Early postoperative flow rates after internal thoracic artery grafting for the left coronary artery system

Abstract  Objective. The low perioperative flow rates of internal thoracic artery (ITA) conduits have been regarded as a limitation of their use in critical coronary situations with a high myocardial blood demand. To clarify whether these restrictions are justified, early postoperative flow rates were determined.

Methods. Following bilateral ITA grafting, 48 of 106 patients (April 1993–September 1994) underwent recatheterization. Subsequent to control angiography between days 8 and 12, 20 of these patients were studied by intravascular Doppler techniques applied for ITA grafts supplying the left anterior descending artery (LAD) and branches of the circumflex system (CX) (n=20). Doppler spectral analysis allowed for determination of the average peak velocity and diastolic-systolic velocity ratio. Vascular diameters were assessed by simultaneously performed quantitative angiography and mean flow rates were calculated. All parameters were recorded at rest and following selective stimulation with nitroglycerin (0.2 mg) and papaverine (12.5 mg) to evaluate the graft flow capacity.

Results. Baseline values of average peak velocity at rest were 24.6±11.5 cm/s for ITA-LAD conduits and 21.9±6.8 cm/s for ITA-CX pedicles. Following dilative stimulation with papaverine, a significant increase in average peak velocities were obtained for both locations (ITA-LAD: 47.3±17.1 cm/s, ITA-CX: 42.3±11.8 cm/s). The application of nitroglycerin had a similar effect (ITA-LAD: 42.6±15.3 cm/s, ITA-CX: 40.3±10.7 cm/s). The vascular diameters of ITA conduits remained unchanged on nitroglycerin stimulation, whereas papaverine effected significant dilatation in both locations. Flow rates at rest were not significantly different (ITA-LAD: 51.0±34.2 ml/min, ITA-CX: 44.7±16.4 ml/min) and maximal flow increase was observed following papaverine stimulation of the LAD conduits (116.1±90.6 ml/min). Dilative stimulation effected an increase in diastolic-systolic velocity ratios from average values at rest in a range between 34% and 41.7% for both groups and substances.

Conclusions. The basic blood flow in functioning ITA grafts appears to be similar in conduits supplying the LAD and marginal branches. Flow rates between 50 and 60 ml/min at rest should meet myocardial demands, even in the LAD position. Increased flow rates were predominantly based on higher flow velocities with an increased diastolic flow proportion. Enlargement of the graft diameter may exert additional effects, at least following papaverine stimulation at a particular concentration. [Eur J Cardio-thorac Surg (1996) 10: 958–964]

Key words Bilateral ITA grafting • Conduit flow • Vascular reactivity • Intravascular Doppler
Introduction

The still expanding use of internal thoracic artery (ITA) conduits in coronary revascularization mainly reflects the unique superiority of this type of conduit regarding its longevity and patency [1, 8]. A high, proven functional adaptability allowing for variation of conduit flow depending on the actual myocardial demands may be a second reason to favor this graft [13]. Moreover, it recently became evident that, even in the short-term course, ITAs are superior to venous conduits, as the rates of postoperative survival and myocardial infarction were more favorable for this conduit type [6]. These new findings raised the question of whether some of the current restrictions for the use of ITAs may be overcome in the near future. So far, the use of ITA in unstable angina and emergency procedures as well as bilateral ITA grafting in the presence of significant left main coronary artery (LMCA) stenosis has presented one of the limits on its application [10]. Optimization of the ITA preparation technique with the aim of increased basic intraoperative conduit flow and simultaneously reduced incidence of perioperative vasospasm is one procedure aimed at overcoming these limitations [7, 12]. To obtain a more detailed insight into the basic vascular function of this type of conduit, which could perhaps lead to a more concrete definition of its usability, intravascular Doppler techniques were applied as part of a routinely performed control angiography in patients who underwent bilateral ITA in situ grafting to the left anterior descending artery (LAD) and the circumflex system (CX) or its marginal branches. Additional selective bolus stimulation with vasodilative agents was performed to define the functional mechanisms of flow regulation.

