The impact of intraoperative transit time flow measurement on the results of on-pump coronary surgery

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Abstract

Objective: The purpose of this study is to evaluate the effect of detection of graft dysfunction by intraoperative transit time flow measurement (TTFM) on the surgical results of on-pump coronary artery bypass grafting. Methods: Two hundred patients undergoing on-pump isolate coronary artery bypass grafting via median sternotomy performed by the same surgical team were included into the study. TTFM was routinely performed for assessment of graft patency during operation after a transit time flow meter became available in our center in February 2006. The last 100 consecutive patients before this date formed the control group (Group A), and the first 100 consecutive patients after this date formed the study group (Group B). Interpretation of the values obtained using the TTFM in Group B patients has allowed us to reach a decision whether or not to revise a graft. Preoperative and postoperative variables of the two groups were compared. Results: The clinical features of control and study groups were comparable. We assessed patency of 303 grafts using TTFM. Revision was required for nine grafts in nine patients based on unsatisfactory TTFM findings. Incidences of overall mortality ($p < 0.05$), peri- or postoperative myocardial infarction ($p < 0.05$) and intraaortic balloon pump insertion ($p < 0.05$) were significantly lower in Group B than Group A. Conclusions: We believe that TTFM seems to be a crucial tool for deciding if a graft is well-functioning or not, and it allows for improvement of graft failure during operation. Our results suggest that detection of graft dysfunction intraoperatively by TTFM improves the surgical outcome.

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Keywords: CABG; Transit time flow measurement; Graft dysfunction

1. Introduction

Coronary artery bypass surgery (CABG) has contributed to an increase in survival, quality of life and life expectancy [1]. The anastomotic quality is directly associated with both early and long-term clinical results after CABG. It is a complication that can lead to refractory angina, myocardial infarction, arrhythmias, and even mortality [2–5]. Although most surgeons believe it to be a rare occurrence, the incidence of perioperative graft failure has been estimated to be from 5 to 11% [6–8]. It was traditionally common for surgeons to determine the adequacy of anastomosis by palpitation of graft pulsation, to assess hemodynamic stability and electrocardiographic chances. But this method is unreliable and indirect. Therefore, it is critical for surgeons to directly evaluate the quality of anastomosis in CABG. To increase the reliability of anastomotic quality several methods have been introduced over the last decade [2–9]. Transit time flow measurement (TTFM) has been reported to be a suitable method for easy and quick intraoperative functional assessment of bypass grafts, independent of vessel size and shape [7–13]. But we could not find a study in English literature comparing the surgical results of patients undergoing on-pump CABG with and without the use of the TTFM.

The purpose of this study is to evaluate the effect of detection of graft dysfunction by intraoperative TTFM on the surgical results of on-pump CABG.

2. Material and methods

2.1. Patient population

Two hundred patients undergoing on-pump isolate coronary artery bypass grafting via median sternotomy performed by the same surgical team were included in this study. A transit time flow meter became available in our center in February 2006. The last 100 consecutive patients before this date formed the control group (Group A), and the first 100 consecutive patients after this date formed the study group (Group B).
2.2. Surgical procedure

All patients were premedicated with midazolam, 0.07–0.1 mg/kg. Anesthesia was induced with fentanyl and dipirvan, and vecuronium was used for muscle relaxation. Anesthesia was maintained with perfusion of fentanyl and dipirvan. A median sternotomy was performed in every case and the grafting material (left internal mammary artery (LIMA), saphenous vein grafts (SVG) and/or radial artery) was harvested simultaneously. Heparin was given at 3 mg/kg and the activated clotting time was kept above 450 s. All operations were performed with mildly hypothermic cardiopulmonary bypass and cross clamping. Cardiac arrest was established initially with antegrade crystalloid cardioplegia, then cooled ante-or retrograde blood cardioplegia containing potassium and finally warm blood cardioplegia were administered for myocardial protection. The distal anastomoses were performed with 7-0 or 8-0 polypropylene running suture on a partially excluded ascending aorta. After decannulation heparin was totally reversed.

In postoperative period, fractionated heparin (s.c.) was administrated at the fourth postoperative hour and continued until the patient was mobilized. Low-dose aspirin treatment was started the day after surgery and continued thereafter.

