/2	16/10	100/50	Systolic
SVG ⇒ OM1	*90*	*2.5*	*15/20*	*15/6.5*	*5.3/4.5*	*Systolic*
LIMA ⇒ LAD	90	2.5	0-1/0	60/60	78/78	Systolic

[a] Bold characters indicate grafts revised on the basis of low flow values despite normal flow patterns. Italic characters indicate grafts revised on the basis of abnormal flow patterns despite flow values greater than 15 ml/min on average.

[b] LIMA, left internal mammary artery; SVG, saphenous vein graft; RIMA, right mammary artery; LAD, left anterior descending; D, diagonal; RCA, right coronary artery; CX, circumflex coronary artery; OM, obtuse marginal.

($P < 0.0001$) and from 6.58 ± 6.00 to 36.29 ± 26.91 ml/min without snare ($P < 0.0001$). PI values also improved from 38.45 ± 56.56 to 3.03 ± 1.6 with snare and from 24.44 ± 46.51 to 2.80 ± 1.68 without snare ($P < 0.0001$). TTFM findings after revision are summarized in Table 2. In three additional grafts (8.1%) revision was performed on the basis of low mean flow values (7.3 ± 2.51 ml/min with snare and 6 ± 1 ml/min without snare) despite normal flow curves (diastolic) and PI values (1.86 ± 2.20 with and 3.06 ± 1.66 without snare). There were no findings at revision and curves, flow and PI values remained unchanged after revision (Tables 1 and 2).

Postoperatively one patient developed a stroke (3%), one had an acute myocardial infarction (AMI) (3%), one required reoperatioin for bleeding (3%), one had a sternal wound infection and one required prolonged ventilatory support (3%). All patients were discharged after a mean hospital stay of 8.15 days.

4. Discussion

Several techniques have been used in the past to test coronary graft flow intraoperatively: electromagnetic flowmeters, initially adopted in coronary surgery, have been recently replaced by ultrasonic technology (Doppler and TTFM). Many authors have demonstrated the superiority of TTFM over Doppler systems in direct real time detection of flow independently of vessel diameter and Doppler angle [2,3].

Increasing interest in intraoperative evaluation of graft flows has followed the advent of CABG without CPB.

Table 2
TTFM findings in 37 grafts after revision[a]

Graft	% Coronary stenoses	Size coronary (mm)	Mean flow w/wo snare (ml/min)	PI w/wo snare	Resistance w/wo snare (Ω)	Flow pattern
SVG ⇒ RCA	*90*	*1.5*	*25/25*	*3/3*	*4/4*	*Diastolic*
LIMA ⇒ LAD	100	2	41/41	1.5/1.5	1.41/1.41	Diastolic
SVG ⇒ RCA	70	2.5	10/10	8.7/8.7	10/10	Diastolic
SVG ⇒ D	85	2.0	21/21	2.5/2.5	2.85/2.85	Diastolic
LIMA ⇒ LAD	90	2.5	31/34	2.8/1.7	2/1.91	Diastolic
SVG ⇒ RCA	**100**	**1.5**	**5/5**	**2/1**	**10/10**	**Diastolic**
LIMA ⇒ LAD	85	2	11/11	1.9/1.9	7.2/7.2	Diastolic
LIMA ⇒ LAD	*90*	*2.5*	*35/35*	*1.2/1.2*	*2.28/2.28*	*Diastolic*
LIMA ⇒ D	90	2	14/31	1.8/1.3	5.8/2.5	Diastolic
RIMA ⇒ RCA	100	2.5	4/47	1/0.8	1.4/1.2	Diastolic
SVG ⇒ CX	50	1.5	22/49	3.1/2.1	2.9/1	Diastolic
SVG ⇒ OM	90	2.0	23/24	5/5	2.69/2.69	Diastolic
LIMA ⇒ LAD	90	1.5	150/150	2.3/2.3	0.53/0.53	Diastolic
SVG ⇒ CX	90	1.5	85/85	2.2/2.2	0.98/0.098	Diastolic
LIMA ⇒ LAD	**85**	**1.5**	**10/5**	**5/5**	**9/13**	**Diastolic**
SVG ⇒ RCA	80	2.0	15/22	2/1.8	4.33/2.9	Diastolic
LIMA ⇒ LAD	90	2.0	23/19	1.8/3.9	3.3/4	Diastolic
SVG ⇒ RCA	*95*	*2.0*	*19/19*	*4/4*	*4/4*	*Diastolic*
LIMA ⇒ LAD	100	1.5	28/49	5.1/3.5	2.6/1.5	Diastolic
LIMA ⇒ LAD	80	2.0	24/35	2.9/1	2.9/1.9	Diastolic
SVG ⇒ OM	80	2.5	64/64	4.1/2.9	0.9/1	Diastolic
SVG ⇒ OM2	90	2	18/14	3.6/5.4	3/6	Diastolic
SVG ⇒ RCA	100	1.0	86/63	1.8/0.7	0.8/1.18	Diastolic
SVG ⇒ D	90	1.5	6/6	4.6/4	11.16/11.16	Diastolic
SVG ⇒ OM2	100	2.5	31/32	6.2/6	1.74/1.74	Diastolic
SVG ⇒ LAD	90	1.5	9/19	1.8/1.9	7.4/3.5	Diastolic
LIMA ⇒ LAD	**50**	**1.5**	**8/6**	**3.4/2.6**	**10.3/14**	**Diastolic**
LIMA ⇒ LAD	90	2.0	22/31	3.5/2.7	3.5/2	Diastolic
SVG ⇒ LAD	60	1.5	31/31	1.6/1	1.83/1.83	Diastolic
SVG ⇒ CX	60	1.5	15/15	3.3/3.3	3.8/3.8	Diastolic
SVG ⇒ RCA	70	2.0	52/56	4/3.2	1.36/1.25	Diastolic
SVG ⇒ OM1	*75*	*2.0*	*19/19*	*3/2.9*	*3.15/3.15*	*Diastolic*
SVG ⇒ D	75	2.0	28/20	3/2.5	3/ 4.2	Diastolic
SVG ⇒ RCA	95	2.5	50/54	4.5/4	2/2	Diastolic
SVG ⇒ OM2	100	1.5	12/20	1.5/1	5/5	Diastolic
*SVG*OM2*	*90*	*2.5*	*40/50*	*2/3*	*3/2.7*	*Diastolic*
LIMA ⇒ LAD	90	2.5	40/33	2/2.3	2/2.4	Diastolic

