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Graft Control by Transit Time Flow Measurement and Intraoperative Angiography in Coronary Artery Bypass Surgery

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ABSTRACT

Background: The aim of this study was to compare the relationship between intraoperative transit time flow measurements and angiographic findings with long-term graft patency in 72 patients who underwent coronary artery bypass surgery.

Methods: Transit time flow measurements with recording of mean flow and pulsatility indexes were performed after completion of the anastomoses. Coronary angiography was performed on-table while the patients were still in general anesthesia, and then at follow-up three months and 12 months after surgery. Based on angiography, the grafts were graded as type A (fully patent), type B (having more than 50% diameter reduction), or type O (occluded).

Results: Of the 67 left internal mammary artery (LIMA) grafts, 51 (76%) were type A on-table, 14 (21%) were type B, and two (3%) were type O. Of the 57 saphenous vein grafts, 49 (86%) were type A, 7 (12%) were type B, and one (2%) was type O. For both LIMA and vein grafts, there were no differences in flow ($p = 0.69$ and 0.47, respectively) or pulsatility index ($p = 0.79$ and 0.83) between type A and B. There were also no differences in flow ($p = 0.37$ and 0.7) or pulsatility index ($p = 0.37$ and 0.24) between type B on-table that either normalized or persisted occluded at the follow-up. Transit time flow measurement failed to detect an occluded LIMA graft as shown by intraoperative angiography.

Conclusions: Blood flow measurements performed intraoperatively could not identify significant lesions in arterial or vein grafts, and could not predict graft patency. We have become cautious in interpreting flow measurements alone and combine blood flow recordings with intraoperative angiography in the assessment of graft quality.

INTRODUCTION

The introduction of off-pump coronary artery bypass surgery, performed without extra-corporeal circulation, has stimulated interest in intraoperative graft and anastomosis quality assessment. Intraoperative quality assessment can be performed by electromagnetic flowmeters [Louagie 1994] and ultrasound-based flowmeters such as Doppler [Segadal 1982] or transit time flowmeters [Lundell 1993, Laustsen 1996]. Today, the transit time flowmeter is the most commonly used tool for control in coronary revascularization because the device is easy to use, the flow values are exact and reproducible, it gives direct volume flow, and the measurements are independent of vessel diameter and Doppler angle. However, interpretation of the findings can be difficult because interpretation of the flow curves is empirical and dependent on the surgeon's experience. Normal flow values are not defined.

Coronary angiography is considered the "gold standard" for the morphological assessment of coronary arteries and bypasses. However, this method does not give information on flow and is normally not available in the operating theater. At the Interventional Centre at Rikshospitalet, fixed angiographic equipment (Advantix, General Electric Medical Systems, Milwaukee, WI) was installed in a specially designed operating room in 1996 [Fosse 2000], allowing coronary angiography to be performed intraoperatively [Barstad 1997].

The aim of this study was to compare the relationship between intraoperative transit time flow measurements and intraoperative angiographic evidence of graft patency in patients undergoing coronary artery bypass surgery.

The regional ethical committee approved the study.

MATERIALS AND METHODS

Seventy-two patients underwent coronary artery bypass surgery. On-pump surgery (with extra-corporeal circulation) was used in 21 cases (13 males and 8 females with mean age 68 ± 7.8 years) and off-pump (without extra-corporeal circulation) in 51 cases (41 males and 10 females with mean age 65 ± 8.7 years). A total of 124 grafts, 67 left internal mammary artery (LIMA) grafts and 57 saphenous vein grafts, were used. Patient characteristics are listed in Table 1 (◎). Five of the off-pump patients were operated upon with a hybrid approach, where anastomosis between the LIMA and the left anterior descending artery (LAD) was combined with percutaneous transluminal coronary angioplasty (PTCA) or stenting of the right or circumflex arteries.

