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Aiming Towards Complete Myocardial Revascularization Without Cardiopulmonary Bypass: A Systematic Approach

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ABSTRACT

Background: Coronary artery bypass grafting (CABG) has become the surgical procedure of choice for symptomatic coronary artery disease. However, the use of traditional cardiopulmonary bypass (CPB) techniques represents an invasive therapeutic system with immediate and long-term complications. Off-pump myocardial revascularization has emerged as an attractive alternative that offers improvements in early outcomes and avoidance of the recognized adverse affects of CPB. A major criticism of this procedure has been a perceived inability to accomplish complete revascularization of the heart. In this report, we describe a surgical technique we have used in a series of patients that has allowed complete myocardial revascularization.

Methods: Combinations of intraoperative techniques were employed, including (1) right pleural-pericardial window, (2) deep pericardial sutures, (3) right heart displacement, (4) intermittent hypotensive anesthesia, (5) multimodality brain monitoring, and (6) coronary shunting. Following surgery, coronary artery grafts performed were statistically compared to each coronary artery's vascular territory to show that all territories were equally treatable with the combination of techniques.

Results: There were 734 coronary artery grafts performed in 200 consecutive patients (mean of 3.7 grafts/patient), and 533 compromised vascular territories were revascularized (mean of 1.38 grafts for each diseased vessel). Eight patients had one-vessel disease, 51 had two-vessel disease and 141 had three-vessel disease. The left anterior descending coronary artery (LAD) was compromised in 192 patients, the circumflex in 171 and the right coronary artery in 170 patients. The overall 30-day estimated hospital mortality was 5.5%; the observed was 4.0% (8 of 200). Postoperative complications included pulmonary insufficiency in 6 patients (3.0%), reoperation for bleeding in 3 patients (1.5%), cerebrovascular accident in 3 patients (1.5%), renal dysfunction in 2 patients (1.0%), perioperative myocardial infarction in 8 patients (4.0%), cardiac arrest in 2 patients (1.0%), low cardiac output in 5 patients (2.5%), and deep sternal infection in 2 patients (1.0%).

Conclusions: Use of intermittent hypotensive anesthesia in conjunction with multimodality brain monitoring, right heart displacement, deep pericardial sutures, coronary shunting and epicardial compression stabilization facilitates complete revascularization of the myocardium.

INTRODUCTION

Coronary artery bypass grafting (CABG) has been found to be an effective procedure for reducing angina, stabilizing ventricular function, and enhancing long-term survival. Although CABG using cardiopulmonary bypass (CPB) is successful in revascularizing the myocardium, it has long been recognized that this technology has some immediate and long-term deleterious effects on the patient [Kirklin 1983, Elefteriades 1997, Stump 1999, Newman 2001].

Off-pump myocardial revascularization has emerged as an attractive alternative for the medical community and for the patient. The major criticism of this procedure has been its inability to provide the patient with complete revascularization of the heart. [Akpinar 2000, Cooley 2000, Hernandez 2000, Omeroglu 2000]. Studies have shown that patients subjected to incomplete myocardial revascularization using off-pump technology experience increased hospital readmissions, additional postoperative coronary angiography, and subsequent percutaneous coronary intervention or reoperation [Gundry 1998].

The advent of the first-generation mechanical heart stabilizers facilitated the revascularization of the left anterior descending coronary artery system via an anterior thoracotomy. However, using this approach, only one vascular territory was addressed [Benetti 1985]. With the availability of more versatile stabilizers, the midline sternotomy approach became possible for patients with multivessel disease. This era was short-lived, however, as the exposure-stabilization of the obtuse marginal territory remained less than optimal and the

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Table 1. Summary of Patient Characteristics, November 1999 to September 2001.

Variables	
Number of Patients	200 (100.0)
Gender	
Male	196 (98.0)
Female	4 (2.0)
Age (y)	
Mean	63.3 ± 9.7
Range	36 to 83
Coronary Artery Disease Risk Factors	
Current smoker	55 (27.5)
Diabetes mellitus	74 (37.0)
Pulmonary disease	97 (48.5)
Hypertension	118 (59.0)
Chronic renal failure	20 (10.0)
Peripheral vascular disease	64 (32.0)
Cerebrovascular disease	33 (16.5)
Cardiomegaly	15 (7.5)
Prior myocardial infarction	104 (52.0)
Recent myocardial infarction	21 (10.5)
Unstable angina	124 (62.0)
Prior percutaneous coronary intervention (<72 hours)	10 (5.0)
Triple-vessel disease	141 (70.5)
Left main disease (>0.50)	69 (35.4)
Ejection fraction (<0.45)	55 (29.7)
Congestive heart failure (class II or >)	44 (22.0)

Numbers in parentheses are percentages

manipulation required for adequate exposure frequently resulted in hemodynamic instability. This approach often precluded the grafting of the obtuse marginal arteries and resulted in conversion to CPB to achieve complete revascularization of the myocardium [Buffolo 1985].

Recognizing the deficiencies and criticisms of off-pump surgery, a series of intraoperative techniques have been developed to assist the surgeon in achieving complete myocardial revascularization. The purpose of this report is to document the substantial benefits of these intraoperative methods and to demonstrate their safety, efficacy, and effect on mortality and morbidity rates and early clinical outcomes.