Material and methods

Following bilateral ITA grafting, 48 of 106 patients operated on between April 1993 and September 1994 underwent recatheterization between postoperative days 8 and 12. Beyond (re)angiography of the native coronary system and attached conduits, investigation of the flow characteristics using intravascular Doppler techniques was performed. For the study only the results of patients with combined in situ ITA grafting to the LAD and CX system were included, as ITA free grafting and attachment to other locations were excluded. Furthermore, the successful intravascular Doppler measurements in both ITA conduits of each individual patient were required for inclusion. Thus, 20 male patients represent our study group (Table 1). Their mean age was 51.7±3.8 years and the majority of patients suffered from 3-vessel disease (80%) with 2-vessel disease in 20%. Significant LMCA stenosis was present in six cases and proximal occlusion of the LAD had been preoperatively diagnosed in six, of whom two patients had both. The mean left ventricular ejection fraction was 63.6±10.2%. For preparation of the ITA conduits a standard no-touch technique was applied combined with injection of diluted papaverine (50 mg/50 ml normal saline) into the perivascular tissue only. The pedicles remained perfused in situ until the anastomoses were performed. Following transaction, the distal ITA was only minimally dissected without cutting the fascia, to prolong the pedicle, in any case. In combination with additional vein grafts, an average of 3.85±0.67 distal anastomoses were performed. In all procedures the right ITA was used as an in situ graft for revascularization of the LAD and left ITAs were attached to marginal branches using 8/0 monofilament running polypropylene sutures.

None of the patients had perioperative myocardial infarction or exhibited signs of local myocardial hypoperfusion. One patient had to be reexplored for bleeding from an intercostal artery, and superficial wound dehiscence occurred in another case. Otherwise, no major complications were observed.

Following informed consent of the patients, control angiography was performed between days 8 and 12 (mean 10.2±1.2). Using 6 F catheters (Cordis), angiographic control of the native coronary system and all attached grafts was performed. The ostia were selectively intubated for visualization of pedicled ITAs. After confirmation of ITA patency and function throughout the diagnostic angiography (non-ionic contrast medium, Solutrust 370) a 18/1000 inch Doppler flow wire (12 MHz, Cardiometrics Inc.) was introduced into the proximal segment. After a resting period of 5–10 min the average peak velocity (APV) and diastolic systolic velocity ratio (DSVR) were assessed, initially at rest and thereafter following selective bolus injection of 0.2 mg nitroglycerin (NTG) and 12.5 mg papaverine (PAP) directly to the ITA. Simultaneous biplane quantitative angiography (Philips DCI) served for the determination of vascular diameters (D) estimated by computerized methods (CAAS, Philips DCI). To exclude additional vasodilative effects, the contrast medium was administered while the response to PAP or NTG was maximal without the occurrence of further changes in flow variables as an effect of the contrast medium. Finally, conduit flows were calculated applying the following formula:

\[ Q = \frac{\pi \cdot D^2 \cdot v}{4} \]

where \(Q=flow\), \(D=diameter\), and \(v=average\ peak\ velocity\). There were no complications related to the control angiography procedure.

The results are expressed as mean values ± one standard deviation. For statistical comparison the paired student’s t-test with a Bonferroni correction was applied and a probability value of less than 0.05 was considered statistically significant. In the event of severely skewed distributions, the Wilcoxon signed rank test was used instead.

Results

Angiography of the investigated ITA grafts revealed properly functioning conduits without string sign phenomena or anastomotic stenoses. At rest APVs (Fig. 1) were 24.6±11.5 cm/s in ITAs supplying the LAD (ITA-LAD)
Fig. 1 Average peak velocity in ITA conduits to the LAD and ITA conduits to the CX system at rest and following stimulation with nitroglycerin (NTG) and papaverine (PAP). *: P<0.01, +: P<0.05