[a] LIMA, left internal mammary artery; SVG, saphenous vein graft; RIMA, right mammary artery; LAD, left anterior descending; D, diagonal; RCA, right coronary artery; CX circumflex coronary artery; OM, obtuse marginal.

Intraoperative flow measurement together with post-operative angiographic follow-up are important methods aimed at documenting the feasibility of this operation. We began using TTFM routinely in off CPB coronary surgery since 1996. After 3 years of clinical experience we believe that this technology is effective in detecting highly stenotic coronary anastomoses.

The sensitivity of TTFM in detecting less than critical stenoses remains to be defined. Cerrito et al. [7] indicated that neural network pattern recognition analysis of graft flow characteristics, can improve detection of anastomotic errors with intra-operative TTFM. After a complex mathematical analysis of the flow curves is possible to detect stenoses causing a 50% or greater narrowing of the anastomoses. It is evident that less than critical stenoses can not be detected by TTFM due to the fact that no modifications in the hemodynamic performances of the grafts happen at this level. At the present, standard or nominal curves and flow values for different type of grafts and revascularized vessels have not been described and the variability between different subjects and within subjects is extremely large.

In an interesting survey, Spence et al. [8] tested the ability of 19 international surgeons to detect anastomotic errors by evaluating mean flow and flow waveforms. More than 70% of the surgeons accepted anastomoses with severe stenoses but, all of them, were able to detect highly stenotic anastomoses (>90% stenosis).

It is important to emphasize the fact that the ability to correctly interpret TTFM findings is slowly acquired with clinical and experimental experience.

Even if we understand there is a limit in TTFM findings interpretation, our clinical experience with more than 1000 grafts tested, has showed that early detection of stenotic grafts can be achieved by the surgeons' simulataneous evaluation of flow patterns, PI values, flow values and clinical findings (i.e. EKG tracing, hemodynamic values). Flow curves in patent grafts have a mainly diastolic pattern with a small component of negative systolic flow. The diastolic flow is the actual flow that at every diastole flows from the graft in to the coronary through the anastomosis, the systolic component is retrograde flow that cannot flow in to the anastomosis during systole and goes backwards in to the graft (Fig. 1). In the case of stenotic anastomosis the flow curve becomes spiky and mainly systolic (Fig. 2): in this situation the main flow through the graft is systolic and there is minimal perfusion of the anastomosis during diastole. Even if these rules apply generally to all vessels, we have noticed some differences whenever testing grafts anastomosed to the right coronary system. A good component of blood flow in to the right coronary takes place during systole simply due to a minor compression of the epicardial vessels during right ventricular contraction. For this reason, a larger component of systolic positive flow can be observed in patent anastomoses to the RCA.