PATIENTS AND METHODS

Patient Population

Myocardial revascularization without CPB was first performed at our institution in 1996 and to date 813 patients have been operated on. Of this group of patients, the last 200 consecutive patients were studied using the reported data from the Continuous Improvement in Cardiac Surgery Study (CICSP) database. From November 1999 to September 2001, 200 consecutive patients underwent off-pump CABG. The group consisted of 196 males (98.0%) and 4 females (2.0%), with a mean age of 63.32 (9.7 years (range 36 to 83 years). There were 97 patients (48.5%) with a history of chronic obstructive pulmonary disease (COPD), 74 (37.0%) with diabetes mellitus (insulin dependent and non-insulin dependent), 64 (32.0%) with peripheral vascular disease, 20 (10%) with chronic renal failure, 33 (16.5%) with cerebrovascular disease, and 118 (59%) with arterial hypertension. Forty-four patients (22.0%) had congestive heart failure (class 2 or greater), 104 (52.0%) had a prior myocardial infarction, and 21 (10.5%) had experienced a recent myocardial infarction (<7 days).

The patients' preoperative angina status was ranked according to the Canadian Cardiovascular Society (CCS) classification system. There were 29 patients (14.5%) in class I, 47 (23.5%) in class II, 80 (40.0%) in class III, and 44 (22.0%) in class IV. Patients with class III or IV symptoms were considered to be in unstable condition. Thirty-five patients (17.5%) were on nitroglycerin and heparin preoperatively, and there were 10 patients (5.0%) who had previously undergone percutaneous coronary intervention (<72 hours).

The operation was performed electively in 143 patients (71.5%), urgently in 51 patients (25.5%), and on an emergency basis in 6 patients (3.0%).

Preoperative Angiographic Findings

All patients in the study had selective coronary angiography before operation. The preoperative angiographic findings revealed that 8 patients (4.0%) had single-vessel disease, 51 (25.5%) had double-vessel disease, and 141 (70.5%) had triple-vessel disease. Left main coronary artery disease (stenosis >50%) was documented in 69 patients (35.3%).

Ejection fractions, which were determined for all patients from left ventriculography or echocardiography, were greater than 0.45 in 130 patients (70.3%), between 0.25 and 0.44 in 47 patients (25.4%), and less than 0.25 in 8 patients (4.3%).

Prior to operation, all coronary angiograms were prospectively analyzed by a cardiologist and a surgeon to identify the arteries that required grafting. All vascular territories were examined and coronaries requiring bypass were assigned to the intent to treat "projected" group. The clinical characteristics of the patient population are summarized in Table 1 (◎).

Operative Technique

All patients underwent a standard median sternotomy. Patients were fully heparinized, and at the completion of surgery the heparin was completely reversed with protamine. The left internal mammary artery (LIMA) was routinely dissected with cautery using the standard extrapleural technique. The radial artery (RA), when used, was harvested from the nondominant forearm.

Pleuro-pericardial Window

A right pleuro-pericardial window is created in patients requiring grafting to the obtuse marginal, the ramus intermedius, and/or the posterolateral left ventricular branch of the right coronary artery (Figure 1, ◎). A pleuro-pericardial window is occasionally employed in patients undergoing bypass to the left anterior descending and the right coronary artery. A wide opening between the right pleural cavity and the pericardium similar to that employed in heterotopic heart transplantation is constructed [Novitzky 1983]. Following the

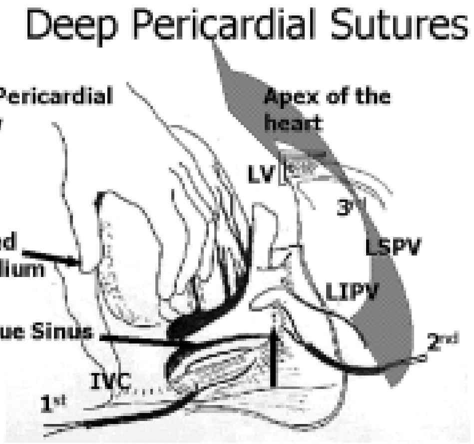

Figure 1. The right pleura has being divided and the parietal pericardium detached from the diaphragm. Manual traction on the heart creates a posterior pericardial fold through which the first deep pericardial suture has been placed and shoded. The second deep pericardial suture is placed anterior to the left inferior pulmonary vein and the third deep pericardial suture is placed anterior to the left superior pulmonary vein.

initial longitudinal incision of the pericardium, the sternum is widely retracted. The pleura is then divided longitudinally between the right pericardial edge and the sternum, and the incision is extended from the body-manubrium junction to the diaphragmatic reflexion. At the diaphragmatic level, the pleura and the parietal pericardium are then divided parallel to the diaphragm and down to the anterior edge of the inferior vena cava. At this stage, the heart is elevated and easily displaced into the right pleural cavity, thereby allowing good exposure of all epicardial arteries.

Deep Pericardial Sutures

Three deep pericardial sutures are then placed, using Novofill #1 on a tapered large radius needle (Figure 1, ◎). Anterior cardiac traction creates a posterior pericardial fold, which extends from the inferior vena cava to the inferior edge of the left inferior pulmonary vein. The first deep pericardial suture is placed through this fold posterior to the left atrium. The needle is then placed through the posterior parietal pericardium within the oblique sinus as deeply as possible, and then covered with a soft rubber tubing to avoid potential damage to the heart during future manipulation. The heart is then rotated toward the right pleural cavity, exposing the entire obtuse area of the heart and the atrio-ventricular groove as well as the pulmonary veins. The second and third deep pericardial sutures are placed on the pericardial reflection anterior to the left inferior and superior pulmonary veins.

Right Heart Displacement

After the pleuro-pericardial window is created, tension is applied on the deep pericardial sutures. The heart is verticalized and is then prepared for displacement into the right pleural cavity. The traction exerted by the deep pericardial sutures mobilizes the entire posterior mediastinum (Figure 2, ◎). The left atrial-left superior pulmonary vein-left inferior pulmonary vein edge is rotated anteriorly 35-60 degrees over the superior vena cava-right atrium-inferior vena cava axis. The left side of the left atrium and the atrial appendage is then mobilized 3-5 cm anteriorly. This results in an anterior rotation of the long axis of the heart by 50-90 degrees. As a result of this maneuver, the apex of the heart is elevated anteriorly toward the zenith. The heart in this position has now been "verticalized."

