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Total Myocardial Revascularization without Cardiopulmonary Bypass Utilizing Computer-Processed Monitoring to Assess Cerebral Perfusion

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ABSTRACT

Background: Total myocardial revascularization without the use of cardiopulmonary bypass (CPB) has been easily achieved using a combination of: a) deep pericardial sutures, b) right pleural herniation, and c) controlled intermittent hypotension.

Methods: Five hundred fifty patients underwent revascularization off CPB, with 344 patients having three-vessel disease, 150 two-vessel disease, and 54 one-vessel disease. The use of controlled intermittent hypotension, administering esmolol and nitroglycerine during anesthesia greatly facilitated access to the marginal territory. The reduction of the systemic arterial blood pressure and the heart rate resulted in decreased ventricular wall stress. The heart was pliable, easy to manipulate, herniated into the right pleural cavity, and thus epicardial stabilization was achieved without inducing hemodynamic instability.

To avoid the potential detrimental effects of intermittent hypotension we used two continuous brain-monitoring techniques: a) cortical brain oxymetry (cerebro-venous oxygen saturation (CVOS)) and b) electroencephalographic spectral array (EEG). Brain oxymetry changes of more than 20% from baseline value were observed in 15% of patients and preceded the EEG changes observed in 6% of patients. A reduction of CVOS, more than 20% for one to two minutes from baseline values required pharmacological intervention with alpha agents. The combination of both CVOS and EEG required temporary placement of the heart back into the pericardial cavity. Normalization of CVOS and EEG to baseline values was always restored. Following recovery the addition of alpha agents and reduction of drug dosage allowed successful cardiac herniation.

Results: We performed a total of 1,579 grafts on 1,389 VD, obtaining a ratio of 1.13 grafts for VD. In the entire group, there were 411 patients with circumflex disease who underwent 456 bypass grafts (ratio of 1.1). The stroke incidence was not significantly different than patients operated on using CPB.

Conclusions: We conclude that using CVOS and EEG monitoring during off CPB, CABG complete coronary revascularization including the obtuse marginal artery is routinely achieved.

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INTRODUCTION

Complete myocardial revascularization without the use of cardiopulmonary bypass (CPB) has been increasingly accepted as a surgical modality with advantages to the patient [Ancona 1999]. By avoiding the use of CPB and limiting the inflammatory response [Meldrum 1999, Murkin 1999], patients with multiple co-morbidity may be considered operable. Complete revascularization is essential to avoid recurrence of symptoms and the need for further interventions such as repeat surgery and/or angioplasty.

In experienced hands, incomplete revascularization may still occur because of cardiac instability or abnormal hemodynamics. Exposure of the obtuse marginal artery or other circumflex branches may be the most difficult in this regard, and if too difficult can cause termination of the procedure or require the use of CPB to complete revascularization.

The brain is constantly monitored using a combination of transcranial near-infrared spectroscopy, which measures cerebro-venous oxygen saturation (CVOS) [Edmonds 1996] and computer processed compressed spectral array electroencephalography (EEG) [Levy 1984]. Utilization of both complimentary modalities helps to document the patient's individual tolerance for intermittent hypotension and adequacy of cerebral perfusion and oxygenation. Systolic arterial blood pressure between 60-90 mmHg, and heart rate between 50–70 bpm is generally tolerated facilitating coronary artery anastamosis, cardiac stabilization and manipulation.

Immediate interventions, such as administration of vasoactive drugs, or temporary repositioning of the heart in the pericardial cavity, are utilized when a >20% reduction from control value occurs in CVOS and or EEG (Peak Power Hz). We summarize our operative surgical technique and pharmacological intervention, which has facilitated complete myocardial revascularization off CPB.