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Table 1. Patient characteristics (n = 72)

	Off-pump (n = 51)	On-pump (n = 21)
Age of patients in years	65 (±8.7)	68 (±7.8)
Males (n)	41 (80%)	13 (62%)
Females (n)	10 (20%)	8 (38%)
Number of vessels diseased	2.0 (±0.8)	2.2 (±0.6)
Number of distal anastomoses	1.6 (±0.8)	2.2 (±0.8)[a]
Mean NYHA classification	2.7 (±0.6)	2.7 (±0.5)
Mean ejection fraction	71.1 (±14.3)	71.2 (±11.4)

Values are in numbers (n) and in mean with standard deviation (±) or percentage (%) in parentheses; [a]statistically significant vs. off-pump (p=0.002).

Immediately after sternotomy, the LIMA was dissected with intact pedicle and divided, papaverine 4% was injected, and the vessel clamped with a clip at the distal end. All patients were anticoagulated postoperatively with acetyl acetic acid (160 mg) for at least three months. If a stent was used, ticlopidine was also administered for three months.

Transit time flow measurement and coronary angiography were performed on-table in all cases. After construction of the bypass grafts, flow was measured at the distal part of the graft using the Cardiomed transit time flowmeter (Medi-Stim, Oslo, Norway). Mean flow, pulsatility index (PI), and waveform were recorded for each graft. When multiple measurements were performed in the same case, the best mean flow value was used for the analysis. Mean flow is the denomination of each single flow measurement, and in group comparisons the median mean flow was named median graft flow (instead of median mean graft flow) and the single mean flow was named flow. PI was defined as the difference between maximum forward flow and maximum negative flow divided by mean flow [D'Ancona 2000]. Immediately after closure of the chest, coronary angiography of the grafts was performed while the patients were still under general anesthesia. A follow-up angiography of both the grafts and the native coronary arteries was carried out at three months in all cases. Forty-eight grafts were assessed by an additional angiography at 12 months. All angiographic examinations were performed by one member of a team consisting of two radiologists and one cardiologist, and were evaluated visually by two independent readers. The patency grade was evaluated as described by FitzGibbon [FitzGibbon 1986], where grade A was defined as a normal graft or graft with lesion of less than 50% reduction in diameter, grade B as graft with lesion of more than 50% reduction in diameter, and grade O as occlusion.

Values are given as mean or median with standard deviation (SD) or range, using the statistical program SPSS, version 9.0 for Windows. The Mann-Whitney test was used for statistical comparisons and $p < 0.05$ was considered significant.

RESULTS

There were a significantly lower number of distal anastomoses in the off-pump group than in the on-pump group (1.6 vs. 2.2) (p = 0.002) (Table 1, ◎). No differences were found in other patient characteristics.

At on-table angiography 46/48 LIMA grafts performed off-pump (96%) and 19/19 LIMA grafts performed on-pump (100%) were patent; 31/31 vein grafts performed off-pump (100%) and 25/26 vein grafts performed on-pump (96%) were patent. All obstructions were found in the conduits, most of them at the distal anastomoses.

The correlation between transit time flow measurements and coronary angiography in LIMA to LAD grafts is shown in Table 2 (◎). Of the 67 LIMA to LAD grafts, 48 constructed off-pump had a median flow of 22 (range of 5-58) ml/min. and median PI of 2.3 (1.2-4.7), and 19 constructed on-pump had a median flow of 26 (13-42) ml/min. and median PI of 2.3 (1.0-6.5). Fifty-one of these 67 grafts (76%) were assessed to be type A on-table, 14/67 (21%) were type B, and 2/67 (3%) type O. All of the type B grafts had diameter reductions in the range of 50 to 75%, except for one that had a 90% diameter reduction. The flow and PI values for this last case were 17 and 2.0, respectively. There was no significant difference in flow and PI between grafts constructed off- and on-pump or between type A and type B grafts. Twelve of the 14 patients with intraoperative type B grafts had angiographic follow-up; seven grafts with median flow of 19 (range of 12-34) ml/min. and median PI of 2.0 (1.0-4.7) were normalized after three months, and in five grafts with median flow of 21