To achieve complete heart displacement, the deep pericardial sutures are then placed toward the left side of the sternotomy and progressive tension is applied. Simultaneously, manual pressure is exerted on the obtuse marginal surface of the heart. The cardiac apex is progressively displaced toward the right pleural cavity and is subsequently positioned behind the right chest wall. In obese patients, heart displacement is greatly facilitated by removing redundant pleuro-pericardial fat.

Stabilization

The next step is to achieve a motionless surgical field along the coronary arteries and surrounding tissues. Following cardiac verticalization and inspection, the heart is manually stabilized and tension is progressively exerted on the deep pericardial sutures. Once the desired position has been achieved, the mechanical stabilizer foot is applied to the surface of the heart. Progressive pressure is then exerted until the specific coronary artery has been fully stabilized, and pressure is maintained for the duration of the construction of the distal anastomoses. Our preferred stabilizer is the USSC disposable Mini-CABG 22 cm Universal Base Retractor (US Surgical Corp., Norwalk, CT).

Once the coronary artery has been stabilized and dissected, two epicardial incisions are made parallel to the proximal

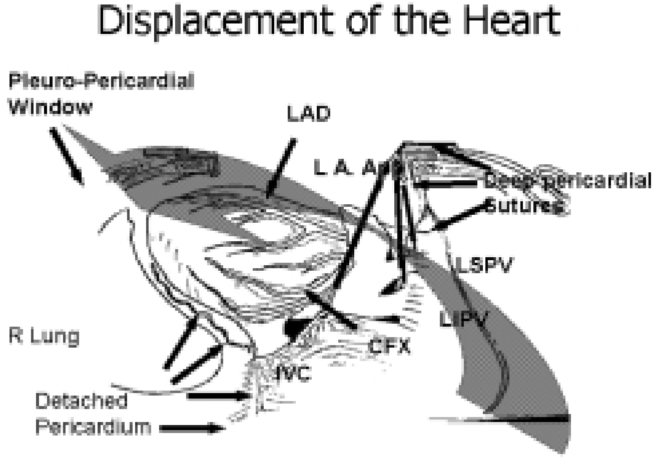

Figure 2. Cardiac displacement into the right pleural cavity. Tension has been applied on the three deep pericardial sutures, and the apex of the heart has been positioned posterior to the right chest wall. The entire obtuse margin of the heart becomes anterior. The large shaded arrow indicates the 180-degree rotation of the apex of the heart.

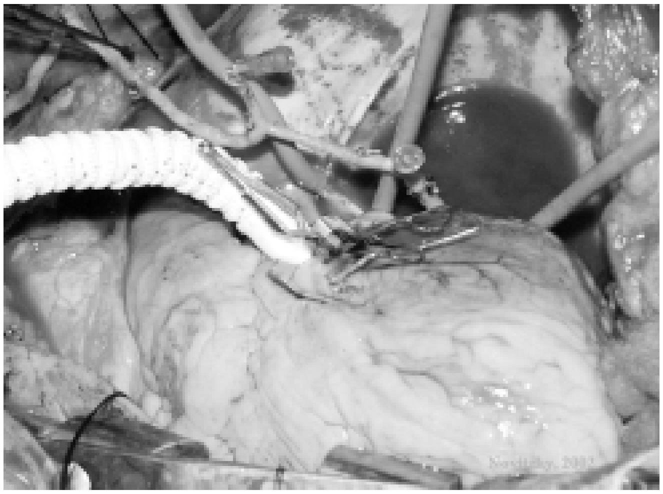

Figure 3. Revascularization of the obtuse margin of the heart. Tension has been applied to the three deep pericardial sutures that have been placed on the left side of the stabilization device. The right ventricle and the apex of the heart have being displaced behind the right chest wall. The graft of the distal end of the natural Y vein to the obtuse marginal artery has being performed, the ramus intermedius has been stabilized, and the vein is held by two #21 gauge needles placed through the shod of a deep pericardial suture, " the virtual assistant."

coronary artery. At this stage a small, soft, vascular "bulldog" is placed across the epicardial incisions, and proximal coronary artery control is achieved. Following occlusion of the proximal coronary artery, the impact on hemodynamic status is assessed by waiting one or two minutes.

In large coronary arteries without complete proximal occlusion stenosis, significant distal myocardial ischemia may develop, indicating the need of intracoronary shunting. At this stage the coronary arteriotomy is performed, and the quality of the retrograde blood flow from the distal end of the arteriotomy is assessed. In the presence of distal oxygenated blood, return would indicate the presence of adequate collateral circulation and shunting would not be required. However, return of desaturated blood would indicate inadequate collateral circulation and potential myocardial ischemia leading to hemodynamic instability. To avoid this adverse event, an intracoronary shunt is placed. At this stage the distal anastomosis is ready to be performed. To facilitate the initial stages of the anastomosis, one deep pericardial suture is placed close to the coronary artery. Using a #21 gauge needle, the adventitia of the vein or the arterial pedicle is pierced and the needle is placed through the sleeve of the deep pericardial traction suture (Figure 3, ◎). The distal end of the conduit is thus 3-5 cm from the coronary artery to which the graft is being anastomosed. This procedure is extremely useful for performing the proximal obtuse marginal end-to-side anastomosis or a side-to-side anastomosis in sequential grafting.