MATERIALS AND METHODS

This report comprises total myocardial revascularization performed at two of the University of South Florida affiliated hospitals (Tampa General Hospital and The James A. Haley Veterans Hospital) in Tampa, Florida. Between September 1996 and March 2000, 550 patients underwent this procedure. There were 516 males and 34 females; the mean age was 63 years (range 35-87). Three hundred thirty-seven (337) operations were elective, one hundred fifty six (156) urgent and fifty seven (57) emergent.

Three hundred forty-four (344) patients had three-vessel disease, 150 had two-vessel disease, and 56 had one vessel disease. The major involved vascular territories consisted of the left anterior descending (LAD) in 539, right coronary artery (RCA) in 439 and circumflex artery (CFX) in 411 patients. Thus a total of 1,389 vessel diseases were present in 550 patients.

Surgical Technique

In our experience, complete myocardial revascularization for multivessel disease is optimally performed via a mid-line sternotomy with full heparinization. To facilitate access to all coronary arteries, we use a combination of: a) deep pericardial sutures, b) creation of a pleuro-pericardial window, and c) cardiac herniation. These three maneuvers, in combination with controlled intermittent hypotension, greatly facilitated revascularization of all vascular territories of the heart.

Deep pericardial sutures: Three deep pericardial sutures are used; soft rubber tubing covers all of them. The first suture is placed behind the left atrium in the oblique sinus between the inferior vena cava (IVC) and the left inferior pulmonary vein (LIPV); the second and third sutures are placed anterior to the LIPV and left superior pulmonary vein. Whenever traction on these sutures is applied, the posterior mediastinum is brought forward, the plane of the back of the heart changes, and the heart rotates anteriorly and superiorly on its base with the apex pointing towards the ceiling (verticalization). At this stage the hemodynamic status is stable.

Pleuro-pericardial window: Following a longitudinal pericardial incision, a wide window is created between the pericardial cavity and the right pleural space. The pleura is divided between the right half of the sternotomy and the pericardial edge, extending the incision from the manubrium towards the diaphragm. At the diaphragmatic level, the pericardium is detached from the diaphragm extending the incision from the retrosternal edge up to the anterior edge of the IVC. Care is required not to injure the phrenic nerve, which lies lateral to the IVC. This wide opening is similar to that used for heterotopic heart transplantation.

Cardiac herniation: Whenever the obtuse marginal aspect of the heart requires revascularization (obtuse marginal and ramus), the stabilization is greatly facilitated by herniating the apex of the heart into the right pleural cavity (Figure 1, ◎). To accomplish this, tension is applied on the deep pericardial sutures, which are secured on the left side of the sternotomy. At this stage the heart has been verticalized by the sutures and slightly rotated counter clock wise. Gentle manual pressure is applied on the marginal aspect and the apex of the heart is placed behind the right sternal edge. The entire left lateral aspect is exposed including the atrioventricular groove, and the area of the coronary to undergo grafting is stabilized.

Anesthesia Management

Hemodynamics: The nature of myocardial revascularization without CPB has inherent periods of hypotension, initially resolved by placing the heart back into the pericardial cavity and by administration of vasoactive drugs. Three sets of hypotensive events may be observe: first, during the initial coronary artery examination and placement of deep pericardial sutures; second, during exposure of coronary arteries, mainly in the initial stages of cardiac herniation. Initial hemodynamic instability is more marked during stabilization of the obtuse marginal (OM) and ramus intermedius (RI), and less evident during stabilization of postero lateral artery (PLV), posterior descending artery (PDA) and RCA. Exposure of the D1 and the LAD has minimal hemodynamic impact. Third, hypotension event may occur whenever a large left ventricular (LV) mass becomes ischemic such as proximal occlusion of the LAD, or excessive pressure exerted by the stabilizer. Early recognition is resolved by placement of an intra coronary shunt or reducing the excessive pressure. Unresolved ischemia may lead to ventricular fibrillation and need of emergent conversion to CPB. While tension is applied on the deep pericardial sutures (verticalization), the hemodynamics remains stable.

