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Pitfalls and Results of Immediate Angiography after Off-Pump Coronary Artery Bypass Grafting

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ABSTRACT

Background: We sought to determine the feasibility of off-pump coronary artery bypass grafting (OPCAB) in a consecutive series and prospectively assess the value of immediate post-operative coronary angiography.

Methods: All patients referred for coronary artery bypass grafting, within a four-month period, were approached as candidates for OPCAB. All 50 OPCAB patients were studied by immediate post-operative coronary angiography.

Results: The OPCAB procedure was feasible in 67% of patients (50/75). Five of 55 patients (9.1%) were converted to on-pump procedures, three for hemodynamic instability, and two because of deeply intramyocardial vessels. The other 20 underwent on-pump revascularization for anatomical and physiological reasons. The average age of OPCAB patients was 68.1 ± 9.6 years; 26% were female, 74% male. Two (4%) were redo operations. Mean number of grafts was 2.9 ± 0.8, 51 internal thoracic artery grafts (ITA), 17 radial artery grafts (RA), and 76 saphenous vein grafts (SVG). Angiographic graft patency was 90.2% for ITA, 88.2% for RA, and 96.1% for SVG. Interpretation of catheterization results was confounded by significant native and arterial graft spasm. Six of seven occluded arterial grafts and one of three SVG were probe patent at immediate reoperation (all had adequate flow by intra-operative doppler at the initial operation). Only two graft occlusions were noted in the 18 patients who did not receive protamine. The patency rate was 95.6% (131/137) when the probe patent anastomoses were excluded. Seven patients (14%) returned to the OR as a result of the catheterization findings; five to revise occluded grafts, one to improve the lie of a kinked SVG, and one to graft an intramyocardial intermediate ramus when an adjacent high diagonal was grafted instead (two of seven on-pump). All graft problems were found in the absence of hemodynamic instability or electrocardiogram changes. In-hospital mortality was 2% (1). Complications in survivors were atrial fibrillation in 12 patients (24.5%), permanent pacemaker in one (2%), endotracheal bleeding in one (2%), and take-back for bleeding in one (2%).

Conclusions: There were a significant number of unexpected arterial graft occlusions. The reversal of heparin and ITA spasm appeared to be contributory. All patients with occluded grafts had no signs of trouble. Interpretation of immediate post-operative catherization is difficult because of significant native vessel and graft spasm. It reliably determines patency but it's value is suspect for determination of long-term graft adequacy.

INTRODUCTION

Current use of post-operative angiography to assess graft patency in coronary artery bypass procedures utilizing cardiopulmonary bypass is generally reserved for patients having significant persistent postoperative localized ST segment elevations on electrocardiogram (ECG) or those with unexpected hemodynamic instability.

With the advent of minimally invasive direct coronary artery bypass grafting (MIDCAB) and off-pump coronary artery bypass grafting (OPCAB), proof of graft patency has become mandatory. There are two reasons for this: 1) the need to show adequacy of the new technique compared to an accepted graft patency rate in routine on-pump cases; and 2) to provide feedback to the surgeon as he/she mas-

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Table 1. Preoperative Risk Factors

	n	%
Smoking	7	14
Hypertension	27	54
Hypercholesterolemia	30	60
Diabetes	10	20
Positive family history	4	8
COPD	7	14
Creatinine		
0.5–1	16	32
> 1–1.5	29	58
> 1.5	5	10
Prior carotid surgery	5	10

Table 2. Preoperative Coronary Disease and Functional Status

	n	%
Prior CABG	2	4
Prior PTCA/stent	10	20
Prior MI	21	42
NYHA class		
I	0	0
II	11	22
III	32	64
IV	7	14
CCS class		
O	1	2
I	0	0
II	12	24
III	30	60
IV	7	14
2-Vessel disease	11	22
3-Vessel disease	39	78
L-main disease	15	30
Elective	39	78
Urgent	10	20
Emergent	1	2

ters these new, more difficult techniques. Feedback concerning graft patency is particularly important during the learning curve associated with OPCAB. Several groups have used systematic post-operative angiography to assess graft patency after the MIDCAB or OPCAB during their initial experience [Alessandrini 1997, Puskas 1998, Possati 1998, Diegeler 1999a, Diegeler 1999b, Calafiore 1999, Poirier 1999, Wiklund 2000]. Most angiograms were performed several days or weeks after surgery with revision only if the patient was symptomatic or ischemic. The use of systematic immediate angiography has been reported for the MIDCAB [Mack 1999] and for the OPCAB [Izzat 1999].