Controlled Intermittent Hypotensive Anesthesia

Standard cardiac anesthetic agents are used. Premedication consists of scopolamine and morphine. In addition, midazolam and Fentanyl are given intraoperatively for amnesia and analgesia. Pancuronium is avoided, as hemodynamically stable sinus bradycardia is desired. Following completion of the sternotomy, the heart rate is maintained at 50-70 bpm. Esmolol is administered for negative chronotropic and inotropic effects, and nitroglycerine is administered for coronary artery vessel dilation and blood pressure reduction. A transient drop in systolic blood pressure may occur with manipulation of the heart during placement of the deep pericardial sutures and heart displacement. Systolic pressure is maintained at 60-90 mmHg after displacement of the heart and while the obtuse marginal area is being revascularized. Usually after 60-90 seconds, the blood pressure rises without pharmacological intervention. Lower pressures are tolerable, but only in the absence of signs of cardiac or brain ischemia. When pharmacological intervention is required for hemodynamic stability, the following agents may be used: esmolol, phenylephrine, nitroglycerine, nitroprusside, epinephrine, or norepinephrine.

If the patient is normotensive and the heart rate is above 70-80 bpm, an infusion of esmolol is initiated during the harvesting of the LIMA. Initially, a small dose of 25 mcg/kg/min is administered to assess the patient's response. This dose is gradually increased until the heart rate is reduced to 60-70 bpm. The mean dose is 250 mcg/kg/min. However, on occasion infusions of up to 600 mcg/kg/min may be required. By reducing the systolic arterial pressure to 70-80 mmHg, multiple beneficial effects on the myocardium may be realized. These include a significant reduction of the left ventricular end-diastolic and end-systolic dimensions as well as left ventricular end-diastolic volume, and a decrease of left ventricular wall stress by 50%. Reducing the left ventricular wall stress is a major determinant of O_2 consumption and helps to normalize the O_2-supply/demand imbalance in the ischemic heart. Intraoperative transesophageal echocardiography has demonstrated recovery of segmental left ventricular wall contractility of previously dyskinetic-akinetic segments. Moreover, the application of this technique reduces the frequency of intraoperative cardiac dysrhythmia. Lowering the left ventricular wall stress and the heart rate greatly improves exposure and stabilization. As a result, less pressure is exerted over the heart to achieve a motionless surgical field.

Multimodality Brain Monitoring

Individual patient tolerance of hypotension varies. Therefore, bilateral dual modality continuous brain function monitoring is essential. A combination of bilateral hemispheric, two-channel, compressed spectral array electroencephalograph (EEG) (Sentinal 4, Axon Systems Inc., Hauppauge, NY) and brain infrared oximetry (INVOS Cerebral Oxymeter, Somonetics Corp., Troy, MI) is used (Figure 4, ◎). Dual modality continuous brain function monitoring EEG and oximetry allow assessment of cerebral perfusion by means of two completely separate but complementary modalities [Edmonds 1996, Novitzky 2000]. Baseline values are obtained once the desired anesthesia level has been achieved before manipulation of the heart and while the patient is hemodynamically stable (Figure 5, ◎). The level of anesthesia,

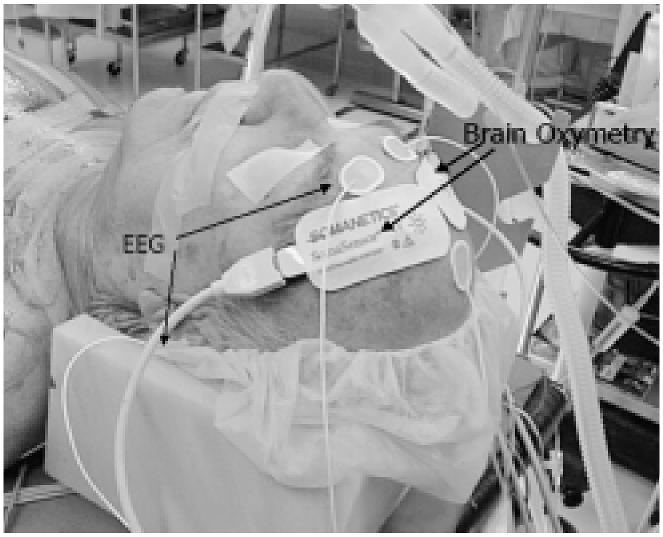

Figure 4. Multimodality brain monitoring. Bilateral placement of the two frontal oximetry sensors and the two fronto-mastoid leads for continuous EEG monitoring.

core temperature, and decreased cerebral perfusion can also alter the EEG. Vasoactive medications may likewise alter cerebral oximetry. It is therefore essential to establish and maintain a stable temperature and level of anesthesia.

The anesthetist-surgeon interaction is critically important for monitoring hemodynamic stability and brain function status. Oximetry is used to gauge the adequacy of bilateral cerebral perfusion and the efficiency of cerebral autoregulation. It is only modified by O_2 changes at the cortical level of the brain and is not affected by drugs or temperature.

Density spectral array (DSA) EEG is used to identify maximal individual tolerance to altered cerebral perfusion or pressure. Computer-generated density spectral array EEG is visually analyzed throughout the procedure for a relative loss of peak or total power. Loss of peak or total power indicates the point at which the brain protectively shuts down electrical activity to preserve metabolic activity. An acute reduction in EEG activity requires immediate action. The peak or total power should not be confused with the "spectral edge," which is a relative percentage value and may be misleading (it may possibly increase) during a true drop in peak or total power.

The two-channel DSA EEG sensors are placed over the fronto-mastoid area and the cerebral oximetry sensors over the frontal area. This monitoring reflects cerebral electrical activity and venous saturation in areas corresponding to cerebral tissue supplied by the anterior and middle cerebral arteries. A transient decrease in blood pressure or heart rate is well tolerated provided the EEG and brain oximetry remain within 20% of control values (no vasoactive agents are required).

Operative Data

The vascular territories are shown in Table 2 (◎). In addition, the "performed" coronary artery bypass grafting for each diseased vascular territory is presented.