We consider baseline for the CVOS and EEG the values obtained once the sternotomy has been performed and the sternal edges retracted. Usually at this stage the anesthetic level has been achieved and will remain stable during surgery.

We attempt to maintain a heart rate between 50 and 70 beats/min to facilitate creation of surgical anastamoses. Esmolol is used as the primary agent for reducing heart rate. At Esmolol doses > 200 mcg/kg/min, the desired

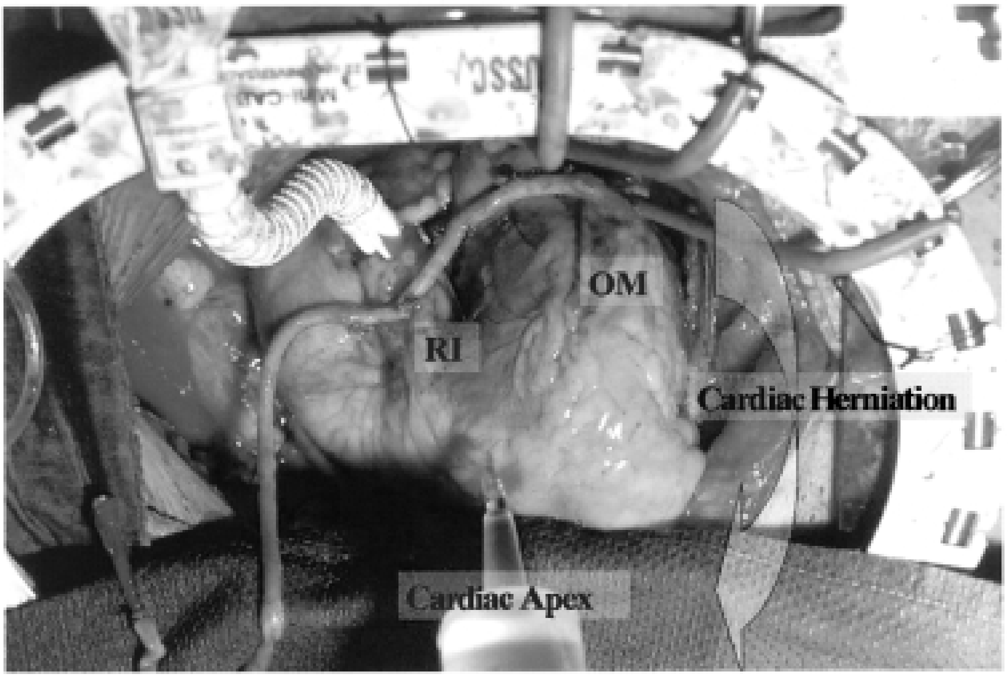

Figure 1. Sequential revascularization of the obtuse marginal artery and ramus. The heart has been herniated into the right pleural cavity exposing the entire circumflex territory. The deep pericardial sutures are placed towards the left.

decrease in heart rate (HR) may be accompanied by undesirable negative inotropic effects. Some degree of hypotension may occur in order to lower the heart rate, higher doses of Esmolol may be utilized provided cerebral/coronary perfusion monitors indicate absence of ischemia.

Positive inotropic agents increase blood pressure and HR, and are used primarily when hypotension results in CVOS reduction of 20% or more and EEG slowing.

ACE inhibitors are frequently withheld the night before surgery to prevent synergism with the anesthetic agents that would result in a decreased systemic vascular resistance. Norepinephrine is occasionally required when phenylephrine is ineffective. The requirement for norepinephrine decreases when ACE inhibitors are withheld.

The tolerance of lower systemic pressures with multimodality cerebral monitoring utilization has decreased the requirement for large intraoperative fluid administration, extreme Trendellenburg positioning, and norepinephrine utilization.