and 21.9±6.8 cm/s in grafts attached to the CX system (ITA-CX). Stimulation with NTG resulted in a significant increase of APV (Fig. 1) for both locations (ITA-LAD: 42.6±15.3 cm/s, ITA-CX: 40.3±10.7 cm/s, P<0.01). The effect of PAP on APV was similar to changes following NTG application (ITA-LAD 47.3±17.1 cm/s, ITA-CX 42.3±11.8 cm/s, P<0.01). When comparing APVs for the different areas supplied we were unable to find significant differences between at rest and following stimulation with NTG or PAP. Vascular diameters under the different conditions (Fig. 2) did not differ between ITA-LAD (at rest: 2.84±0.59 mm, PAP: 3.05±0.65 mm, NTG: 2.90±0.57 mm) and ITA-CX conduits (at rest: 2.87±0.40 mm, PAP: 3.14±0.42 mm, NTG: 3.03±0.42 mm). The increase in diameter following vasodilative stimulation varied between 2.1 and 9.4%. Papaverine stimulation resulted in a significant (P<0.05) diameter enlargement when compared to values at rest and following NTG application. Stimulation with NTG did not reveal significant vasodilation.

Flow rates (Fig. 3) at rest were calculated at 51.0±34.2 ml/min (ITA-LAD) and 44.7±16.4 ml/min (ITA-CX). Bolus stimulation using PAP resulted in a significant increase in flows (ITA-LAD 116.1±90.6 ml/min, ITA-CX 101.9±43.0 ml/min, P<0.01), the response to NTG was slightly less pronounced (ITA-LAD 97.4±80.9 ml/min, P<0.01; ITA-CX 90.8±36.6 ml/min, P<0.01). The differ-
Fig. 3 Calculated flow rates of pedicled ITA conduits to the LAD or the CX system at rest and following stimulation with nitroglycerin (NTG) or papaverine (PAP). *: \( P<0.01 \), +: \( P<0.05 \)

![Fig. 3](image)

Fig. 4 Diastolic systolic velocity ratio (DSVR) in pedicled ITA conduits to the LAD or the CX system at rest and following stimulation with nitroglycerin (NTG) or papaverine (PAP). *: \( P<0.01 \), +: \( P<0.05 \)

![Fig. 4](image)

ence between the two groups in flow increase following dilative stimulation was not significant. Along with vasodilative stimulation, DSVRs (Fig. 4) significantly \( (P<0.01) \) increased for both locations and substances from average values at rest (ITA-LAD: 1.15±0.27, ITA-CX: 1.01±0.31) to values between 1.34±0.33 (NTG: ITA-CX) and 1.63±0.47 (PAP: ITA-LAD). These findings demonstrate that an increasing diastolic flow mainly contributes to the overall increase in APV.

To evaluate how the degree of proximal coronary stenosis may influence flow variables of the supplying conduit, the results of ITA-LAD grafts attached to proximally occluded vessels \( (n=6) \) were compared with the remainder of this group \( (n=14) \). With respect to this subdivision of the ITA-LAD grafts, \( D (3.20\pm0.73 \text{ mm vs } 2.68\pm0.47 \text{ mm}) \), \( \text{APV (32.7}\pm15.9 \text{ cm/s vs } 21.1\pm7.3 \text{ cm/s}) \), \( \text{DSVR (1.26}\pm0.29 \text{ vs } 1.1\pm0.25 \text{) and Q (78.7}\pm45.5 \text{ ml/min vs } 39.1\pm20.0 \text{ ml/min}) were higher in grafts supplying proximally occluded vessels, without reaching significance for any of the variables. In both subgroups the response to stimulation with NTG and PAP appeared proportional to the values at rest. For the CX system a similar subdivision of the whole group did not make sense as the proximal CX was occluded in only two cases and just one patient had a proximal occlusion of a marginal branch being supplied by an ITA graft.
Intravascular miniaturized Doppler techniques have recently been applied to investigate coronary flow dynamics [18]. Beyond studying the physiologic functional processes of the coronary circulation, this technique has been used for the characterization of coronary vascular stenoses and the evaluation of interventional methods in the treatment of such stenoses [15]. Using this technique, selective pharmacologic intracoronary stimulation allows for a detailed analysis of vascular reactivity in normal and diseased coronary vessels [16].