Complete myocardial revascularization was achieved in all patients and no conversions to CPB were required. A total of 734 grafts were constructed in the series. The LIMA was used as the conduit in 161 patients (80.5%), and an additional 81 grafts were constructed with radial arteries and the remaining with autologous veins.

The mean number of grafts was 1.9 ± 0.0 for patients with one-vessel disease, 3.3 ± 0.80 for patients with two-vessel disease, and 3.9 ± 0.92 for patients with three-vessel disease. The overall mean number of grafts per patient in the series was 3.7 ± 1.07 (range of 1 to 6). In Table 2 (◎), the distribution of the number of grafts for patients with single-vessel, double-vessel, and triple-vessel disease is shown.

Statistical Analysis

Perioperative data were collected applying a standardized methodology and definition of terms. The collection process included prospective review of the patient's hospital record, cardiac catheterization reports, and cine-angiograms.

Data was obtained and analyzed from the CICSP protocol. Data are presented as frequency and percentage distributions, and values of continuous variables are expressed as mean ± standard deviation. Comparison of mean numbers of projected and actual grafts performed was conducted by a paired *t*-test. All statistical procedures were performed using Statistix Analytical Software (Tallahassee, FL).

RESULTS

Hospital complications included pulmonary insufficiency (6 patients, 3.0%); reoperation for bleeding (3 patients, 1.5%); cerebrovascular accident (3 patients, 1.5%); renal failure (2 patients, 1.0%); perioperative myocardial infarction (8 patients, 4.0%); cardiac arrest (2 patients, 1.0%); low cardiac output (5 patients, 2.5%); and deep sternal infection (2 patients, 1.0%).

Patients with pulmonary insufficiency included those who required intubation for more than 48 hours. Cerebrovascular accident included a neurological deficit that presented for more than 24 hours and remained unresolved, and renal failure was defined as renal insufficiency requiring dialysis. Myocardial

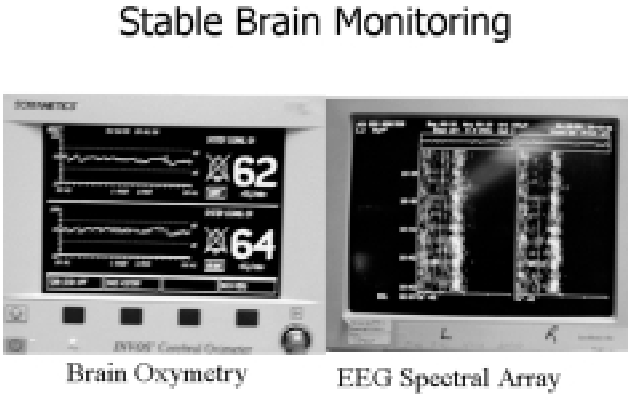

Figure 5. Stable brain oximetry as observed during the surgical procedure.

Table 2. Distribution of Coronary Artery Bypass Grafts Performed by Number of Diseased Vessels.

Diseased Vessels	Patients	Vascular Territories	Number of Grafts	Mean Number of Grafts
Single	8	8	15	1.88
Double	51	102	169	3.31
Triple	141	423	550	3.91
Total	200	533	734	3.68

infarction was defined as a new onset of Q waves with or without elevation of myocardial enzymes, or a substantial elevation of myocardial enzymes alone. Low cardiac output referred to clinical evidence of hypotension, oliguria, and peripheral vascular constriction with normal or supranormal left ventricular filling pressure or a measured cardiac index of less than 2 $L \cdot min^{-1} \cdot m^{-2}$, necessitating the administration of catecholamines or use of the intraaortic balloon pump, or both.

Placement of the intraaortic balloon pump was required in 14 patients (7.0%) preoperatively. None of the patients requiring the use of the intraaortic balloon pump experienced a major vascular complication.

Hospital mortality was defined as death occurring during the operation or the hospitalization in which the procedure was performed, or death occurring after discharge from the hospital but within 30 days of the surgical procedure, unless the cause of death was unrelated to the operation. The overall in-hospital or 30-day mortality rate was 4.0% (8 of 200).

DISCUSSION

Despite major advances in the prevention, diagnosis, and treatment of atherosclerotic heart disease, it remains the leading cause of mortality and disability for Americans. The advent in the 1960s of coronary bypass surgery with CPB marked a major turning point in the surgical treatment of coronary artery disease. Immediate, short-term, and long-term results have been encouraging.

However, the deleterious effects of CPB have detracted from the efficacy of the procedure. By avoiding the systemic inflammatory response induced by the pump apparatus and its effect on existing preoperative comorbid conditions such as chronic obstructive pulmonary disease, chronic renal failure, cirrhosis, and diabetes, postoperative morbidity and mortality rates are reduced. Patients with greater preoperative risk factors and higher expected mortality rates may now be considered candidates for off-pump myocardial revascularization.

A consistent criticism of the off-pump technology has been its failure to achieve complete revascularization of the myocardium. Incomplete revascularization may fail to relieve disabling angina and may precipitate the recurrence of symptoms, require new angiography, and dictate the need for percutaneous coronary intervention or even reoperation. Controversy continues within the surgical community regarding the use of off-pump procedures for patients presenting with multi-vessel disease.

One of the major challenges in off-pump surgery is to overcome the hemodynamic instability that may result from right atrial and right ventricular underfilling. Echocardiographic and hemodynamic studies have confirmed that this instability is mainly attributable to compression of the right heart, thus inducing right atrial-right ventricular dysfunction. The exposure and stabilization of arteries in the circumflex territory may induce compression of the right atrium-right ventricle against the right parietal pericardium, thus impeding the systemic venous return to the heart. This results in underfilling of the left ventricle [Geskes 1999].