Neurologic Monitoring

One of the significant challenges in performing CABG surgery without the use of CPB is to guarantee adequate cerebral perfusion as the blood pressure is allowed to decrease in order to facilitate creation of distal graft anastomosis. While numerous cerebral function monitors have been described in recent years, we have been impressed with the combination of the computer-processed EEG and the CVOS as complimentary modalities for documenting adequacy of cerebral perfusion and oxygenation.

Electroenceplalogarphic compressed spectral array: Monitoring the EEG with computer-processed compressed spectral array, has become a widely accepted technique over the past decade. There are many such devices currently available and, for our clinical purposes, any monitor capable of simultaneously evaluating both cerebral hemispheres is probably adequate for cardiac surgery. We use a 2-channel bilateral fronto-mastoid electrode array (Sentinel 4, Axon Systems, Inc., Hauppauge, NY) so that we can detect inadequate perfusion to the cerebral cortex in either hemisphere (frontal, parietal and temporal lobes).

The primary confounding factor in EEG monitoring is the impact of anesthetic agents which tend to slow the predominant EEG frequencies and increase the EEG power (density increase in the lower frequency range). In the case of cerebral ischemia induced by limited cerebral perfusion, the changes are typically bilateral and symmetrical, and may be confused with changes in anesthetic depth unless anesthetic management is kept reasonably constant during critical phases of the operation, such as during anastomosis of the obtuse marginal branches.

When the EEG is used for cerebral monitoring during carotid endarterectomy [Mahla 1994], it is a simple matter to detect ischemia as unilateral loss in EEG power (decrease peak power in density spectral array), or a leftward shift toward slower overall EEG frequency ipsilateral to the carotid cross-clamp. Of course, this can be alleviated by shunt insertion or by augmenting collateral flow by increasing mean arterial pressure.

Table 1. Number of coronary bypass grafts for vessel disease

Vessel Disease	Patients	Grafts	Graft/Vessel Disease Ratio
1	56	178	1.32
2	150	365	2.43
3	344	1,132	3.29
Total	550	1,579	1.137

Table 2. Number of coronary bypass graft for specific vessel disease

Vessel Disease	Patients	Grafts	Graft/Vessel Disease Ratio
LAD	539	710	1.32
RCA	439	413	0.94
CFX	411	456	1.11
Total	1,389	1,579	1.137

Cerebral oximetry: In the case of global cerebral insufficiency, the EEG changes are not only bilateral but also more subtle. Accordingly, we have found that confirmatory data for a cerebral oxymetry probe are invaluable in assuring that EEG changes are the result of inadequate cerebral blood flow and not simply the effects of anesthetic depth changes or other confounding factors such as reduction in core body temperature.

Cerebral oximetry monitors cerebral oxygen tension (a mixture of arterial (25%), venous (75%), and brain tissue values) by the reference of an infrared beam aimed through the scalp, bone, and surface brain tissues (INVOS Cerebral Oximeter, Somanetics Corp, Troy, MI). Whenever cerebral oxygen demand exceeds oxygen delivery, the cerebral oxygen tension decreases, thus suggesting that an improvement in perfusion is required. While this device appears to be extremely sensitive to shifts in cerebral oxygen tensions, it is subject to artifact (such as placement over arteries or veins), and to considerable intrinsic drift during general anesthesia. Some groups have found it to be extremely useful for cerebral monitoring during on-pump CABG surgery [Stump 1999]. Likewise, we have found it to be of value as confirmatory evidence for the need to improve cerebral perfusion, particularly when accompanied by concomitant EEG changes, as described above.

RESULTS

A total of 1,579 bypass grafts were performed in 550 patients; the graft distribution and graft/VESSEL DISEASE ratio is shown in Table 1 (◎) and Table 2 (◎).

Changes in brain oxymetry of more than 20% was observed in 82 patients (15%), and EEG density reduction in 33 patients (6%) (Figure 2, ◎). In the remaining 49 patients, EEG remained unchanged. Hemodynamic instability in seven patients required conversion to CPB, in four patients CVOS and EEG indicated inadequate oxygen supply to the brain. Ventricular fibrillation, while graft to the LAD was performed, occurred in three patients, progressive LV dysfunction preceded the arrhythmic event (intracoronary shunt was not available), and two patients were converted to CPB.