We sought to determine the feasibility of OPCAB during the learning curve in a consecutive series and prospectively assess the value of immediate post-operative coronary angiography.

MATERIALS AND METHODS

All patients referred for coronary artery bypass grafting between April 1999 and July 1999 were prospectively approached as candidates for OPCAB. Feasibility was determined by vessel size, position and myocardial function. OPCAB procedures were performed using either the CTS retractor/stabilizer (Guidant CTS Corporation, Indianapolis, IN) or the Octopus II stabilizer (Medtronic, Inc., Fridley, MN). An intraluminal coronary artery shunt (Flow-coil Shunt, Guidant CTS Corporation, Indianapolis, IN) was used for the left internal thoracic artery to left anterior descending anastomosis when required to maintain hemodynamic stability (three patients). Heparin was administered to maintain the activated clotting time (ACT) > 350 seconds. All proximal anastomoses were constructed with running 6-0 polypropylene suture. All distal anastomoses were constructed with running 7-0 polypropylene suture. The first 23 patients had full heparin reversal with protamine. The remaining 27 patients received no protamine (n=17) or protamine to partially reverse the heparin (n=10).

All 50 OPCAB patients were transferred directly from the operating room to the angiography suite for immediate multiplane coronary angiography. If a significant graft(s) problem was found, the patient was immediately returned to the operating room for revision of the bypass graft(s). Patients undergoing graft revision were again returned to the angiography suite for repeat angiogram. Angiography results were assessed simultaneously by the surgeon and cardiologist. Appearance of the anastomoses, grafts, native vessels and run-off were evaluated.

RESULTS

The OPCAB procedure was feasible in 67% of patients (50/75). Five of 55 patients (9.1%) were converted to on-pump procedures, three for hemodynamic instability, and two because of deeply intramyocardial vessels. The other 20 underwent on-pump revascularization for anatomical and physiological reasons.

The average age of OPCAB patients was 68.2 ± 9.6 years, 26% were female, 74% male (range 42–85 years, median 69.5 years). Two (4%) were redo operations. Preoperative patient risk factors, functional status, extent of coronary artery disease and urgency of surgery data are detailed in Tables 1 and 2 (◎).

Mean number of grafts was 2.9 ± 0.8. Fifty-one internal thoracic artery grafts (ITA), 17 radial artery grafts (RA), and 76 saphenous vein grafts (SVG) were placed (Table 3, ◎). Interpretation of catheterization results was confounded by significant native and arterial graft spasm. Angiographic results are detailed in Table 4 (◎). Angiographic graft patency was 90.2% for ITA, 88.2% for RA, and 96.1% for SVG. In one patient, all four grafts were

Table 3. Grafting Data

	n	%
Number of anastomoses		
1	2	4
2	12	24
3	26	52
4	10	20
Type of fraft placed		
LAD – LITA	49	98
First obtuse marginal		
SVG	15	30
Radial artery	10	20
RITA	1	2
Second obtuse marginal		
SVG	2	4
Radial artery	1	2
Intermediate ramus		
SVG	5	10
Radial artery	2	4
Diagonal		
SVG	16	32
Posterior lateral		
SVG	2	4
Radial artery	2	4
RCA		
RITA	1	2
SVG	36	72
Radial artery	2	4
Total grafts		
LITA	49	
RITA	2	
Radial artery	17	
SVG	76	

LAD = left anterior descending; LITA = left internal thoracic artery; RCA = right coronary artery, SVG = saphenous vein graft

Table 4. Angiogram Results

	n	%
Patients with native vessel spasm		
None	13	26
Mild	9	18
Moderate	17	34
Severe	11	22
Number of occluded grafts	10/144	6.9
ITA	5/51	9.8
Radial artery	2/17	11.8
SVG	3/76	3.9
Number of stenotic grafts		
FitzGibbon Grade B	5/144	3.5
Patent but hard to define	16/144	11.1
Arterial spasm and run-off		
ITA spasm with patent graft	46	
None	13	28.3
Mild	9	19.6
Moderate	19	41.3
Severe	5	10.9
ITA run-off with patent graft	46	
Good	36	78.3
Poor	10	21.7
Radial artery spasm in patent grafts	15	
None	6	40
Mild	2	13.3
Moderate	6	40
Severe	1	0.7