To facilitate the revascularization process in the obtuse marginal territory of the heart, a series of intraoperative maneuvers has been developed. To reduce right atrium-right ventricle compression, a wide right pleuro-pericardial window is created, followed by the placement of three deep pericardial sutures. By applying tension on the deep pericardial sutures, the apex of the heart may be initially rotated 90 degrees anteriorly. By gently compressing the left ventricle a further 90 degrees, rotation is achieved that places the apex of the heart behind the anterior right chest wall into the right pleural cavity without right atrial-right ventricular compression. In addition, to normalize and prevent O_2 supply/demand imbalances, the left ventricular wall stress is reduced by administering intermittent hypotensive anesthesia.

The introduction of intermittent controlled hypotensive anesthesia has greatly minimized myocardial ischemia. Reduction of left ventricular wall stress has been observed, which indicates normalization of the O_2 supply/demand. In our experience with this technique, the perioperative development of metabolic acidosis or postoperative organ failure has not been observed. A further protective mechanism is the drift of the core temperature toward 35.0°C, which is beneficial in reducing the metabolic rate and providing some protection to the brain and other organs.

Using the described anesthetic approach, central nervous system monitoring becomes mandatory if hypotensive anesthesia is to be used. To assess brain function during the procedure, multi-modality monitoring is essential. Continuous bilateral EEG spectral array and transcranial near-infrared cortical brain oximetry is used. Both monitoring systems are complementary and sensitive to the detection of brain hypoxia. Cortical brain venous desaturation is detected first by brain oximetry; if it is prolonged, it will affect EEG density.

Normally, a reduction in brain oximetry values precedes EEG changes, thus allowing pharmacological intervention before any EEG abnormalities occur. Asymmetrical EEG changes are generally related to unilateral inadequate hemispheric blood supply (carotid-vertebral). Pharmacological intervention can be initiated immediately by discontinuing hypotension-inducing medication. In the event of persistent hypotension, alpha agents such as neosynephrine are administered, and, if required, the heart should be returned to the pericardial cavity.

The preceding measures have been sufficient to reverse EEG changes and permit completion of the procedure in all cases. Brain oximetry is influenced by inadequate blood supply (O_2) to the brain cortex only (unilateral and/or bilateral) and is not affected by drugs, whereas EEG changes may occur in the presence of hypoxia, drugs, hypothermia, and anesthetic agents. The presence of carotid-vertebral disease requires judicious hemodynamic monitoring. A unilateral reduction of brain monitoring values clearly indicates the need for higher perfusion blood pressure.

The application of these intraoperative techniques has allowed us to provide patients with complete revascularization of the myocardium with excellent outcomes. The hospital mortality rate of 4.0% (8 patients) in the present series is acceptable and consistent with the reports of other groups using off-pump technology. Moreover, the hospital morbidity rate is also low. The mean number of grafts performed in this series was 3.7 ± 1.07 (range of 1 to 6) and is higher than in recently published reports. [Gundry 1998, Hart 1999, Spooner 1999]. In the present study, coronary artery bypass grafting to the anterior, inferior, and lateral wall of the myocardium has been performed successfully, delivering increased blood flow to a larger muscle mass. This should favorably influence long-term, event-free survival.

CONCLUSION

This study is limited in that it represents an observational retrospective analysis of data. Moreover, no control group exists that would permit any direct comparison. Furthermore, there is no long-term follow-up, which is necessary to quantify subsequent major adverse cardiac events and patient long-term survival. However, it is clear that the intraoperative techniques that we describe are safe and have contributed to excellent early results, with low hospital mortality and morbidity rates. It has become increasingly evident that off-pump coronary artery bypass grafting is no longer merely an emerging surgical technique.

There is a growing body of evidence that off-pump coronary artery bypass grafting can be accomplished with relative ease. It is a feasible and safe procedure that can provide complete revascularization of the myocardium even for patients with multi-vessel disease. The application of off-pump technology can avoid the adverse effects of cardiopulmonary bypass [Diegeler 2000], minimize postoperative bleeding, and permit extubation shortly after the operation. This approach to revascularization of the myocardium may, in time, represent the procedure of choice for patients with symptomatic coronary artery disease.

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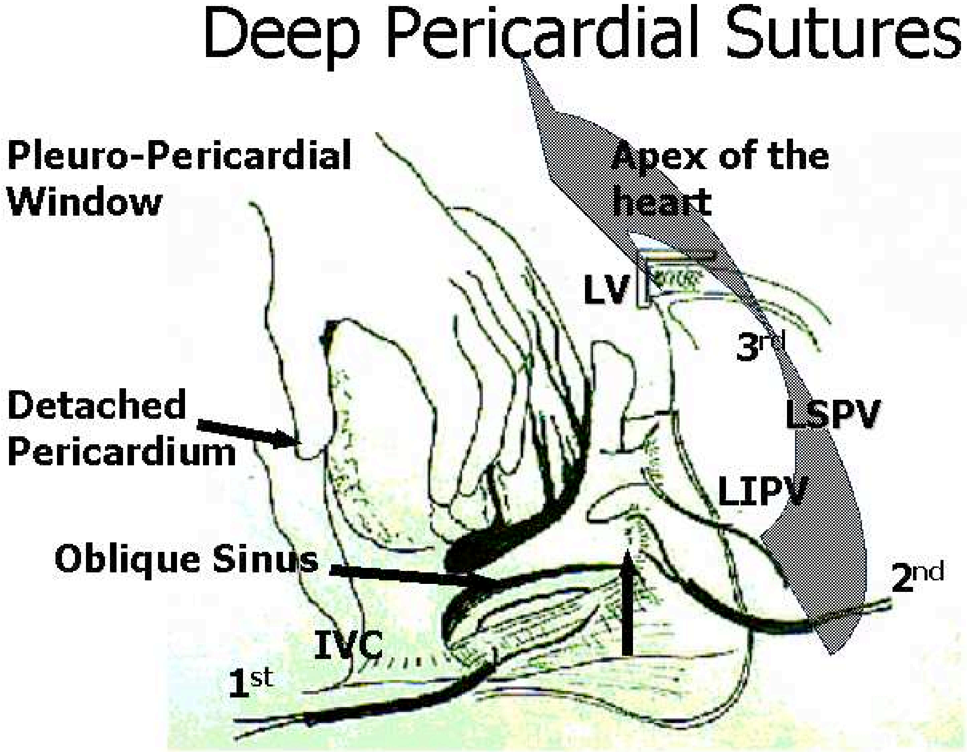

