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Recent Advances in Multivessel Coronary Grafting Without Cardiopulmonary Bypass

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ABSTRACT

Background: Coronary artery bypass grafting (CABG) without the heart lung machine has been possible for easily accessible targets such as the anterior descending or proximal right coronary. Until now technical difficulty in reaching lateral and inferior wall targets imposed significant barriers to multivessel off-pump grafting. To expand the potential for off-pump CABG the authors have devised new exposure and stabilization techniques suitable for all target vessels. In this report we relate our experience with these new techniques and demonstrate that multivessel coronary bypass can be safely performed without cardiopulmonary bypass (CPB).

Methods: From February 8, 1993 to December 16, 1997 a total of 280 patients underwent myocardial revascularization on the beating heart via median sternotomy. Until May 20, 1997 only patients with high preoperative risk factors for CPB were considered for this approach (Group A; N = 122). After this date any patients with favorable anatomy were included (Group B; N = 158) and were subsequently compared with patients operated on using CPB during the same time interval (Group C; N = 114). In Group B patients lateral and/or inferior wall targets were exposed by means of 4 cloth slings (2 through the transverse sinus and 2 behind the inferior vena cava) and by positioning the patients in Trendelenburg with rightward rotation of the table. Regional stabilization of the target artery was obtained with a commercial stabilizing foot plate.

Results: Thirty-day hospital mortality was only 2 patients (1.6%) in Group A, 3 patients (1.9%) in Group B, and 3 patients (2.6%) in Group C (NS). Postoperative complications were low in both Group A and B. When Group B was compared with a similar cohort in whom CPB was used (Group C), there were statistically significant improvements in ICU and hospital stay demonstrated when CPB was not used (16.8±10.7 vs 26.3±38.6 hours respectively; p = 0.007, and 4.1±1.5 vs 5.5±2.4 days respectively, p<0.001). Angiographic follow-up was available for 78 patients in Groups A and B with a global patency rate (all grafts) of 98.6%, including a patency rate of 96.7% for 60 grafts to obtuse marginal branches of the circumflex.

Conclusions: Multivessel CABG without CPB is possible with results similar to those obtained with pump-oxygenator support using simple exposure and stabilization techniques.

INTRODUCTION

Coronary artery bypass grafting (CABG) was born as surgery on the beating heart. However, improvements in cardiopulmonary bypass (CPB) and the introduction of cardioplegia into clinical practice caused a huge expansion in arrested heart surgery. The bloodless and motionless environment offered by cardioplegic arrest allowed every surgeon to accomplish a safe operation with excellent graft patency rates. Despite these advantages, some surgeons continued to perform coronary revascularization on the beating heart [Ankeney 1975, Trapp 1975, Benetti 1991, Pfister 1992, Buffolo 1996]. These surgeons were able to prove that easily accessible vessels like the left anterior descending (LAD), diagonal, and proximal right coronary artery (RCA) could be effectively grafted without arresting the heart. However long-term results and patency rates were not well established and lateral wall vessels were seldom grafted.

Recently, interest in off-pump coronary grafting has risen as a result of the success of the LAST operation (limited access small thoracotomy), a new approach to grafting the LAD [Benetti 1995, Calafiore 1996]. As a result of our favorable experience with the LAST procedure, the authors expanded their use of off-pump coronary grafting to include other target vessels. However, exposure to the deep reaches of the ventricle, particularly the obtuse marginal

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branches of the circumflex and the posterior descending branch of the RCA has always been problematic. To address this, the authors developed a simple and yet remarkably effective retraction system that can be used to expose any region or target vessel. Using this retraction and stabilization system, multivessel beating heart CABG via median sternotomy was explored.

MATERIALS AND METHODS

Exposure and stabilization are the two most important technical aspects of beating heart CABG. To permit multivessel off-pump CABG, our team has steadily developed a series of exposure and stabilization techniques over the last four and a half years. Early in our experience (see Group A below), exposure was obtained using two primary techniques. First, deeply placed traction sutures in the left pericardium caused the heart to rotate forward and medially for exposure to the LAD and high lateral branches. For further support and versatility, the authors developed a system of thick cloth slings to help position the ventricle. Each sling was constructed from vaginal packing twisted tightly into a rope approximately 2 cm wide and 45 cm long. Although this system extended our access to the ventricle compared with prior exposures, stability was still not ideal.