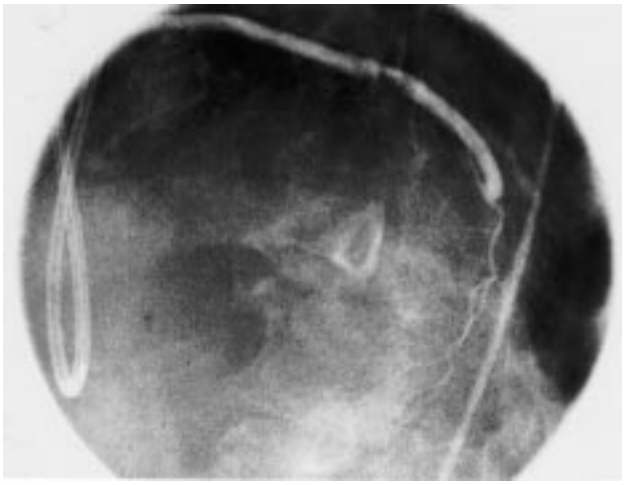
ITA = internal thoracic artery

occluded—the ITA, 2 RA, and 1 SVG. This patient accounted for four of the 10 total graft occlusions. Seven patients (14%) returned to the OR as a result of the catheterization findings. Five underwent anastomotic revision of occluded grafts. One patient required external repositioning of a kinked SVG. One patient underwent reoperation to graft an intramyocardial intermediate ramus when an adjacent high diagonal coronary artery was grafted initially. Five out of seven revision operations were performed off-pump. All graft problems were found in the absence of hemodynamic instability or ECG changes. Six of seven occluded arterial grafts and one of three occluded SVG were probe patent at re-operation. All had adequate flow by intra-operative Doppler at the initial operation. The patency rate was 95.6% (131/137) when the probe patent anastomoses were excluded.

There was marked native vessel spasm seen on immediate angiography (Figures 1a-2a, ◎), 56% of patients had moderate to severe spasm. Because of this spasm, it was difficult to categorically identify an anastomotic stenosis in 11.1% (16/144) of grafts. Five of 144 grafts (3.5%) were found to have > 50% stenosis (FitzGibbon Grade B) [FitzGibbon 1986]. The ITA exhibited moderate to severe spasm in 52.2% (21/46) of patent ITA grafts. Because of this coupled with native vessel spasm, 21.7% (10/46) of patent ITA grafts had poor run-off. Radial artery grafts also showed a degree of spasm, with 40.7% (7/15) of patent grafts exhibited moderate to severe spasm. These results are tabulated in Table 4 (◎).

Only two graft occlusions were noted in the 18 patients who did not receive protamine. Initially protamine was administered to completely reverse the heparin in 23 patients. The remaining patients received either partial reversal (10) or no protamine (17). There were five occlusions of the left ITA. Of these patients, two received protamine and three no protamine. Those with occlusions of a SVG or RA all received protamine. Statistical analysis was prevented due to lack of sufficient events to provide an accurate and reliable analysis.

There was one in-hospital mortality (2%). The patient died after the decision was made not to dialyze him after his post-operative course was complicated by mediastinitis and acute chronic renal failure. Complications in survivors were atrial fibrillation in 12 patients (24.5%), permanent