Table 2. Correlation between flow, pulsatility index, and coronary angiography (performed on-table and at follow-up) in LIMA to LAD grafts

		N	Flow (ml/min)	PI
All LIMA grafts	off-pump	48	22 (5-58)	2.3 (1.2-4.7)
	on-pump	19	26 (13-42)[a]	2.3 (1.0-6.5)[a]
Intraoperative	Type A (36 off-pump, 15 on-pump)	51	24 (10-58)	2.2 (1.2-6.5)
	Type B (10 off-pump, 4 on-pump)	14	20 (12-39)[b]	2.3 (1.0-4.7)[b]
	Type O (2 off-pump)	2	9 (5-13)	3.4 (2.6-4.1)
Intraoperative	Type B, Normalized at follow-up (4 off-pump, 3 on-pump)	7	19 (12-34)	2.0 (1.0-4.7)
	Type B, Persisted at follow-up (4 off-pump, 1 on-pump)	5	21 (16-39)[c]	2.5 (1.9-2.9)[c]

Flow and pulsatility index (PI) are in median (range); [a]not statistically significant (ns) vs. off-pump grafts; [b]ns vs. intraoperative type A; [c]ns vs. intraoperative type B that normalized at follow-up.

Table 3. Correlation between flow, pulsatility index, and coronary angiography (performed on-table and at follow-up) in saphenous vein grafts

		N	Flow (ml/min)	PI
All vein grafts	off-pump	31	30 (5-99)	2.6 (0.7-12.1)
	on-pump	26	36 (2-112)[a]	2.5 (1.3-49.3)[a]
Intraoperative	Type A (26 off-pump, 23 on-pump)	49	34 (5-112)	2.5 (1.0-13.1)
	Type B (5 off-pump, 2 on-pump)	7	24 (11-70)[b]	2.8 (0.7-12.1)[b]
	Type O (on-pump)	1	2	49.3
Intraoperative	Type B, Normalized at follow-up (3 off-pump, 2 on-pump)	5	27 (19-99)	1.9 (0.7-3.1)
	Type B, Occluded at follow-up (2 off-pump)	2	24 (24-24)[c]	2.9 (2.8-2.9)[c]

Flow and pulsatility index (PI) are in median (range); [a]ns vs. off-pump grafts; [b]ns vs. intraoperative type A; [c]ns vs. intraoperative type B that normalized at follow-up.

(16-39) ml/min. and median PI of 2.5 (1.9-2.9), the stenosis persisted. The p-values for flow and PI between these two groups were both 0.37. The majority of the changes in angiographic grading had taken place at three months. A further improvement from grade B to grade A took place from three to 12 months in only two LIMA grafts.

The correlation between transit time flow measurements and coronary angiography in the vein grafts is shown in Table 3 (). Of 57 saphenous vein grafts, 31 constructed off-pump had median flow of 30 (range of 5-99) ml/min. and median PI of 2.6 (0.7-12.1), and 26 constructed on-pump had median flow of 36 (2-112) ml/min. and median PI of 2.5 (1.3-49.3). Forty-nine of these 57 grafts (86%) were angiographic type A on-table, 7/57 (12%) were type B, and 1/57 (2%) were type O. All seven on-table type B vein grafts had diameter reductions of 50-75%. There was no significant difference in flow and PI between grafts constructed off- and on-pump or between type A and type B grafts. The one type O graft had flow of 2 ml/min. and PI of 49.3. On the angiographic follow-up of the seven intraoperative type B grafts, five with median flow of 27 (19-99) ml/min. and median PI of 1.9 (0.7-3.1) were normalized after three months, and two (median flow of 24 and median PI of 2.9) were occluded. P-values for flow and PI were 0.7 and 0.24, respectively. All changes in angiographic grading had taken place at three months, with no further development at 12 months.