Beside providing a control of results following interventional treatment, it has also been used to analyze surgical revascularization. Thus, Bach et al. [2] described “the characteristics of phasic blood flow velocity of arterial and venous coronary artery bypass conduits”. For ITA conduits they found “a gradual longitudinal transition in phasic flow patterns from predominantly systolic velocity proximally to predominantly diastolic velocity distally”. In contrast with his findings of a DSVR of 0.6±0.2, we observed a balanced DSVR in proximal ITAs when attached to the LAD or marginal branches. With routine use of only a proximal location of the guidewire tip in our study we cannot comment on the flow pattern along the course of the conduit. Comparing ITAs and saphenous vein grafts with respect to mean and systolic peak velocity, Bach [2] observed significantly higher values for ITA conduits.

Pharmacologic stimulation of ITA grafts in our series resulted in an increased APV predominantly caused by a diastolic flow increase. This finding would suggest that variation of the flow profile in ITA pedicles and the supplied coronary vessels is significantly involved in the regulation of vascular reactivity of this type of conduit. Enlargement of ITA vascular diameters may represent an additional, perhaps minor, effect of “dilative” stimulation as the inhomo-geneous results for PAP and NTG (n.s.) would indicate. However, this conclusion appears preliminary as pharmacologic intracoronary stimulation allows for a detailed analysis of vascular reactivity in normal and diseased coronary vessels [16].

Derived from APV and vascular diameter, the calculated flows obtained for ITA-LAD conduits at rest were similar to the flow rates reported when using intraoperatively applied electromagnetic flow probes [11] or postoperative transthoracic Doppler flow measurements [5], when supplying the LAD with ITA grafts. Applying electromagnetic techniques for intraoperative flow assessment in coronary grafts, Louagie [11] recently found somewhat lower flow rates (36±2 ml/min) in ITAs connected to the LAD. Transthoracic flow measurements, in contrast, have inherent limitations with respect to the detectability of ITA pedicles. De Bono [5] could evaluate transthoracic Doppler signals in only 16 of 26 attempted studies performed within the first postoperative year, due to insufficient imaging of the pedicle. For pedicles suitable for transthoracic evaluation, a flow rate of 47 ml/min was determined [4]. Even with transthoracic means he found an altered flow pattern in ITAs supplying the coronary artery system, with increase of the diastolic flow proportion when compared to native ITA flow. Nevertheless, it appears that intravascular techniques seem to produce more reliable results in assessing the function in ITA grafts, compared to a trans-thoracic approach. Compared to electromagnetic techniques, it has the additional advantage of postoperative applicability.

In addition, simultaneous angiography appears to be necessary to assess a proper conduit function excluding string sign phenomena and anastomotic site problems, which may essentially influence results obtained by mere transthoracic means. Flow rates of venous conduits in the LAD position assessed by electromagnetic techniques by Louagie [11] were significantly higher (66±9 ml/min, but did not seem to result in fewer episodes of clinically detectable ischemia. Moreover, it was impossible in that study to confirm any relation between ITA free flow rates before grafting and flow rates following its connection to the coronary system. Thus, on the one hand, it in general may appear questionable whether an ITA free flow rate below a specified limit should exclude this conduit for grafting and what limits could be accepted. On the other hand, the increase of ITA free flow rates by “optimized” preparation techniques before attaching the conduit may be unnecessary and would also not imply beneficial effects in terms of reducing the perioperative risk of ischemia. Therefore, even ITA free flow rates of more than 100 ml/min obtained by mechanical or hydrostatic dilatation techniques [7, 12] may not represent a guarantee of optimal graft function. When applying “aggressive” dilatation techniques, structural and functional impairment of ITA conduits has to be considered independently of free flows under intraoperative conditions [3, 17].