Figure 1. The right pleura has being divided and the parietal pericardium detached from the diaphragm. Manual traction on the heart creates a posterior pericardial fold through which the first deep pericardial suture has been placed and shoded. The second deep pericardial suture is placed anterior to the left inferior pulmonary vein and the third deep pericardial suture is placed anterior to the left superior pulmonary vein.

Displacement of the Heart

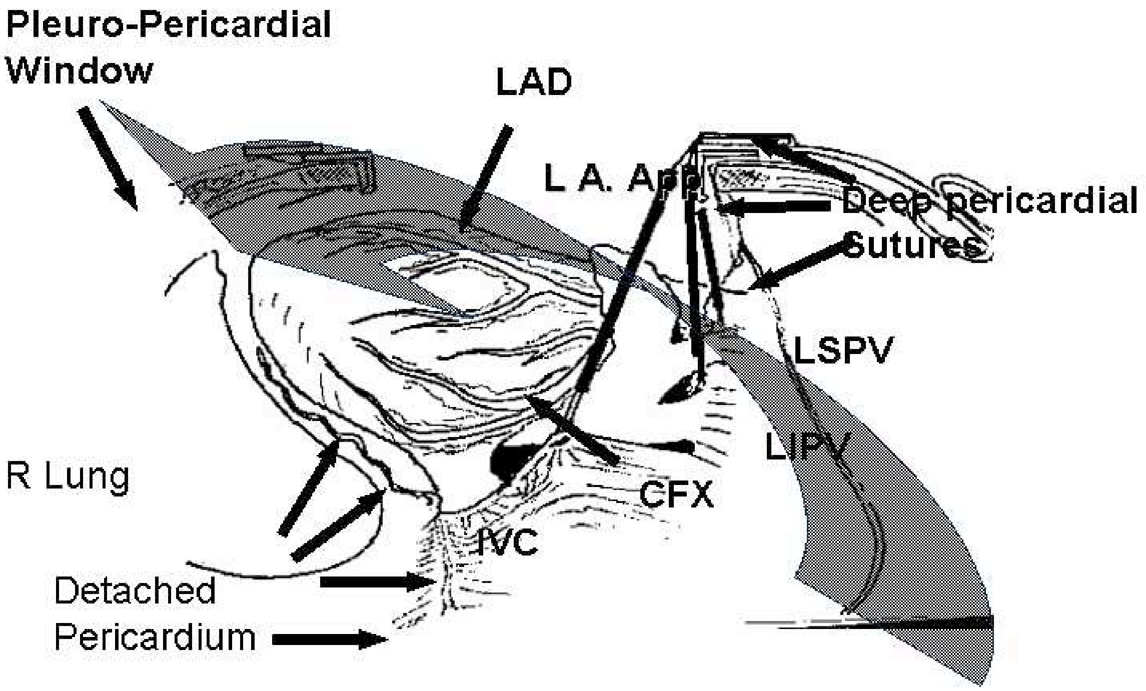

Figure 2. Cardiac displacement into the right pleural cavity. Tension has been applied on the three deep pericardial sutures, and the apex of the heart has been positioned posterior to the right chest wall. The entire obtuse margin of the heart becomes anterior. The large shaded arrow indicates the 180-degree rotation of the apex of the heart.

