The Heart Surgery Forum #2004-1021
7 (4), 2004 [Epub June 2004]
doi:10.1532/HSF98.20041021

Online address: www.hsforum.com/vol7/issue4/2004-1021.html

Magnetic Resonance Imaging to Detect Acute Cerebral Events in On-Pump and Hybrid-Pump Patients

Aftab R. Kherani, MD,[1] Ronald M. Lazar, PhD,[2] Steve Xydas, MD,[1] Pamela A. Mazzeo, BA,[1] Jennifer M. Fal, BA,[1] Linda Mongero, CCP,[3] Deon W. Vigilance, MD,[1] Jeffrey A. Morgan, MD,[1] Faisal H. Cheema, MD,[1] Elizabeth H. Burton, BA,[1] Garrett W. Moss, MBA,[1] Mehmet C. Oz, MD[1]

Divisions of [1]Cardiothoracic Surgery, [2]Neurology, and [3]Clinical Perfusion, Columbia University, College of Physicians & Surgeons, New York, New York, USA

ABSTRACT

Background: Conventional cardiopulmonary bypass results in cerebral ischemic sequelae that may be reduced with hybrid pump technologies, such as the CardioVention system (CardioVention, Santa Clara, CA, USA). CardioVention differs from conventional bypass in that it has a novel air elimination module and reduced membrane surface area and priming volume. This preliminary study tested whether this pump confers neurological safety advantages over conventional bypass.

Methods: Ten patients were studied, with 6 assigned to on-pump coronary artery bypass grafting and 4 to the CardioVention system. No patients had any stroke history. Within 72 hours postsurgery, each underwent diffusion-weighted magnetic resonance imaging, a sensitive test for cerebral ischemic events.

Results: Two on-pump patients (33%) had postoperative findings on imaging, but none of the CardioVention patients demonstrated comparable changes (P = .47). No patients had symptoms of acute stroke.

Conclusion: Postoperative magnetic resonance imaging showed a trend toward a greater rate of ischemic events in patients undergoing traditional on-pump surgery. These preliminary findings suggest that hybrid pump technologies, such as the CardioVention system, may attenuate the risk of short-term neurological complications. Future studies are indicated to confirm these subclinical ischemic changes and to correlate them with long-term neurocognitive changes.

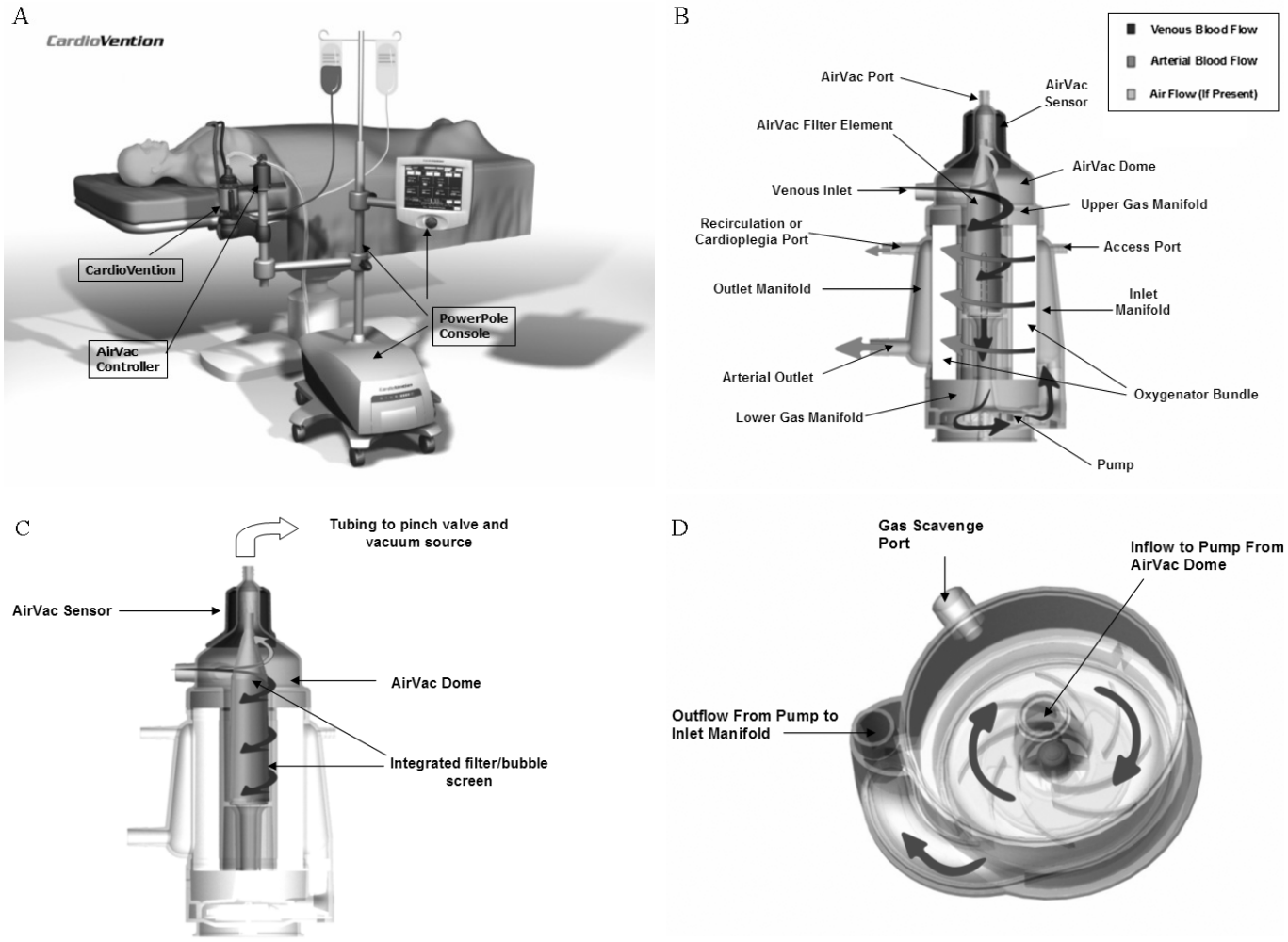
Received March 1, 2004; accepted March 31, 2004.