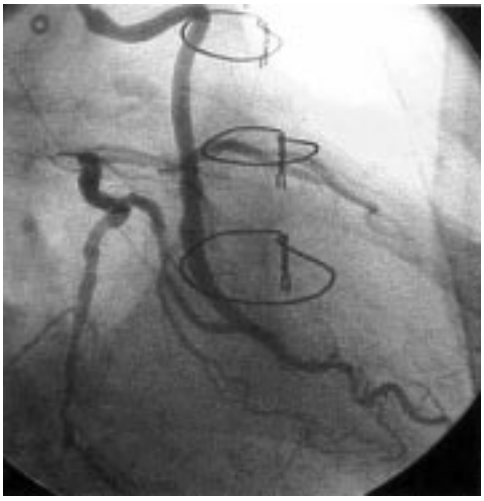
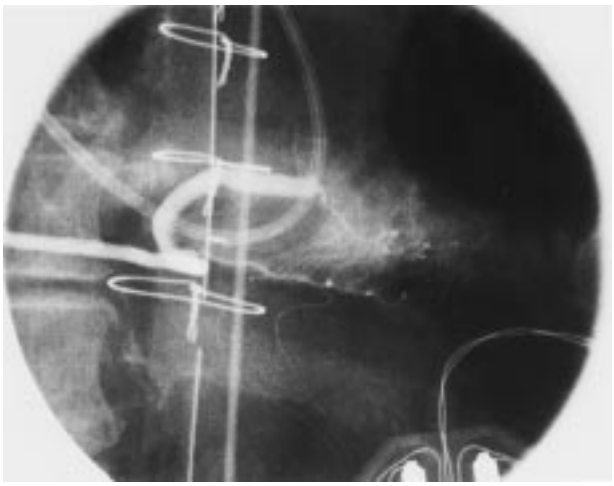


Figure 1. (A) Coronary angiogram showing a saphenous vein graft to an obtuse marginal coronary artery showing severe native vessel spasm with poor run-off. (B) Coronary angiogram of the same graft in figure 1a, two months later with complete resolution of native vessel spasm.



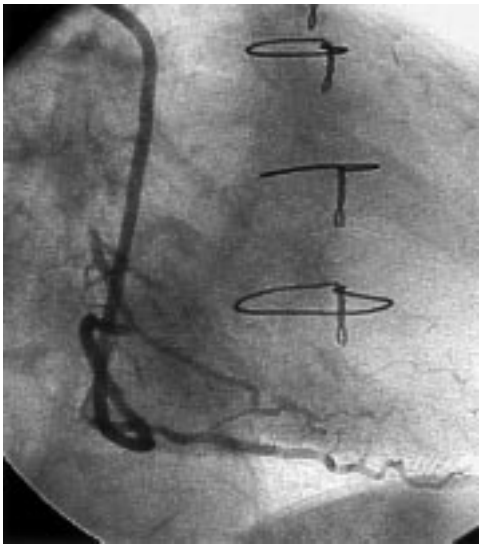


Figure 2. (A) Coronary angiogram showing a sequential saphenous vein graft to the posterior descending and posterior lateral coronary arteries with severe native vessel spasm and potential stenoses at both anastomoses proximally and at the posterior lateral graft distally. (B) Coronary angiograms of the same graft in figure 2a with complete resolution of potential anastomotic problems and native vessel spasm.

pacemaker in 1 (2%), endotracheal bleeding in 1 (2%), and take-back for bleeding in 1 (2%).

DISCUSSION

Direct feedback for quality control and technical improvement is a requirement for the adoption of any new surgical technique. There is no doubt that performance of the graft to coronary artery anastomosis is more difficult in the OPCAB or MIDCAB procedure compared to conventional coronary artery bypass grafting (CAB) on an arrested, flaccid heart. This is due to the cardiac motion and lack of a blood free operative area. The anastomosis is often performed in a vertical position, particularly when sewing to the lateral and inferior wall vessels. This creates a parallax view with poor depth of vision for judging distance between stitches. The coronaries undergo significant spasm when manipulated on the hemodynamically active heart. All of these factors contribute to the theoretical possibility of decreased quality of the anastomoses. With experience, the above barriers to sewing on a beating heart can be overcome with complete revascularization in the majority of patients with low morbidity and mortality [Baumgartner 1999, Cartier 1999].

The angiogram is the gold standard for qualitative and quantitative assessment of native coronary disease and patency of bypass grafts. Prior to the introduction of the MIDCAB and OPCAB, angiographic control studies have been used in an attempt to validate more widespread use of arterial grafts. Tyras et al. [Tyras 1980] catheterized 527 of 765 patients, one month after receiving a left internal thoracic artery (LITA) graft showing a patency of 95% in surviv-

ing patients. Barner et al. [Barner 1976] catheterized 139 of 307 patients with a LITA graft several weeks after bypass and showed a patency rate of 95%. The largest series to undergo systematic catherization in the modern era was part of the protamine IMAGE study [Berger 1997]. Eighty four percent of patients received a LITA graft with a patency rate at a mean post-operative interval of 11 days of 98.8%. Eight percent exhibited a FitzGibbon Grade B graft [FitzGibbon 1986]. In an attempt to analyze early patency rate of the radial artery graft, Chen et al. [Chen 1996] studied 60 of 150 patients receiving radial artery grafts. The patency rate was 95.7% (90 of 94 grafts). Gurne et al. [Gurne 1994] studied 122 of 150 patients receiving a free inferior epigastric CAB. The angiographic control study showed a 98% patency rate. Because of this, this prospective study was undertaken to determine the role of immediate angiography in providing useful information in regards to the adequacy of the coronary bypass grafts during the learning curve of the routine OPCAB at our institution.