With two additional steps, we were finally able to accomplish excellent exposure to every target vessel without difficulty. We learned that crossing two pairs of slings at a point just distal to the target anastomotic site consistently provided excellent exposure. Gradual retraction on these tapes allowed deeper target vessels to come into view without hemodynamic compromise. The addition of a commercially available stabilizing foot plate to reduce the motion around the anastomotic site greatly enhanced our ability to suture on the beating heart. The combination of these technical modifications were incorporated into our second group of patients (Group B) as described below.

Our current multivessel surgical technique can then be summarized as follows. For off-pump grafting of the LAD we only place surgical sponges behind the heart to medially displace the anastomotic target. For the diagonal branch of the LAD, a swab is first placed lateral to the left ventricle. Then two slings coming from the transverse sinus are pulled caudally around the apex and fixed to the lower wound as shown in Figure 1 ◎ below.

For access to all other coronary vessels, two pairs of thick cotton slings are used to gradually retract and position the beating ventricle. The first pair is passed through the transverse sinus. The second pair is passed underneath the inferior vena cava. One end of each sling is fixed to the right arm of the sternal retractor while the other end is kept free. Final sling positioning depends on the course of the target vessel.

Lateral wall target vessels are exposed by first manually lifting the heart out of the pericardial sac. Then two slings, one from above and one from below, are crossed to identify the target vessel. The proposed anastomotic site is positioned below (posterior to) the crossing point as shown in Figure 2 (◎)below.

The remaining two slings are positioned near the previous ones to improve the exposure and help contain the heart. Gradual increase in tension on the slings will improve exposure without compromising hemodynamics. It may take several minutes to achieve full exposure. It is essential to use both Trendelenburg and extreme rotation of the table to the patients right side to improve the exposure and hemodynamic tolerance. The anesthesiologist can help by filling the patient and injecting, if necessary, small boluses of vasopressors.

Exposure of the PDA and inferior wall branches is somewhat easier than the lateral wall. The heart is elevated vertically with the apex pointed towards the patients chin. The slings are then crossed to maintain this position and to properly present the target vessel. This position is surprisingly well tolerated and hemodynamic stabilization takes only a few minutes. (Figure 3, ◎)

Stabilization of the anastomotic site is achieved pharmacologically and mechanically. Diltiazem is infused at a rate of 5 mg/hr in order to slow the heart rate to 45–50 beats per minute. This drug is also able to control coronary artery spasm which may occur with manipulation of the heart. An alternative for induced bradycardia would be short acting beta-blockers but these agents are not effective in controlling coronary spasm. For mechanical stabilization of the target vessel, we use a commercially available retractor with stabilizer (CTS Systems, Inc, Cupertino, California). This device is a prototype adapted from the mini-thoracotomy device specifically for use in transsternal cases. Good regional stabilization was possible in the majority of cases. Control of bleeding from the coronary arteriotomy is achieved with proximal and distal encircling 4–0 Prolene sutures and snares.

RESULTS

From February 8, 1993 to December 16, 1997, 280 patients underwent myocardial revascularization on a beating heart via median sternotomy in our institution. We have divided the patient population into two groups according to the period when the operation was performed:

- Group A: 122 patients operated from February 8, 1993 to May 20, 1997, and,
- Group B: 158 patients operated on from May 21, 1997 to December 16, 1997

Group A consisted of an initial cohort selected for off-pump grafting based on indicators of high perioperative risk (Table 1). Clinical, surgical and postoperative data on these 122 patients are listed in Table 1, Table 2 and Table 3, respectively. Surgical exposure of the target vessels in this group was obtained with deeply placed pericardial traction sutures and 2 cloth slings (one underneath the IVC and one through the transverse sinus). This original exposure technique enabled access to most coronary tar-

Table 1. Group A, High risk for CPB (N = 122) Preoperative Data

Age	69.5 ± 8.8 (43–84) years
Sex (M/F)	96M : 26F
Left Main	1 (.08%)
Redo	6 (4.9%)
Ejection Fraction	55.7% ± 14.8 (20–89%)
≤35%	12 (9.8%)
High Risk Factors for CPB	76 (62.3%)
Age ≥75 years	19
Cerebrovascular Disease	14
COPD	14
Peripheral Vascular Disease	8
Malignancy	7
Chronic Renal Failure	4
Chronic Liver Failure	4
Untouchable Aorta	2
Neurologic Disease	2
Liver Transplant	1
Kidney Transplant	1

EF=Ejection Fraction, LM=Left Main, COPD=Chronic Obstructive Pulmonary Disease, CPB=Cardiopulmonary Bypass