So far, a clear intraoperative demonstration of low flow rates of conduits supplying the LAD and CX system separately has only been described for saphenous vein conduits. In this context, Louagie [11] found flow rates of 66±9 ml/min for LAD grafts and 42±6 ml/min for obtuse marginal branches following chest closure, whereas Conner [4] reported flow rates between 35±7.8 ml/min and 38±4.5 ml/min for venous grafts to obtuse marginal branches intraoperatively. These results of saphenous vein conduits appear similar to our early postoperative results for ITAs at rest even with the use of different flow measurement techniques. The similarity between the flow rates of saphenous vein and ITA conduits suggests that these flow rates would depend more on the coronary run-off than on the conduit flow capacity, since conduit-dependent flow limitations in the range of 50 ml/min should not be expected in venous conduits at least. However, the sufficient postoperative flow reserve of ITA conduits under conditions of increased myocardial flow demand has been reported earlier using thallium-scintigraphy [9] or radionu-
cleid washout kinetics [14]. But a subtle analysis of vascular flow variables could not be achieved with such techniques.

Our early postoperative results on calculated flow rates of properly functioning ITA grafts to the LAD and the CX system would support the assumption that the LAD region and the CX system require similar flow rates at rest and under conditions of stress. Thus, a preference for the ITA with higher flow rates for the supply of the LAD region does not seem to be justified in cases of bilateral ITA grafting. High intraoperative ITA flow rates do not appear to be essential to prevent regional, conduit-related hypoperfusion. Applying appropriate ITA preparation techniques, an adequate flow regulation according to the myocardial demands of the area supplied can be expected, even early postoperatively, provided that distal anastomoses are created which do not restrict the blood flow. Thereby, the increase of flow rates at stress may be based rather on an increase in flow velocity and diastolic flow proportion than on conduit vasodilation.

References

Dr. R. Dion: (Brussels, Belgium) I have enjoyed your paper, as the previous ones we have already discussed together. We have also measured postoperative ITA flows using intravascular Doppler technique at an interval of 6 months – 1 year after surgery. We also measured the ITA diameter at rest and during pacing, which resulted in a significant increase of the cardiac output, hence of the coronary flow: the ITA diameter significantly increased during pacing.

My question is: why didn’t you add to the pharmacologic stimulation – which is testing the flow reserve of the conduit – a pacing stimulation, which is probably going to test the flow reserve of the myocardium? You would probably also find a dilatation of the ITA conduit under these circumstances.

My second point is: I am a bit disturbed by the fact that you don’t describe the tightness of the stenosis at the origin of the LADs. In my opinion, the absence or the persistence of an antegrade flow in the LAD should definitely influence your measurements.

Dr. Cremer: Thank you for your detailed comments. Concerning the question of pacing, I think it is quite another approach to use pacing, and there are data on flow measurements in PTCA situations which also applied stimulation by nitroglycerin or papaverine, and it’s more a principal decision whether you want to compare with pacing or pharmacologic stimulation. We tried to look at the degree of LAD stenosis and there were six cases with proximal LAD occlusion, but so far we haven’t been able to find any striking differences for this subgroup.

Dr. F. Fontan: (Bordeaux, France) Dr. Cremer I would like to ask a question. Do you think in your study you have assessed only the internal thoracic artery? Since you have no change in the diameter of the vessel, the coronary artery resistances must be involved.

Dr. Cremer: For this study we didn’t calculate the vascular resistance of the coronary vasculature. That’s part of a larger study being published by our cardiology team. But, of course, you are right to assume a reduction of the coronary vascular resistance with respect to our results.

Dr. P. Spence: (Louisville, Kentucky) I think these are remarkable data and very nicely collected and presented. I would just like to make a comment that the resting flow rates in these mammary artery grafts are quite low and there may be, in fact, occasions in the perioperative period where flow demands exceed the maximum capacity of the mammary arteries. In these days with modern myocardial protection there are few examples, but probably the one that should be considered is a situation where a large vein graft is replaced with a mammary artery at reoperation. It may be possible that the flow capacity of the mammary is exceeded at this time. Have you any information comparing immediate postoperative measurements with the numbers you have derived in the early postoperative period?

Dr. Cremer: So far we have not included patients with reoperations in this study and, when comparing it to other studies, independent of the method applied for measuring the flow, the flows given here are quite similar to those reported. We intend to look at a subgroup of patients a second time after 1 year to get more information on this basic flow demand, but for the group of patients included in this study we did not observe hypoperfusion phenomena within the postoperative course.