Other groups have used angiographic assessment to examine patency rates for the OPCAB procedure [Puskas 1998, Califiore 1999, Diegeler 1999c, Wiklund 2000]. Most of these studies were performed several days to weeks after the bypass procedure. Patency rates ranged from 95.3% to 98.9%. Revision of the failed grafts was performed only in the event of symptoms and ischemia.

There have been three studies using immediate angiography to assess the LITA to left anterior descending (LAD) anastomosis in the MIDCAB procedure. Mack et al. [Mack 1999] systematically and prospectively studied 100 MIDCAB patients with immediate angiography. There was one occluded graft and nine with a stenosis > 50%. Three grafts were revised immediately. One required a reoperation and three underwent percutaneous transluminal coronary angioplasty (PTCA). Schaff et al. [Schaff 1996] prospectively performed immediate angiography on 15 of 16 MIDCAB patients with three patients requiring graft revision. Gill et al. [Gill 1997] did angiography on 29 MIDCAB patients four to six hours after surgery. They had a patency rate 97.5% and 19% had a stenosis of > 50%. Angiography was not used for immediate feedback and no grafts were revised as a result of the study. A prospective study using systematic, immediate angiography with immediate revision of occluded grafts has not been published for the OPCAB procedure.

This study points out the difficulty in qualitative assessment of the anastomoses using immediate angiography after the OPCAB procedure. The main problem was the significant amount of native vessel spasm. This occurred as the sites proximal and occasionally distal to the anastomosis where ligatures or clips were used to occlude the native vessel. Many of the native coronary target vessels were pruned by spasm, which resulted in poor run-off in the immediate post-operative period. The ITA grafts had significant spasm as well. The vessel was free of spasm up high near the subclavian artery where it was not manipulated. However, spasm was often seen starting where it was manipulated during ITA take down. Spasm was particularly prominent distally, near the anastomosis. It is possible that the higher rates of occlusion of the ITA grafts as found in this study were related to ITA spasm. Many were probe patent at re-operation. The differential diagnosis of the reason for occlusion was spasm versus thrombosis. If the angiogram were delayed until resolution of spasm, several of the revisions may not have been required. On many of the anastomosis, a pseudostenosis was seen, appearing at the shoulder of the anastomosis, both proximally and distally. This was often seen only in one plane and likely due to edema and spasm from manipulation. This was seen in vessels with torrential run-off as well as vessels with poor run-off because of diffuse native vessel spasm. As a result of these findings, IV nitroglycerin is started pre-operatively and continued post-operatively for 24 hours in our practice.

There is evidence that some of these anastomotic problems are transient, when seen on early angiography. Several patients in this series have returned for angiography for various reasons several months after their bypass surgery. There is mounting evidence in our series that most of the hard to define anastomoses have no anastomotic problems (Figures 1a-b and 2a-b, ◎). This is likely due to resolution of surgically induced spasm of the graft, native vessels and resolution of anastomotic edema. Wiklund et al. [Wiklund 2000] found that 2/3 of the patients with FitzGibbon Grade B stenoses at early angiography (0-5 days) after OPCAB had normal angiograms at re-angiography. Diegeler et al. [Diegeler 1999a] found a decrease or disappearance of the stenosis in four of 15 patients (26.6%) comparing early angiography to angiography at six months in MIDCAB patients. Determination of the true stenosis rate in our study patients will require later follow-up angiography.

Determination of patency was reliable. This proved to be the most important value of immediate angiography. All the occluded grafts occurred in the absence of any hemodynamic instability or ECG changes. This was even true for the patient with all four grafts occluded. This was surprising to find as conventional wisdom suggests that ST changes and hemodynamic instability are invariably present in the face of occluded grafts. All patients were successfully revised with confirmation by repeat angiography.