Table 2. Group A, High risk for CPB (N = 122) Operative Data

Arterial Conduits	172
LIMA	104
RIMA	56
RGEA	6
RA	1
IEA	5
Saphenous Vein Grafts	39
Anastomoses per patient	1.7 ± 0.6 (1–4)
Coronary Target Vessels	
LAS	110
Diagonal	22
Cx system	18
RCA system	61
Operation Time	4.1 ± 1.2 hours (1–9)

LIMA=Left Internal Mammary Artery, RIMA=Right Internal Mammary Artery, RGEA=Right Gastroepiploic Artery, RA=Radial Artery, IEA=inferior epigastric artery, LAD=Left Anterior Descending, Cx=Circumflex, RCA=Right Coronary Artery

gets but was not as reproducible nor as stable as the use of the 4 sling technique applied to the latest cohort (Group B) described below. Despite inadequacies of our original retraction system, outcomes were still very gratifying. The 30-day hospital mortality for this high-risk subset was only 1.6% (2 patients).

The excellent clinical results obtained in high-risk Group A patients were so encouraging that a decision was made to expand the clinical trial. In addition, exposure and stabilization were advanced by the introduction of a mechanical stabilizing foot and a second pair of cloth slings as described above. Since May 21, 1997, our standard policy has been to perform multivessel coronary revascularization in all patients with favorable anatomy using this four sling technique rather than CPB. These patients constitute the 158 cases reported here as Group B. Since making this decision, 58% of all CABG patients operated via a median sternotomy in our center were revascularized with the beating heart technique described above. For the sake of comparison, we have also included an analysis of the remaining population who received CPB during the same time interval (Group C; 114 patients). Data comparing Group B (off-pump) and Group C (on pump) patients are summarized in Table 4, Table 5 and Table 6 respectively. The Students T-Test was used for statistical analysis of categorical values between Groups B and C.

DISCUSSION

Coronary artery bypass grafting on the beating heart is a surgical strategy that has gained increasing popularity over the past few years for a variety of reasons. The first and foremost reason is the declining quality of the surgical referral population. Patients in the current surgical referral pool are not only older but more often affected by comorbid states and increased perioperative risk factors than candidates seen a decade ago. The increasing age of the surgical population is associated with a greater frequency of calcified aorta, previous stroke, disseminated peripheral vascular disease, and end organ failure. The risk of cerebrovascular complications in these patients is a very concerning factor in the decision to operate and the type of surgical approach used. Such patients will poorly tolerate the side effects of the cardiopulmonary bypass circuit, hypotensive non-pulsatile perfusion, systemic cooling and full heparinization. In order to gain improvements in operative morbidity and mortality in these higher risk patients, avoidance of exposure to cardiopulmonary bypass is one possible strategy.

Less invasive coronary bypass (the LAST operation) has recently been reported [Benetti 1995, Calafiore 1996]. This new approach is based on grafting of a single target vessel through a limited access thoracotomy without CPB. The success of the LAST procedure has stimulated a resurgence in off-pump grafting techniques for all target vessels.

Table 3. Group A, High risk for CPB (N = 122) Post-Operative Data

Bleeding (cc/24hr)	638 ± 463 (40–3500)
Reoperation for bleeding	4 (3.3%)
Transfused patients	19 (15.6%)
ICU Stay (hrs)	22.4 ± 18.9 (2–192)
CK MB peak (IU/L)	41.5 ± 63.7
Atrial Fibrillation	17 (13.9%)
Postoperative Hospital Stay (days)	4.4 ± 1.6 (1–10)
Perioperative Mortality (30 day)	2 (1.6%)
Survival (max 57 mo.)	89.5 ± 21.6
Event Free Survival (max 57 mo.)	82.1 ± 27.1

ICU = intensive care unit

Table 4. Multivessel Off-Pump vs On-Pump During the Same Time Interval, Preoperative Data, Group B = Without CPB, Group C = With CPB

	Group B (No CPB) N=158	Group C (CPB) N=114	P value
Age	64.5 ± 10.6	62.4 ± 9.6	ns
Female	28	19	ns
EF	54 ± 15.2	58.3 ± 14.4	0.025
≤ 35%	15	7	ns
Urgent	13	16	ns
Left Main	11	10	ns
Redo	2	9	0.042
High Risk Factors	41	12	0.003
Age ≥ 75 yrs	16	9	
Cerebrovascular disease	6	—	
Malignancy	5	—	
Diffuse Vasculopathy	4	—	
Chronic Renal Failure	5	—	
COPD	11	3	