DISCUSSION

The relationship between flow and morphology is complex and dependent on many factors, including the degree of stenosis. Dog studies have shown that the resting coronary flow is reduced only in the presence of 85% reduction in diameter, while hyperemic flow is reduced with 30 to 45% diameter reduction [Gould 1974a, Gould 1974b, Gould 1975]. In an angiographic study in dogs, Jaber showed that resting graft flow decreased at well-defined and short stenoses larger than 75% [Jaber 1998a]. With increasing length of stenosis the resting flow reduction could be detected already after 40 to 60% diameter stenosis in the laboratory [Feldman 1978]. In a questionnaire among 19 surgeons, Jaber found that, from recorded flow tracing in a dog study, the surgeons could only reliably point out stenoses with diameter reduction of more than 90% [Jaber 1998b]. The degree of stenosis that resting transit time flow measurements can detect in diffusely diseased human coronary arteries is, thus, not clear. In our study there were no significant differences in flow between angiographic type A and B grafts either in the LIMA or in the vein grafts (Figure 1A, 1B,). This could be explained by the fact that nearly all stenoses were graded 50-75%. However, one LIMA to LAD anastomosis with a 90% diameter reduction was undetectable by transit time flow measurement (flow 17 ml/min., PI 2.0) and one LIMA graft with flow 13 ml/min. and PI 4.1 was demonstrated occluded by angiography (Figure 2A, 2B,).

The lowest acceptable flow value in LIMA grafts is not defined. Graft revision has been advised if graft flow is less than 5 ml/min. [Barnea 1997], and the normal range for PI has empirically been considered to be 1-5 [D'Ancona 2000]. One of the LIMA grafts occluded at intraoperative angiography had a flow of 5 ml/min. (PI 2.6). The lesion in the native vessel was probably not significant enough and caused competitive flow that would account for the low flow value and the filling of contrast material only halfway down the graft found at angiography, which was the reason for the graft being identified as occluded. The other occluded LIMA graft had, surprisingly, an acceptable flow value of 13 ml/min. with PI 4.1 (Figure 2A, 2B,). The native LAD was in this case occluded. The distal part of the LAD, where the LIMA was anastomosed, was heavily diseased and contrast medium injected in the LIMA graft never filled the native LAD. The graft may have occluded in the interval between the flow measurement and the angiography. Further attempt at revascularization was not performed. The second lowest LIMA flow was 10 ml/min. (PI 2.8), measured in a graft with type A anastomosis. The lowest vein flow (2 ml/min., PI 49.3) was measured in a graft that was occluded intraoperatively as judged by angiography. With its low flow value and high PI, it was not accepted as a functional graft. The second lowest vein flow was 5 ml/min. (PI 6.8) and had an excellent type A anastomosis, but with poor runoff.

Although flow values per se could not indicate stenoses of the grafts, the transit time flow measurement should be able to predict an occluded graft. Our study had too few occluded grafts to indicate a lower flow level where occlusion could be suspected. Such a lower limit is difficult to determine because the size of the graft, the quality of the target coronary artery, and the size of the vascular bed influence the absolute flow value. In addition, both central hemodynamics and coronary artery resistance might influence graft flow. A flow curve of systolic spikes and diastolic flow with absolute flow less than 5 ml/min. would strongly raise the suspicion of an occluded graft.

Our findings have limitations. First, the flow measurements have been performed intraoperatively but not during standardized hemodynamic conditions. Second, there is a time interval between the flow measurement and the coronary angiography. During this period hemodynamic management and level of anticoagulation may have been altered, and open grafts may occlude. Third, in this study hard variables like mean flow value and PI were analyzed. Subjective values like flow curve patterns were not included. This could have given other results.

Not all lesions detected by intraoperative angiography are of significance, as grafts have the ability to remodel over time [Calafiore 1998]. Intraoperative lesions may be caused by reversible events like spasm, localized thrombosis, edema, or bleeding. Anastomotic lesions demonstrated by intraoperative or immediate postoperative angiography may thus have no impact on later patency. Remodeling of grafts seems to have taken place rapidly after surgery, as nearly no further development in angiographic grading took place after three months.