Very little data is available concerning adequate anticoagulation and appropriateness of reversal of anticoagulation during the OPCAB procedure. There is much anecdotal evidence that patients undergoing off-pump procedures are not in the same protected state from graft thrombosis compared to those suffering from the inflammatory state initiated by cardiopulmonary bypass. The cytokine and inflammatory responses have shown to be reduced during off-pump surgery [Wan 1999, Ascione 2000]. This theoretically may result in a more intact clotting system. Mariani et al. [Mariani 1999] showed an increased procoagulant activity in-patients undergoing off-pump coronary bypass procedures irrespective of the surgical approach. They found significantly increased prothrombin factor one and two, and evidence of endothelial activation because of increased von Willebrand factor and decreased factor VII in the 24 hours following the procedure. Fibrinolysis was increased on post-operative day one. Our study suggests that the complete reversal of heparin with protamine may contribute to arterial graft thrombosis. In six of seven of

the occluded arterial grafts, the anastomosis was probe patent when the patient was taken back to the OR for graft revision. The graft was ligated several millimeters proximal to the anastomosis and a probe was able to pass easily down through the anastomosis. The presumptive reasons for the occlusion are occlusive spasm or thrombosis. It is interesting that only two of the seven patients who had graft occlusions did not receive protamine. There were too few events to provide a reliable statistical analysis. However, the events suggest a correlation. This has resulted in the adoption of only partial reversal of heparin in our practice.

In conclusion, systematic immediate angiography is useful during the learning curve of the OPCAB. It provides valuable feedback concerning technical aspects of the procedure, such as the lie of the grafts, position where the graft is placed on the target vessel, and anastomotic patency. It's role in quantitative assessment of the anastomoses is suspect, but it is reliable for deciding the issue of patency. Accurate determination of the presence of real or pseudo-stenosis was confounded by significant native vessel and arterial graft spasm. Administration of pre-operative and post-operative IV nitroglycerin is advisable. Immediate revision of the occluded grafts was able to be performed off-pump in the majority of cases without additional morbidity and mortality. There were a significant number of unexpected arterial graft occlusions. The reversal of heparin and ITA spasm appeared to be contributory. All patients with occluded grafts had no signs of trouble. While immediate angiography was helpful for direct feedback for determination of patency of grafts during the learning curve of the OPCAB procedure, it's routine use to determine the adequacy of graft anastomoses is unadvisable. Delay of the angiogram to several days after the operation will likely result in more easily interpretable data.