EF=Ejection Fraction, LM=Left Main, COPD=Chronic Obstructive Pulmonary Disease

Industry has responded with new technology to assist in mechanical stabilization of the target coronary artery. Early experience with LAST operations has proven that off-pump CABG can yield identical graft patency rates when compared to CPB cases if the target coronary is stabilized to prevent motion during suturing [Subramanian 1997]. To increase the versatility of off-pump CABG, especially to inferior and lateral wall targets, the authors have developed a simple system for presentation and exposure of all regions of the heart. The fundamental principle is slow and gradual retraction of the beating heart using thick, porous tapes placed in a criss-crossing manner. Hemodynamic tolerance to lifting is excellent if several precautions are taken. First, displacement of the beating ventricle from the pericardial cradle is gradual. It may take several minutes to expose the deeper target vessels by gradually tightening the retraction tapes. Second, ventricular filling must be augmented by use of the Trendelenburg position. Third, exposure of the lateral vessels is improved by sharp rotation of the operating table to the patient's right. This allows the surgeon to augment the view of the circumflex branches without extreme retraction. Finally, mechanical stabilization in the region of the target vessel is accomplished with a commercially available stabilizing foot plate (CTS Systems, Inc, Cupertino, California). This permits local control of motion for safe anastomotic construction

This intial report includes 280 patients undergoing transsternal off-pump CABG. Early results in our highest

Table 5. Multivessel Off-Pump vs On-Pump During the Same Time Interval, Operative Data

	Group B (No CPB) N=158	Group C (CPB) N=114	P value
Arterial Conduits	269	220	ns
LIMA	150	110	ns
RIMA	79	86	ns
RGEA	18	11	ns
RA	18	11	ns
IEA	4	2	ns
Saphenous Vein Grafts	62	44	ns
Anastomosis per patient	2.0 ± 0.8 (1–4)	2.5 ± 0.8 (2.5)	<0.001
Coronary Target Vessels			
LAD	156	115	ns
Diagonal	19	21	ns
Cx system	81	96	ns
RCA system	65	52	ns
Carotid Surgery	1	2	ns

LIMA=Left Internal Mammary Artery, RIMA=Right Internal Mammary Artery, RGEA=Right Gastroepiploic Artery, RA=Radial Artery, IEA=inferior epigastric artery, LAD=Left Anterior Descending, Cx=Circumflex, RCA=Right Coronary Artery.

Table 6. Multivessel Off-Pump vs On-Pump During the Same Time Interval, Postoperative Data

	Group B (No CPB) N=158	Group C (CPB) N=114	P value
Awakening	1.6 ± 1.8	2.3 ± 1.5	<0.001
Mechanical Ventilation (hrs)	6.8 ± 9.1	3.4 ± 2.3	<0.001
Inotropes (>12 hrs)	6	1	ns
Acute MI	—	—	
Bleeding (ml/24 hr)	410 ± 389	655 ± 372	<0.001
Reoperation for Bleeding	1	2	ns
Transfused patients	9	16	0.049
CVA	—	2	ns
ICU Stay (hrs)	16.8 ± 10.7	26.3 ± 38.6	0.007
In-hospital mortality	3 (1.9%)	3 (2.6%)	ns
In-hospital stay	4.1 ± 1.5	5.5 ± 2.4	<0.001
Late deaths	0	2 (1.7%)	ns

CVA=cerebrovascular accident, ICU=intensive care unit

Angiographic followup was performed on 78 patients from Groups A and B. A total of 211 anatomoses were examined. Global patency rate was 98.6% (208 of 211 anastomoses). Individual target vessel patency rates were as follows:
1. LAD = 100% (78 of 78 anastomoses) 2. Diagonal = 100% (13 of 13 anastomoses) 3. Obtuse Marginal branches = 96.7% (58 of 60 anastomoses) 4. Right Coronary Artery branches = 98.3% (59 of 60 anastomoses)

risk subset (Group A) were so encouraging that we expanded the indications to include all patients with suitable anatomy. For example, it is noteworthy that patients in the high risk group were discharged at an average of only 4.4 days and the maximum length of stay was only 10 days for the entire cohort. Thirty-day hospital mortality was only 1.6% despite the presence of significant operative risk factors.