2.3. Intraoperative flow measurement

The protocol established by D’Ancona et al. [12–14] was used while TTFM was performed. Before measurement, we use inotropic agents to maintain the systolic pressure at 90–100 mmHg in patients with lower pressure. TTFM was performed for assessment of every graft after completion of anastomosis during operation by using a transit time flow meter (Medistim VQ-1101, Medistim ASA, Oslo, Norway), and all measurements were repeated before the closure of the sternum. The TTFM probe was perfectly fitted around the graft. When necessary, different probes, which fit the actual size of the vessel were used to avoid distortion or compression of the graft. The 3-mm probe was most commonly used. Skeletonization of a small segment of the mammary artery was necessary to reduce the quantity of the tissue interposed between the vessel and the probe. Flow through the whole sequential bypass and flows through the both proximal and distal segment of graft were examined. Measurements were done both with and without proximal occlusion 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 if high level of retrograde blood flow existed. The device displays a flow curve and calculates the mean flow (ml/min), pulsatile index (PI) and diastolic filling percentage (DF%). In case of the DF < 50% and/or PI > 5 it was accepted as an indicator of poor flow. The mean flow was not solely used as an indicator of poor flow, and it was evaluated together with the other two parameters. Interpretation of the values obtained has allowed us to reach a decision whether or not to revise a graft. In case of unsatisfactory TTFM findings, the length and property of the graft was checked. It was also checked for twisting, kinking, air bubbles or spasm. If one of them was detected it was corrected. If no obvious cause was found then the graft was opened by a small incision approximately 1 cm away from the anastomosis. The patency of the anastomotic site and the distal coronary artery was checked by using a small coronary probe. In patients with a second severe lesion in distal coronary artery, a new anastomosis with another graft was performed. In patients with LIMA–LAD grafts in whom TTFM findings were unsatisfactory, patency of the LIMA was also checked by a coronary probe, and evaluation of antegrade blood flow. If a severe stenosis in the proximal segment of LIMA was detected, the LIMA was transected and then anastomosed to the aorta. All measurements were repeated before the closure of the sternum to confirm graft patency and to detect any possible new graft kinking or compression even if satisfactory TTFM findings were obtained in the last measurement.

2.4. Statistical analysis

All data were expressed as means ± standard deviation. Comparison of data between the two groups was performed using the independent two-sample t-test, the independent two-ratio test (z test) and the independent Fisher’s χ² test. A p value of less than 0.05 was considered to be statistically significant.

3. Results

Demographic features and intraoperative data of both groups are given in Tables 1 and 2, respectively. The incidences of all variables that can influence the clinical
and the technical data for these nine grafts are given in Table 4. When a stenosis in distal LAD was detected, revision of the anastomosis or the bypass graft was performed (Fig. 2), and the operation was ended when a good flow was achieved. The defined reasons of the poor flow and the technical data for these nine grafts are given in Table 4.

The grafts were transected and shortened in the case of the graft that was too long, and repositioned in the correct orientation in the one that was twisted. In three patients with LIMA–LAD grafts that were unsatisfactory TTFM findings, there were severe second lesions in right posterior descending coronary artery (RCA) grafts that were unsatisfactory TTFM findings, there were severe second lesions in right posterior descending artery and a new anastomosis with saphenous vein grafts were performed to posterior descending arteries and then anastomosed to the SVG-RCA grafts as an end-to-side fashion. After revision, all flow values and flow patterns improved. No electrocardiographic changes were noted in those patients in whom unsatisfactory TTFM findings were noticed and the anastomoses were corrected.

The major postoperative complications, overall morbidity and mortality rates are shown in Table 5. Complication rates were lower in study group than control group (p < 0.05). All patients in study recovered without acute myocardial infarction while five patients in control group had a postoperative acute myocardial infarction (p < 0.05). Incidence of intra aortic balloon pump (IABP) insertion for low cardiac output was significantly higher among patients in Group A than in Group B (p < 0.05). There were four postoperative deaths in the control group while death in course of intraaortic balloon pump.

Table 2

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Group A (n = 100)</th>
<th>Group B (n = 100)</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of grafts (n)</td>
<td>281</td>
<td>278</td>
<td>n.s.</td>
</tr>
<tr>
<td>LIMA</td>
<td>100</td>
<td>100</td>
<td>n.s.</td>
</tr>
<tr>
<td>Radial artery</td>
<td>15</td>
<td>14</td>
<td>n.s.</td>
</tr>
<tr>
<td>Saphenous vein grafts</td>
<td>168</td>
<td>164</td>
<td>n.s.</td>
</tr>
<tr>
<td>Sequential bypass</td>
<td>23</td>
<td>25</td>
<td>n.s.</td>
</tr>
<tr>
<td>Grafts per patients (mean ± SD)</td>
<td>3.06 ± 0.81</td>
<td>3.03 ± 0.80</td>
<td>n.s.</td>
</tr>
<tr>
<td>Total distal anastomosis (n)</td>
<td>306</td>
<td>303</td>
<td>n.s.</td>
</tr>
<tr>
<td>LAD</td>
<td>102</td>
<td>102</td>
<td>n.s.</td>
</tr>
<tr>
<td>Diagonal</td>
<td>47</td>
<td>48</td>
<td>n.s.</td>
</tr>
<tr>
<td>Cx system</td>
<td>82</td>
<td>80</td>
<td>n.s.</td>
</tr>
<tr>
<td>RCA system</td>
<td>77</td>
<td>73</td>
<td>n.s.</td>
</tr>
</tbody>
</table>

LAD: left anterior descending artery, Cx system: circumflex system, RCA system: right coronary artery system, LIMA: left internal mammary artery, IABP: intraaortic balloon pump.