REFERENCES

1. 1. Alessandrini F, Gaudino M, Glieca F, Luciani N, Piancone FL, Zimarino M, Possati G. Lesions of the target vessel during minimally invasive myocardial revascularization. Ann Thorac Surg 64:1349–53, 1997.
2. Ascione R, Lloyd CT, Underwood MJ, Lotto AA, Pitsis AA, Angelini GD. Ann Thorac Surg 69:1198–204, 2000.
3. Barner HB, Mudd JG, Mark AL, Ahmad N, Dickens JF. Patency of internal mammary-coronary grafts. Circulation 54 (Suppl III):70–3, 1976.
4. Baumgartner FJ, Gheissari A, Capouya ER, Panagiotides GP, Katouzian A, Yokoyama T. Technical aspects of total revascularization in off-pump coronary bypass via sternotomy approach. Ann Thorac Surg 67:1653–8, 1999.
5. Berger PB, Alderman EL, Schaff HV. Frequency of early occlusion and stenosis in the left internal mammary artery among patients undergoing CABG through median sternotomy on conventional bypass: Benchmark for the MIDCAB. Circulation 96 (Suppl I):681, 1997.
6. Calafiore AM, Teodori G, Giammarco GD, Vitolla G, Maddestra N, Paloscia L, Zimarino M, Mazzei V. Multiple arterial conduits without cardiopulmonary bypass: Early angiographic results. Ann Thorac Surg 67:450–6, 1999.
7. Cartier R. Systematic off-pump coronary artery revascularization: Experience of 275 cases. Ann Thorac Surg 68:1494–7, 1999.
8. Chen AH, Nakao T, Brodman RF, Greenberg M, Charney R, Menegus M, Johnson M, Grose R, Frame R, Hu EC, Choi HK, Safyer S. Early postoperative angiographic assessment of radial artery grafts used for coronary artery bypass grafting. J Thorac Cardiovasc Surg 111:1208–12, 1996.
9. Diegeler A, Matin M, Kayser S, Binner CH, Autschbach R, Battellini R, Krankenberg H, Mohr FW. Angiographic results after minimally invasive coronary bypass grafting using the minimally invasive direct coronary bypass grafting (MIDCAB) approach. Eur J Cardiothorac Surg 15(5):680–4, May, 1999.
10. Diegeler A, Matin M, Falk V, Binner C, Walther T, Autschbach R, Mohr F. Quality assessment in minimally invasive coronary artery bypass grafting. Eur J Cardiothorac Surg 16 (Suppl 2):67–72, Nov. 1999.
11. Diegeler A, Matin V, Falk R., Battellini W, Autschbach R, Mohr FW. Coronary bypass grafting without cardiopulmonary bypass – technical considerations, clinical results, and follow-up. Thorac Cardiovasc Surg 47(1):14–8, Feb. 1999.
12. FitzGibbon GM, Leach AJ, Keon WJ, Burton JR, Kafka HP. Coronary bypass graft fate. J Thorac Cardiovasc Surg 91(5):773–8, May 1986.
13. Gill IS, FitzGibbon GM, Higginson LAJ, Valji A, Keon WJ. Minimally invasive coronary artery bypass: A series with early qualitative angiographic follow-up. Ann Thorac Surg 64:710–4, 1997.
14. Gurne O, Buche M, Chenu P, Paquay JL, Pelgrim JP, Louagie Y, Marchandise B, Schroeder E. Quantitative angiographic follow-up study of the free inferior epigastric coronary bypass graft. Circulation 90 [Part 2]:148–54, 1994.
15. Izzat MB, Khaw KS, Atassi W, Yim APC, Wan S, El-Zufari MH. Routine intraoperative angiography improves the early patency of coronary grafts performed on the beating heart. Chest 115:987–90, 1999.
16. Mack MJ, Magovern JA, Acuff TA, Landreneau RJ, Tennison DM, Tinnerman EJ, Osborne JA. Results of graft patency by immediate angiography in minimally invasive coronary artery surgery. Ann Thorac Surg 68:383–90, 1999.
17. Mariani MA, Gu YJ, Boonstra PW, Grandjean JG, van Oeveren W, Ebels T. Procoagulant activity after off-pump coronary operation: Is the current anticoagulation adequate? Ann Thorac Surg 67:1370–5, 1999.
18. Poirier NC, Carrier M, Lesperance J, Cote G, Pellerin M, Perrault LP, Pelletier LC. Quantitative angiographic assessment of coronary anastomoses performed without cardiopulmonary bypass. J Thorac Cardiovasc Surg 117:292–7, 1999.
19. Possati G, Gaudino M, Alessandrini F, Zimarino M, Glieca F, Luciani N. Systematic clinical and angiographic follow-up of patients undergoing minimally invasive coronary artery bypass. J Thorac Cardiovasc Surg 115:785–90, 1998.
20. Puskas JD, Wright CE, Ronson RS, Brown WM, Gott JP, Guyton RA. Off-pump multivessel coronary artery bypass via sternotomy is safe and effective. Ann Thorac Surg 66:1068–72, 1998.

21. Schaff HV, Cable DG, Rihal CS, Daly RC, Orszulak TA. Minimal thoracotomy for coronary artery bypass: Value of immediate post-procedure graft angiography. Circulation 94 (Suppl I):1–51, 1996.
22. Tyras DH, Barner HB, Kaiser GC, Codd JE, Pennington DG, Willman VL. Bypass grafts to the left anterior descending coronary artery: Saphenous vein versus internal mammary artery. J Thorac Cardiovasc Surg 80:327–33, 1980.
23. Wan S, Izzat MB, Lee TW, Wan IYP, Tang NLS, Yim APC. Avoiding cardiopulmonary bypass in multivessel CABG reduces cytokine response and myocardial injury. Ann Thorac Surg 68:52–7, 1999.
24. Wiklund L, Johansson M, Wognsen GB, Bugge M, Radberg G, Berglin E. Difficulties in the interpretation of coronary angiogram early after coronary artery bypass surgery on the beating heart. Eur J. Cardiothorac Surg 17(1):46:51, Jan. 2000.