Address correspondence and reprint requests to: Aftab R. Kherani, MD, Division of Cardiothoracic Surgery, Department of Surgery, Columbia University, College of Physicians & Surgeons, 177 Ft Washington Ave, MHB 7GN-735, New York, NY 10032; 1-212-305-5108; fax: 1-212-305-5337 (e-mail: khera001@mc.duke.edu).

INTRODUCTION

The large surface area of the standard cardiopulmonary bypass (CPB) circuit contributes to morbidity secondary to systemic inflammatory reaction and hemodilution. In order to minimize the potential for adverse events, a compact arteriovenous loop with pumping, oxygenating, air removal, and gross filtration capabilities has been developed and previously described [Mueller 2002, Mueller 2003]. The CardioVention hybrid CPB system (CardioVention Santa Clara, CA, USA) (Figure, part A) features a disposable "cartridge," which is placed into a drive console and consists of a single, integrated device that performs the functions of oxygenation, blood pumping, and air elimination. This single unit allows for the reduction of the connections required in the CPB circuit (Figure, part B). Blood from the patient enters the venous inlet and then enters an air elimination module (Figure, part C) and subsequently flows down the inlet manifold to the centrifugal pump (Figure, part D), propelling the blood through the membrane oxygenator and back to the patient.

The CardioVention system addresses 3 main issues that may impact post–coronary artery bypass grafting (CABG) morbidity [Mueller 2002, Mueller 2003]. The first is venous air handling. The CardioVention air elimination module is a sensor-regulated venous air-handling system, aimed to minimize the risk of air embolization. It tangentially directs flow to the conical top, forcing air into the center of the vortex where it is concentrated at the top of the module's dome. The sensor detects air via a change in capacitance, opening a pinch valve on the tubing to a vacuum source, which efficiently evacuates air. In the case of massive air entrapment (eg, from a displaced venous cannula), the sensor also reduces the pump cycle speed when air is persistent. Secondly, the CardioVention addresses the issue of foreign surfaces with a low surface area, closed-loop tubing circuit. Platelet activation and inflammatory response to foreign surface area exposure may be mitigated by the reduction of CPB system surface area from more than 12 m^2 in conventional CPB circuits to 1.4 m^2 [Mueller 2002]. Lastly, the CardioVention targets hemodilution by reducing the standard adult CPB prime vol-