Table 3

Before sternal closure intraoperative TTFM findings of study group

<table>
<thead>
<tr>
<th>Grfts</th>
<th>Number of grafts</th>
<th>Mean flow (ml/min) mean (range)</th>
<th>PI mean (range)</th>
<th>DF% mean (range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIMA–LAD grafts</td>
<td>102</td>
<td>53.14 ± 21.22 (25–110)</td>
<td>2.32 ± 0.88 (1–4.9)</td>
<td>66.29 ± 7.66 (60–84)</td>
</tr>
<tr>
<td>Ao-diagonal grafts</td>
<td>48</td>
<td>43.19 ± 17.32 (16–98)</td>
<td>2.26 ± 0.81 (1.1–4.2)</td>
<td>64.90 ± 7.45 (50–81)</td>
</tr>
<tr>
<td>Ao-Cx system grafts</td>
<td>80</td>
<td>49.86 ± 21.81 (23–115)</td>
<td>2.51 ± 0.94 (1.1–4.9)</td>
<td>63.22 ± 7.67 (50–80)</td>
</tr>
<tr>
<td>Ao-RCA system grafts</td>
<td>73</td>
<td>59.15 ± 29.55 (18–146)</td>
<td>2.23 ± 0.94 (0.9–4.5)</td>
<td>62.04 ± 6.74 (51–81)</td>
</tr>
</tbody>
</table>

LIMA–LAD: left internal mammary artery–left anterior descending artery, Ao-diagonal: aorta-diagonal, Ao-Cx system: aorta-circumflex system, Ao-RCA system: Ao-right coronary artery system.
study group did not occurred (p < 0.05). Our patients were discharged after a mean hospital stay of 8.3 days in Group A and 8.2 days in Group B.

4. Discussion

Coronary artery bypass surgery performed for almost half a century has contributed to an increase in survival, quality of life and life expectancy [1]. Despite substantial improvement in surgical technique the operative treatment of the ischemic heart disease is still only palliative. Closure of 10—15% of saphenous vein grafts in first month, followed by another 5—10% in the next 11 months is mostly secondary to a failure in surgical technique. This could be caused by kinking of graft, linear tension due to insufficient graft length but most frequently because of failure in construction of the anastomosis itself [11]. The anastomotic quality in CABG is directly associated with both early and long-term clinical results. It is a complication that can lead to refractory angina, myocardial infarction, arrhythmias, and even mortality [2—5]. For this reason graft patency is a very important issue and is strictly followed by many researchers [11].

Several techniques have been used in the past to evaluate graft patency intraoperatively: electromagnetic flowmeters, initially adopted in coronary surgery, have been recently replaced by ultrasonic technology (Doppler and TTFM). Using TTFM technique several authors have reported excellent results in diagnosing technical failures during CABG and resolving the problem during the same operation [1,7,9,12—14].

The studies of D’Ancona et al. [13] and Walpoth et al. [17] have reported that in 6—8% of all patients a technical failure can be diagnosed with TTFM and resolved during the same operation. This is of great benefit for the patient avoiding unnecessary perioperative complication. Three important flow parameters in TTFM are flow, DF% and PI. Flow is expressed through (1) a flow curve that displays the systolic and diastolic filling of the graft through color coding (systolic: light red, diastolic: light blue), and (2) a mean flow value (ml/min). The curves should always be coupled with the electrocardiography (ECG) tracing to correctly differentiate the systolic from the diastolic flow. Mean flow is dependent on many variables including blood viscosity, the size and quality of the graft, resistance in the graft, the quality of the outflow bed, the size of the native coronary artery and spasms in arterial grafts. Absolute blood flow value is not a good indicator of the quality of the anastomosis, and must be considered together with the two other indicators and clinical findings (ECG, hemodynamic values). DF% indicates the percentage of coronary filling in diastole. By using ECG synchronization, the DF% is defined as the blood volume filling in diastole divided by the total blood volume in one heart cycle. DF% is especially important in low flow situations where the mean flow value is less than 10 ml/min. This is because the DF% is the metabolic part of the flow, i.e., what is useful for the heart. The systolic flow on the other hand is useful for the compliance. Recent studies suggest that DF% is the most important indicator for intraoperative graft patency verification. 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. The PI is proportional to the vascular resistance. Therefore, a high PI is an indicator of poor quality of a graft or anastomosis. Clinical studies have shown that a PI < 5 indicates a well-functioning graft [1,7,9,12—14].