We were able to obtain similar success when expanding the protocal to include all patients with suitable anatomy. The operative mortality was identical in Group B patients (1.9%). This result also compared very favorably with our results in an identical group operated with CPB during the same era (2.6%). However in patients operated without exposure to the heart-lung circuit there were statistically significant improvements in early awakening, the duration of mechanical ventilation, the total amount of bleeding, length of ICU stay, and total hospital stay (see Table 6).

To verify our technical results, we were able to obtain angiographic proof of graft patency in 208 of 211 anastomoses studied in 78 off-pump patients. This overall graft patency rate of 98.6% (including both arterial and venous conduits) is very similar to other studies of early graft patency obtained with either the LAST procedure or conventional CPB techniques [Subramanian 1997]. The results were equally encouraging with grafts to the more inaccessible regions such as the circumflex (96.7%) and the inferior wall (98.3%). This confirms that we were able to achieve adequate presentation and stabilization with this retraction system to perform technically correct anastomoses. Although the angiographic results only address early patency rates, this is still a very important finding which confirms that off-pump CABG to all targets can be accomplished with the same technical results that surgeons expect with CPB and full cardioplegic arrest.

With the advent of off-pump CABG to all target regions, we now have the ability to safely operate on virtually every patient regardless of cormorbid medical conditions or risk. The techniques we propose can be helpful to expose and stabilize all of the proposed anastomotic sites without compromising safe and accurate anastomotic construction. The system takes a few cases to learn but is simple, inexpensive, and readily available in any operating room environment. The reduction in material costs per case is very significant since neither cardiopulmonary bypass circuitry nor expensive new equipment is required. It is not possible to foresee the future of this strategy but the initial experience seems very encouraging and opens the door to accepting patients in all different risk categories.

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REVIEWS AND COMMENTARY

Invited Commentary from Kit V. Arom, MD:

The performance of revascularization via complete sternotomy without cardiopulmonary bypass (CPB) is a reconfiguration of accepted surgical techniques. Development of stabilization devices has allowed more accurate anastomosis on the beating heart. Although many stabilizing devices are useful for the anterior wall of the heart, a retracting (presenting) and stabilizing device such as the Medtronic Octopus with its suction cups allow adherence to and retraction of the inferior and lateral aspect of the heart into the operative field. Other pressure-plate type, compressing, stabilizing devices have no means of adherence to the epicardium and do not seem to serve the dual purpose of being a retractor as well as a stabilizer. However, they do function well in many circumstances, even in the inferior and lateral aspect of the heart.

The retracting and presenting methods described in this manuscript by Calafiore et al. appears to allow the surgeon to perform coronary anastomoses to the branches of the right coronary artery and the branches of the circumflex system on the beating heart with adequate short-term results. However, the procedure still requires a mechanical stabilizer, which in this report was the Cardiothoracic Systems stabilizing device. The homemade retraction system described in this manuscript is easily available and much less expensive than cardiopulmonary bypass equipment, even when combined with the cost of the CTS stabilizer.

Avoiding CPB is an important aspect in expanding surgical indications in that multi-vessel coronary bypass surgery can be completed in patients who have contraindications to the use of standard techniques. With further development of these retracting or presenting devices, the indications for multi-vessel, off-pump coronary surgery could be expanded to the routine CABG procedure as described in this communication.

The ongoing development of new technology like the one being reported is easing the burden on the surgeon for completing such procedures. An excellent short-term outcome in this communication has been accomplished, but more information is necessary. The author presents the results and angiographic study in a select group of patients and has shown that the patency rate is excellent. However, he did not go into details about the degree of deformity that is usually seen at the site of the anastomosis. Patency means the flow from the graft through the native artery is maintained and this could represent either no defect at the suture line or a more significant lesion.

This manuscript provides two significant pieces of information. The first is that multi-vessel, off-pump bypass grafting can be accomplished on a routine basis with good patency rates. Secondly, a homemade retraction system can effectively present the inferior and lateral aspects of the beating heart. Hemodynamic stability is usually compromised when the heart is elevated anteriorly. The author did not mention the drop in blood pressure, cardiac outputs and other changes in hemodynamics when the heart is elevated. The author did mention a key maneuver during cardiac elevation (the Trendelenberg position) which increases the filling pressure and helps maintain hemodynamic stability. I believe this is an important maneuver for every surgeon to remember who wishes to use this technique. Lastly, just a word of caution. Performing an anastomosis with the beating heart, particularly on the inferior and lateral aspect, is not as easy and simple as stated in this manuscript. Not everyone should jump in and try this technique unless he or she has already performed several off-pump anastomosis on the blood vessels in front of the heart.