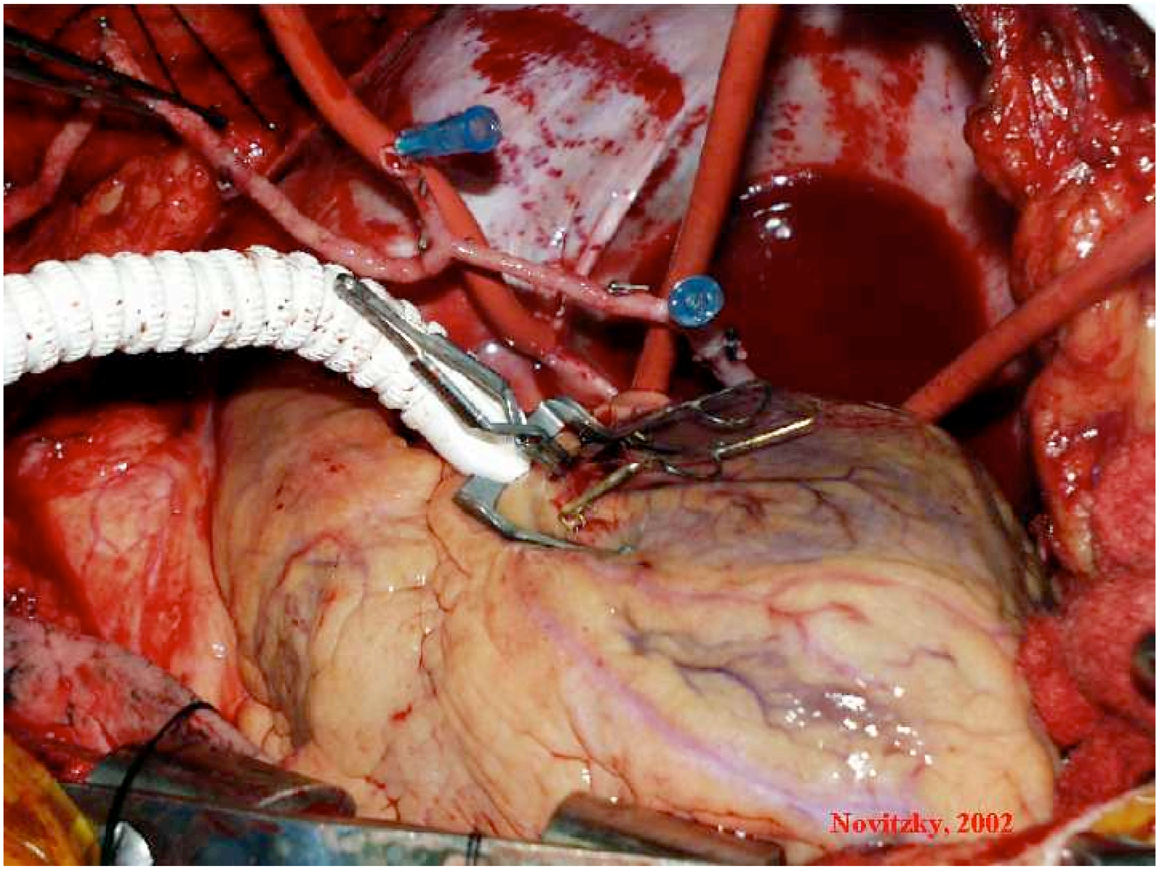

Figure 3. Revascularization of the obtuse margin of the heart. Tension has been applied to the three deep pericardial sutures that have been placed on the left side of the stabilization device. The right ventricle and the apex of the heart have being displaced behind the right chest wall. The graft of the distal end of the natural Y vein to the obtuse marginal artery has being performed, the ramus intermedius has been stabilized, and the vein is held by two #21 gauge needles placed through the shod of a deep pericardial suture, " the virtual assistant."

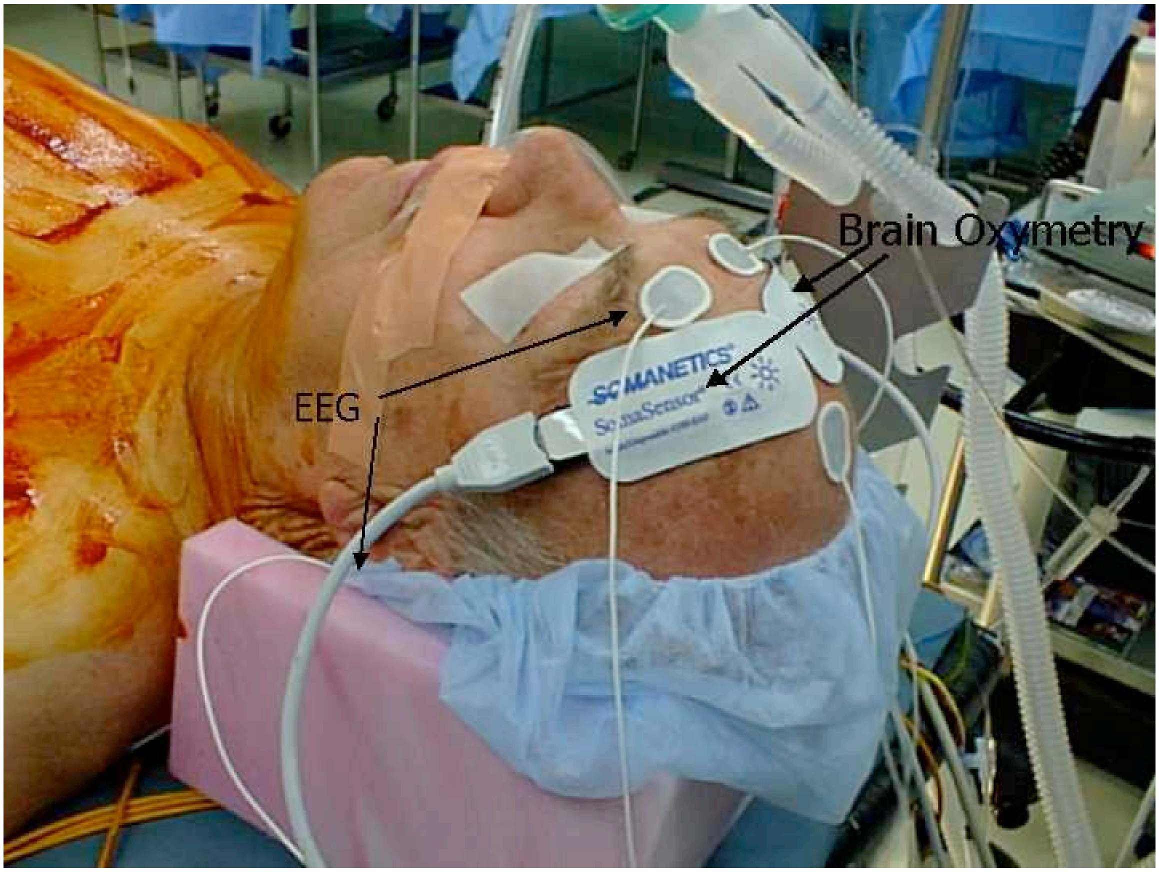

Figure 4. Multimodality brain monitoring. Bilateral placement of the two frontal oximetry sensors and the two fronto-mastoid leads for continuous EEG monitoring.

Stable Brain Monitoring

Brain Oxymetry

EEG Spectral Array

Figure 5. Stable brain oximetry as observed during the surgical procedure.