CONCLUSION

We conclude that blood flow measurements performed intraoperatively could not identify significant stenoses in arterial or vein grafts and were not predictive of long-term graft patency. Blood flow measurements should be interpreted cautiously and viewed as additional evidence to other indicators of graft dysfunction.

Acknowledgments

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REVIEW AND COMMENTARY

1. Editorial Board Member JZ39 writes:

I did not get a clear picture from the tables as to why the authors said there was no correlation between the doppler measurements and the caths. Perhaps they could construct a clearer table of those with suspicious doppler flow that were patent angiographically and those with good doppler flow that were plugged.

Author's Response by Per Kristian Hol, MD:

The definition of suspicious Doppler flow is not clear, but it is stated that flow below 5 ml/min and PI above 5 indicate an unacceptable graft. In our study there was only one graft with a flow below 5 ml/min (the intraoperative type O graft in Table 3, with flow 2 ml/min and PI 49.3), and that graft was occluded at angiography. All other grafts had flow above 5 ml/min. Six grafts had PI-values above 5, one (flow 11 and PI 12.1) was significant stenosed and five (median flow 16 with range 5-31 and median PI 6.8 with range 6.3-13-3) were excellent as judged by angiography. The importance of the finding of a "high" PI-value in these five angiographically excellent grafts can be discussed.

Only three patients had good Doppler flow measurements and poor /plugged angiography. This is shown in Table 2 (two patients with intraoperative type O graft (flow 5 and 13, PI 2.6 and 4.1)) and the patient referred to in the Results section with a 90% diameter reduction (flow 17 and PI 2.0). There are too few patients to draw any conclusion.

2. Editorial Board Member GX21 writes:

This paper concludes a negative result, that there is no significant relationship between patency and flow measurements. But two steps are taken in the analysis which might limit the ability to find such a relationship. First, the patency is collapsed from the raw percentage

measurements into three groups (A,B,O), and only 2 of the groups are compared. Second, the 124 grafts are separated into two groups – 67 LIMA and 57 veins and separate significance tests are performed in each group. Thus one comparison has 51 vs. 14 LIMA, and the other has 49 vs. 7 veins.

If, instead, one tested the Spearman rank correlation between the raw patency percentages and flow values, and all conduits were used, one might find significance. The median flows in both groups go in the same direction (24-20-9) and (34-24-2), as do the PI's (2.2-2.3-3.4), (2.5-2.8-49.3).

For maximum power in finding significant relationships, both groups (LIMA and vein) could be used simultaneously by calculating a partial rank correlation coefficient.

Author's Response by Per Kristian Hol, MD:

It is a good suggestion to use the Spearman rank correlation between the raw patency percentage and flow value. Unfortunately the patency was not graded in percentages (continuous data), but grouped as excellent, significant stenosed or occluded (categorical data). To perform a rank correlation is therefore not possible.

How much a material like this should be broken down before analyzing could always be discussed. We did find it interesting to analyze the material with respect to the difference between arterial and vein grafts, and grafts constructed on- or off-pump. We do agree that power is important. A Mann-Whitney test for all 124 grafts, however, showed no significant difference between intraoperative type A and type B grafts.

We did not present statistical analyzes of the type O grafts in the article because the group type O grafts is small (only 3 grafts). By regrouping the results in two groups, one group with excellent grafts (grafts type A) and the other with non-excellent grafts (grafts type B and O), we had two groups that could be statistically compared, but with no statistical difference.

3. Editorial Board Member SG14 writes:

This article may fail its initial target to define the true value of intraoperative flow measurement, but it is a great contribution to understand early angiographic results.

As the authors criticize not performing measurements under standardized hemodynamic conditions, it would be of interest to know in how many patients catecholamins were used.

Author's Response by Per Kristian Hol, MD:

Catecholamines (adrenalin, metaraminol or ephedrine) were used in 38% of the patients.