The incidence of perioperative stroke was analyzed in 409 patients operated at the VA Hospital; 204 patients operated off CPB were compared to 205 patients operated on CPB. The off CPB group had a higher preoperative incidence of cerebrovasclar disease (19.5 vs. 11.3%) $p<0.02$; however, following CABG the stroke rate between the groups was not different (2 vs. 1%). The off CPB group had significant shorter intensive care unit (ICU) and hospital stay, less blood products transfusion, shorter operative time, and operating room time. There was no difference in the perioperative myocardial infarction (MI) on the off CPB and on CPB groups (4.9 vs. 6.4%).

When used in concert, the processed EEG and cerebral oximetry afford a visual representation of the adequacy of cerebral oxygenation, especially during episodes of hypotension or relative bradycardia. When these devices both suggest that the threshold for cerebral ischemia is approaching, the surgeon should temporarily stop manipulating the heart and allow the anesthesiologist to titrate vasoactive medication to rapidly reestablish adequate cerebral perfusion. Once this has been accomplished, then the anastomosis in question can be completed after optimal cerebral oxygenation has been improved.

In this group of 550 patients, we have not seen evidence of a perioperative stroke in a patient who underwent CABG without CPB, providing ischemic changes on EEG and cerebral oxymetry are recognized and treated in a timely fashion. Given the well-known problems with cerebral embolization associated with cardiopulmonary bypass, we believe that the non-bypass alternative with meticulous cerebral monitoring is a suitable method of assuring adequate cerebral perfusion during off-pump CABG surgery.

CONCLUSION

Fluctuations of arterial blood pressure are common during coronary surgery off CPB and also frequently observed in CPB surgery. Using trans-esophageal echocardiography, we have measured, in 10 anesthetized patients, the effect of controlled hypotension on the cardiac function. Left ventricular (LV) dimensions, LV wall thickness, and the left ventricular wall stress (LVWS) was calculated and segmental wall motion were measured at normotension, following administration of Esmolol and nitroglycerine during controlled hypotension. There was a significant reduction of the LV dimensions, increase of LV wall thickening, and 50% reduction of the LVWS ($p< 0.01$). The latter is one of the major determinants of myocardial O_2 consumption.

Non-infarcted segments with abnormal wall motion (akinetic-diskinetic), recover the ability to contract, thus indicating that the O_2 supply/demand in the ischemic ter-