The CardioVention system (figures modified from originals provided by CardioVention, Santa Clara, CA, USA) A, The hybrid pump system: the CardioVention is a disposable "cartridge" system, which is placed into a drive console. B, Components and flow path: blood from the patient enters the top of the CardioVention system into the integrated air-elimination, pumping, and oxygenating unit. This system allows for only 2 connections (blood-in and blood-out) in the cardiopulmonary bypass circuit. C, The air elimination module: the air elimination system receives blood from the patient and tangentially directs flow to the conical top, forcing air into the center of the vortex where it is concentrated at the top of the module's dome. The sensor detects air via a change in the capacitance at the top of the unit, opening a pinch valve on the tubing to a vacuum source, which evacuates air. D, The low-prime centrifugal pump: the centrifugal pump is a fixed-bearing, magnetically driven impeller pump located between the air elimination system and the inlet manifold, leading to the membrane oxygenator. This pump allows for kinetic-assisted venous drainage from the patient into the air elimination module.

ume from approximately 1500 mL to less than 500 mL with the use of a low-prime centrifugal pump. The small, compact CardioVention system does not have several components central to the standard CPB circuit [Mueller 2002, Mueller 2003, Mongero 2003]. These include the open hard-shell venous reservoir, cardiotomy reservoir, arterial line filter, and heat exchanger, although each of these may be added at the user's discretion.

Animal experiments with the CardioVention system have demonstrated improved gas exchange and improved hematocrit levels with no evidence of hemolysis compared to a conventional CPB circuit [Mueller 2002]. Air filtration experiments have also shown an excellent bubble count and size after injection with large boluses of air [Mueller 2003]. In addition, early results from a data registry that includes data from 186 "mini-system"–supported patients and 55 traditional CPB patients suggested improvements in levels of postdilutional hematocrit, end-of-support hematocrit, allogenic blood units transfused, and postoperative mechanical ventilator duration [Mongero 2003].

But do these results translate to fewer cerebral ischemic events? Diffusion-weighted magnetic resonance imaging (DWMRI) is a proven method for assessing post-CABG focal brain lesions, even if they are subclinical [Restrepo 2002]. We conducted a small-scale trial with the use of postoperative DWMRI to detect acute cerebral events in patients undergoing traditional on-pump and CardioVention hybrid-pump CABG.

Table 1. Baseline and Operative Characteristics of the 2 Patient Groups*

	Traditional On-Pump (n = 6)	CardioVention Hybrid Pump (n = 4)	*P*
Baseline age, y	59.3 ± 11.5	67.5 ± 7.00	.244
Diabetes, n (%)	3 (50%)	1 (25%)	.571
Hypertension, n (%)	5 (83%)	3 (75%)	1.000
Hypercholesteremia n, (%)	6 (100%)	4 (100%)	—
Baseline ejection fraction, %	55.0 ± 4.47	57.8 ± 6.34	.441
No. of grafts performed	3.33 ± 1.21	3.00 ± 0.00	.604

*Variables are listed as a mean ± SD for continuous variables. *P*-values are for student *t* tests for continuous variables and for Fisher exact test (chi-square) for categorical variables.

Table 2. Positive Diffusion-Weighted Magnetic Resonance Imaging Findings by Patient Group*

	Traditional On-Pump (n = 6)	CardioVention Hybrid Pump (n = 4)	*P*
No. of imaged patients	6	4	—
No. (%) of patients with positive findings	2 (33.3%)	0 (0.00%)	.467

**P* is for the Fisher exact test (chi-square) analysis.

MATERIALS AND METHODS

This study was approved by the Institutional Review Board of Columbia University and all patients gave written informed consent. Ten patients undergoing cardiac surgery performed by a single surgeon (M.C.O.) at Columbia-Presbyterian Medical Center were studied between 2001 and 2003. All surgeries were elective operations in patients with no prior thoracic surgery. At the surgeon's discretion, 6 patients were assigned to traditional on-pump CABG and 4 to the CardioVention system. Generally, patients in the CardioVention group had smaller distal targets or a large heart, conditions considered to preclude off-pump CABG because of technical challenges.