D’Ancona et al. [12—14] evaluated the TTFM in a large serial and underlined that a meticulous and controlled method of assessing the results of intraoperative flow measurements can improve the quality of information and increase the accuracy of diagnosing technical problems with newly constructed bypass grafts. They have developed a standard algorithm for using and interpreting intraoperative TTFM. Measurements should always be done with and without proximal occlusion of the revascularized coronary artery to detect any stenosis localized at the toe of the anastomosis and to exclude flow competition from the native vessel. High level of retrograde blood flow from graft before proximal anastomosis was performed may exist in spite of stenosis at the toe of the anastomosis; in this case drastic reduction in absolute flow is observed after proximal snaring of the coronary artery. On the contrary, low flow status may be

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Group A (n = 100)</th>
<th>Group B (n = 100)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall morbidity (n)</td>
<td>16</td>
<td>6</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Re-exploration for bleeding</td>
<td>3</td>
<td>3</td>
<td>&gt;0.05</td>
</tr>
<tr>
<td>Deep sternal infection</td>
<td>1</td>
<td>1</td>
<td>&gt;0.05</td>
</tr>
<tr>
<td>IABP Insertion</td>
<td>7</td>
<td>1</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Peri-or postoperative infarction</td>
<td>5</td>
<td>—</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Overall mortality (n)</td>
<td>4</td>
<td>—</td>
<td>&lt;0.05</td>
</tr>
</tbody>
</table>
detected in perfectly patent anastomosis, whenever competition is present from less than critically stenosed coronary arteries. In these cases, after placement of proximal snare, an increase in absolute graft flow will be observed [12—14].

Graft patency evaluation on the only basis of absolute flow value should be discouraged. Blood flow is directly proportional to blood pressure and inversely proportional to vascular resistance. For this reason, absolute blood flow is not a good predictor of anastomotic quality because high vascular resistances may exist in spite of fully patent anastomosis. In conclusion they agree that mean graft flow, being very dependent on the quality of the revascularized coronary artery, is not per se a good indicator of the quality of the anastomosis. On the contrary, TTFM technology may be very useful if mean flow values are interpreted together with TTFM curves, DF% and PI values [1,3—15].

A protocol suggested by D’Ancona et al. [12—14] was used to detect graft dysfunction in present study. Our practice is to perform TTFMs immediately after the anastomosis is completed during cardiopulmonary bypass and then several more times thereafter to detect spasm resulting from manipulation and any possible graft kinking or compression before closure of the sternum. Close monitoring of the systemic pressure is also necessary especially when arterial grafts are used. Low systemic pressure and manipulation can cause spasm of the graft resulting in decreased absolute flow. We use inotropics to maintain the systolic pressure at 90—100 mmHg in patients with lower pressure. The size of probe used to measure flow is important. Only good contact with flow probe can guarantee an accurate measurement. For this reason, selection of correct probe size is mandatory. The importance of TTFM for evaluating coronary artery bypass grafts lies in the interpretation of the data. Therefore, we measured simultaneously flow curves, PI, DF % and mean flow values to correctly interpret TTFM findings in our study, which is crucial to reduce the number of undetected technical errors.

Graft dysfunction has been reported in 0.6—3.2% of all grafts and 1.8—8.1% of all patients [13,16—19]. These values were 2.97 and 9%, respectively, in our Group B patients. Our results and the others’ show that TTFM is effective in detection of graft dysfunction. But we do not know whether this improves the surgical results. There is no study that compares the pre TTFM and post TTFM surgical results. Our study is the first. For this purpose, we compared the results of two groups where the operations were performed by the same surgeons with the same techniques. The patients’ preoperative characteristics and risk factors were not different between the two groups. We think that makes two groups comparable. In our study, we noticed significantly lower incidences of overall mortality (p < 0.05), peri-or postoperative myocardial infarction (p < 0.05) and IABP insertion (p < 0.05) in Group B than Group A. This suggests that detection of graft dysfunction intraoperatively by TTFM improves the surgical results.

Our main goal in coronary artery bypass grafting is to provide a long-lasting reconstruction of the coronary artery system with good graft patency. Therefore we have routinely used intraoperative the TTFM for all types of revascularization in order to obtain high quality bypass surgery as well as to improve the outcome for the patients. Transit time flow measurement given important and accurate intraoperative information about the status and patency of coronary grafts. It enables technical problems such as kinked, twisted, or stenotic grafts to be diagnosed accurately, thereby allowing prompt revision of the constructed grafts before the patient leaves the operating room.

In conclusion we strongly believe that a meticulous operative technique should be supported with intraoperative TTFM in completed bypass grafts. Because our results suggest that detection of graft dysfunction intraoperatively by TTFM improves the surgical results.

Acknowledgment

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References