As mentioned, we do not have nominal flow and PI values to suggest for a correct interpretation of TTFM findings and our statements are based on the simple visual assessment of

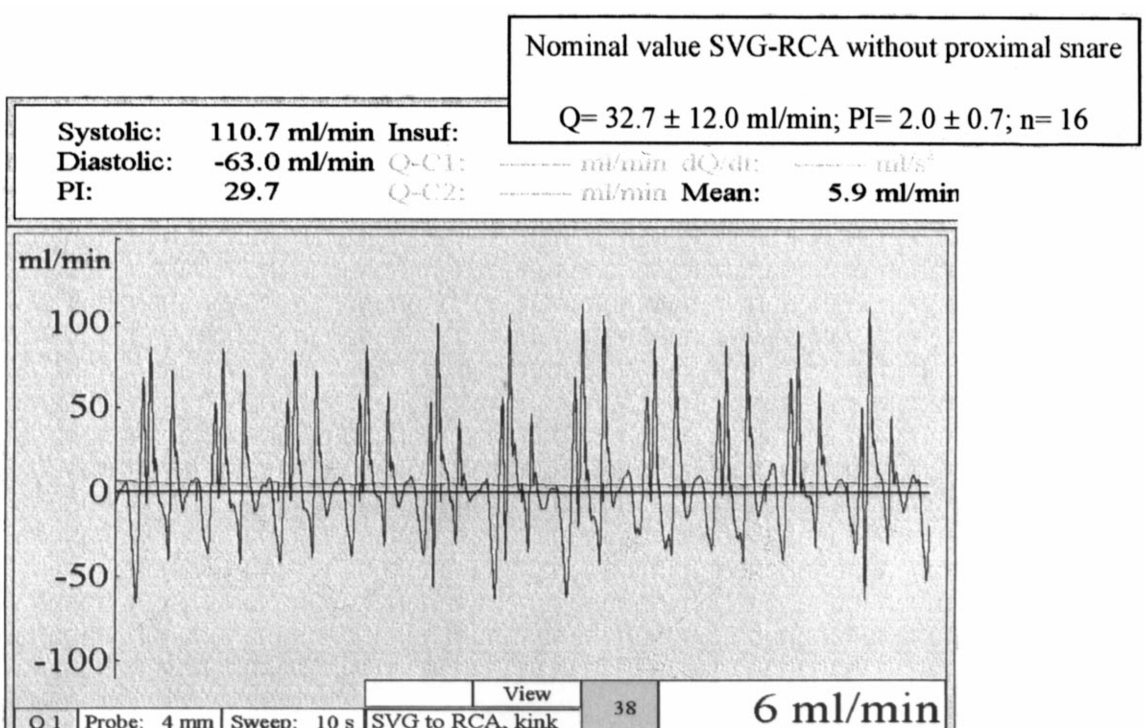

Fig. 2. TTF curve in a severly stenotic saphenous vein graft to the RCA.

flow curve morphology and clinical findings. Di Giammarco et al. [9] have analyzed the differences in TTFM patterns in different coronary grafts but, at present, no standard values have been reported.

We are convinced that flow value per se is not a good indicator of the quality of the anastomosis and can not justify graft revision: absolute flow is influenced by too many variables including type and size of the graft, and quality of the coronary artery distal territory. In our experience graft revision was erroneously performed in three cases only on the basis of low flow values despite satisfactory flow patterns and low PI values: at surgical inspection no anastomotic lesions were found and the flow values remained unchanged after revision (Tables 1 and 2). Use of vasodilating agents (i.e. papaverine and nitroglycerine) did not improve the flow values and the small caliber of the revascularized coronary arteries (<1.5 mm) was responsible for our findings.

Coronary flow reserve can help in correctly diagnose anastomotic imperfections and, as described by Walpoth et al. [10], the quality of the anastomosis can be tested by recording the modifications of flow during infusion of adenosine. We do not have experience with calculation of flow reserve but we believe that a more precise detection of anastomotic imperfections with TTFM could be achieved by testing the dynamic ability of the anastomoses to increase the blood flow whenever the oxygen requests of the myocardium are increased.

If mean flow values are not good predictors of grafts' quality, on the contrary PI values are, per se, very suggestive of the actual status of the anastomoses. As mentioned in the results, we correctly revised five grafts on the basis of abnormal flow curves and high PI values (22.04 ± 21.17 with snare and 13.94 ± 19.77 without snare) despite flow was on average higher than 15 ml/min. At surgical inspection all five anastomoses resulted to be severely stenotic and after revision flow patterns and PIs were improved (2.64 ± 1.07 with snare and 2.82 ± 1.01 without snare) (Tables 1 and 2).