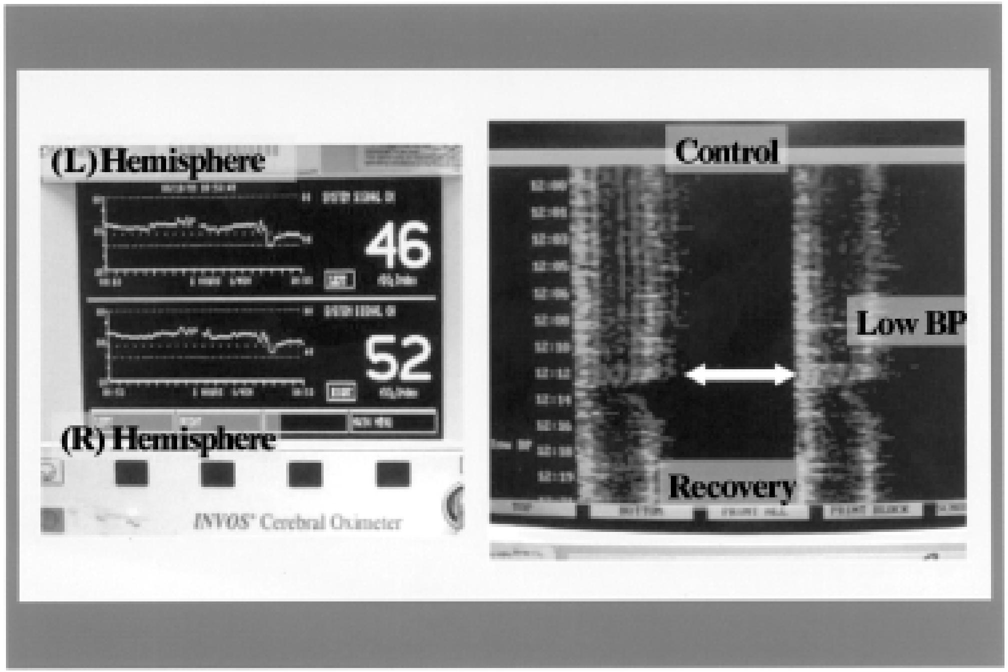

Figure 2. Multimodality brain monitoring during a hypotensive episode. On the left side (INVOS) bilateral cerebral oxymetry is shown. There is a sudden index fall to 40, followed by partial recovery after neosynephrine administration. The cortical saturation is symmetrical affecting both brain hemispheres simultaneously. On the right side bilateral compressed spectral array is shown. The EEG density reduction corresponds to the oximetry index drop which preceded one minute prior EEG changes, complete EEG recovery is observed.

ritory has been normalized, therefore, the major benefit of the induced hypotension for the heart is reduction/reversal of myocardial ischemia. Another benefit of the controlled hypotensive state is the ability to work with a less irritable myocardium (electrical stability) and in a more relaxed state (less LVWS) allowing easy manipulation and stabilization during the cardiac herniation.

During controlled hypotension, blood plasma lactate was measured throughout the entire surgical procedure and the postoperative period indicating that by retaining pulsatile blood flow the cardiac output was adequate to meet the metabolic demands of the body.

The multimodality of brain monitoring using cerebral oximetry and EEG allowed safe controlled reduction of the systolic blood pressure without compromising brain oxygenation.

Myocardial revascularization off CPB is constantly expanding. However, limitations of the completeness of the revascularization are directly related to the surgeon's experience, dexterity, and mind-set for the procedure. Constant innovations and the development of new stabilization devices, as well patient management before, during, and following surgery will attract more practitioners to off-pump CABG. We have presented the anesthetic and hemodynamic management used at our institution, which facilitates exposure and stabilization of the epicardial arteries, especially the obtuse marginal segment.

REFERENCES

1. Ancona GD, Karamanoukian HL, Soltoski PS, Salerno TA, Bergsland J. Changing referral pattern in off-pump coronary artery bypass surgery: A strategy for improving surgical results. Heart Surgery Forum #1999-4534:1–4, 1999.
2. Edmonds HL, Rodriguez RA, Audenaert SM, Austin EH, Pollock SB, Ganzel BL. The role of neuromonitoring in cardiovascular surgery. J Cardiothorac Vasc Anesth 10 (1):15–23, 1996.
3. Levy WL. Intraoperative EEG patterns: implications for EEG monitoring. Anesthesiology 60:430–4, 1984.
4. Mahla ME. Carotid surgery: anesthesia and monitoring update. Semin Anesth 13 (1):75–85, 1994.
5. Meldrum DR, Donnahoo KK. Role of TNF in mediating renal insufficiency following cardiac surgery: Evidence of a postbypass cardiorenal syndrome. J Surg Res 85 (2):185–99, 1999.
6. Murkin Jm. Etiology and incidence of brain dysfunction after cardiac surgery. J Cardiothorac Vasc Anesth 13 (4):12–7, 1999.
7. Stump DA, Jones TJJ, Rorie KD. Neurophysiologic monitoring and outcomes in cardiovascular surgery. J Cardiothorac Vasc Anesth 13 (5):600–13, 1999.