To our knowledge, an absolute PI value has never been officially proposed and we empirically decided the limit of 5 on the basis of our clinical experience. Di Giammarco et al. [9] proposed a value of 2.5 as the limit PI above which an anastomosis should be revised but, again, this value seems to be derived by personal clinical experience.

Flow curves, PI and mean flow values should always be evaluated with and without occlusion of the native coronary arteries: proximal snaring of the native coronary is, in our opinion, important in order to achieve a reliable interpretation of TTFM findings. The shape of the curve should remain unchanged when snaring the coronary proximally and an increase in absolute flow should be recorded if competition from the native coronary was present with the unsnared coronary. The proximal snare will also permit to detect lesions at the level of the toe of the anastomosis: in this situation whenever the coronary is snared the absolute flow will drastically decrease documenting lack of antegrade flow through the anastomosis.

Verification of intraoperative TTFM findings can be obtained with immediate postoperative angiographic studies. Even if we do not have a systematic angiographic follow up for our revised grafts, we believe our immediate postoperative clinical results being satisfactory and somehow confirming intraoperative TTFM findings. Angiography, per se, gives a limited bidimensional view of the coronary arteries and the coronary grafts without giving any specific information about the hemodynamic parameters of the anastomoses; for this reason a comparative study between postoperative angiography and intraoperative TTFM may result difficult. In reoperative CABG for example, we found conflicting results when comparing preoperative angiography and intraoperative TTFM; in one particular case angiographic documentation of anastomotic subocclusion of an old saphenous graft, was not confirmed during surgical revision and intraoperative TTFM.

In an interesting study, Louagie et al. [11] reported that intraoperative hemodynamic assessment, via pulsed Doppler flowmeter, can have a satisfactory predictive value for midterm graft occlusion, on the contrary the same hemodynamic parameters are useless for prediction of midterm graft stenosis. Together with Dr Louagie we feel that midterm stenosis development is a dynamic process related to scar tissue formation and degeneration of the graft and, for this reason, can not be detected at the time of the procedure.

TTFM has also been compared with other techniques of postoperative graft patency verification that, differently from angiography, can give more precise informations about the hemodynamic characteristics of the grafts. In a series of 22 patients, Walpoth et al. [12] have shown a significant correlation between intraoperative TTFM and post-operative magnetic resonance findings of the internal mammary artery grafts.

In conclusion we may say that there are certainly some limits in the interpretation of TTFMs findings and there is still necessity to define the sensitivity of TTFM in detecting less then critical stenosis [7,8]. Correct interpretation of flow curves, mean flows and PI values are crucial in reducing the number of undetected technical errors and in decreasing the number of grafts erroneously revised. The mean flow value per se is not a good indicator of the quality of the anastomosis. Acceptable flow values with abnormal flow patterns and high PIs may underline highly stenotic lesions of the anastomoses (five cases in our experience). On the contrary, we observed low flow conditions with good flow curves in three anastomoses which, at revision, resulted in fully patent anastomoses. This situation may occur whenever the revascularized territory has poor run off.

TTFM is reliable in detecting technical errors after CABG without CPB. Graft revision should be promptly performed whenever flow curves, mean flows, and PI values are abnormal. In this situation, revision of the distal anastomoses leads to improvement in flow patterns. Postoperative outcome can be improved by a meticulous use and understanding of TTFM in patients undergoing coronary artery surgery with and without CPB.

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Appendix A. Conference discussion

Dr A. Royse (*Victoria*, *Australia*): You certainly have a very large series. I think you have shown us fairly well from your data that a high PI value and abnormal flow curves was correlated with a critical conduit of anastomotic stenosis, but what you haven't shown us is what is the denominator? How many of those who had a normal or slightly abnormal flow curve actually had a critical stenosis but you missed it or you didn't revise it? In other words, you are only telling us of the critical stenoses that you actually revised, not how many theoretically there were in those that you didn't revise.

My question is, have you done any other tests such, as, perhaps angiography to try and establish if there is a critical stenosis in those who you didn't revise?

Dr D'Ancona: No, we didn't make any angiographic study. I outlined in the conclusion, we really are not able to say how critical should be the stenosis to be detected by the TTFM. Dr Paul Spence's group in Louisville, Kentucky did make some experimental settings showing that TTFM is able to detect stenosis that at angiography result higher than 50%.

Dr J. Melo (*Carnaxide*, *Portugal*): When we measurements low flows should we take precautions like a late angiography?

Dr D'Ancona: In our experience, if we are sure that the size of the vessel and the territory revascularized were very poor, we are not really very much concerned when we have low flows if we have good curves and good PI values, so we don't do anything, and as a matter of fact, we didn't have any clinical postoperative implication using this strategy. So I think you shouldn't be worried about any angiographical study in those patients. This is our personal opinion.