Conventional CPB was performed with mild hypothermia (32°C to 34°C) after the administration of porcine heparin (300 IU/kg; American Pharmaceutical Partners, Schaumburg, IL, USA). The aorta was assessed for cross-clamping by palpation only and clamped prior to CABG anastomoses. Myocardial protection was provided with intermittent, antegrade, and retrograde crystalloid cardioplegia and topical cooling. A cardiotomy reservoir (Hardshell BCR-3500; Baxter Healthcare, Irving, CA, USA), a Quadrox oxygenator (Jostra, The Woodlands, TX, USA), a Quart arterial filter, (Jostra), a CellSaver system (Cell Saver 5; Haemonetics, Braintree, MA, USA), and a soft-shell venous reservoir (BMR 1900; Baxter Healthcare) were routinely used. CPB flow rates were kept at approximately 2.4 L/m^2 per minute. The activated clotting time (Hemochron; International Technidyne, Edison, NJ, USA) was kept above 480 seconds during bypass. Acid-base balance was maintained between 7.38 and 7.42, mean arterial pressures between 60 and 80, and the hematocrit above 25%. Protamine (variable dosing; Eli Lilly, Indianapolis, IN, USA) and aminocaproic acid (10 gm; Amicar, Immunex, Seattle, WA, USA) were given to all patients.

CardioVention patients underwent CABG with use of CPB under similar conditions, although without the use of a cardiotomy reservoir, CellSaver, or heat exchanger. The aorta was palpated and cross-clamped as with the conventional CPB cohort. Patient core temperature while on bypass varied between 34°C and 37°C. The hematocrit was kept above 30%. The anticoagulation, reversal, and antifibrinolytic regimens were the same for the CardioVention patients as for the conventional CPB cohort.

No preoperative screening or imaging was performed, and no patients had a history of prior stroke or examination results indicating focal neurological findings. Between 48 and 72 hours following surgery, all patients underwent diffusion-weighted, fluid-attenuated inversion recovery (FLAIR) and T1- and T2-weighted magnetic resonance imaging, which was read by a single radiologist blinded to the patient's treatment group.

All statistical analyses were carried out with SPSS (SPSS, Chicago, IL, USA). Values of continuous variables are expressed as a mean ± SD. Differences between groups were assessed with chi-square tests for categorical variables and Student *t* tests for continuous variables. A P value < .05 was considered statistically significant.

RESULTS

Baseline age, left ventricular ejection fraction, and number of grafts performed were comparable in the 2 groups (Table 1). There were no differences in the percentage of patients with diabetes, hypertension, or hypercholesteremia (Table 1). Postoperatively, only 2 patients had positive DWMRI findings indicating acute cerebral events; both had undergone traditional on-pump CABG. One patient had an occipital lesion, and the other had a pontine lesion. Findings on DWMRI were consistent with fluid-attenuated inversion recovery (FLAIR) imaging results. There was no significant difference (Fisher exact test, P = .467) in the incidence of positive DWMRI findings between the 2 groups (Table 2). None of the patients, including the two with positive findings, had any symptoms of acute clinical stroke.

DISCUSSION

The incidence of stroke following CABG is 1% to 5% [Roach 1996], but the incidence of neurocognitive dysfunction is substantially higher, approximately 21% to 34% [van Dijk 2002]. The most recent, highly powered, randomized data demonstrate no significantly increased risk of stroke [Puskas 2003] or long-term neurocognitive impairment [van Dijk 2002] associated with the use of CPB. In the postacute

period, there are randomized data regarding neurocognitive function that favor off-pump patients [van Dijk 2002, Zamvar 2002, Diegeler 2000]. Our study suggests that a hybrid CPB pump, such as the CardioVention, may decrease the incidence of subclinical neurological events associated with the use of CPB. There have been 2 pathophysiological mechanisms that have been proposed to underlie neurological events arising from the use of CPB: microemboli and cerebral hypoperfusion arising from intraoperative hypotension [Diegeler 2000]. CardioVention's novel air elimination module may be responsible for the observed trend in postoperative DWMRI findings.

Inflammatory response stemming from blood contact with a foreign surface (the CPB circuit) also contributes to postoperative patient morbidity [Rubens 1999]. Contact with a foreign surface activates white blood cells and platelets and the coagulation, fibrinolytic, and complement cascades and may result in systemic inflammatory response syndrome (SIRS). SIRS is a syndrome that involves numerous pathological conditions, including capillary leak, and may be associated with neurological dysfunction [Taylor 1998]. As such, one potential improvement in the CPB circuit involves the reduction of the foreign surface area with which blood comes in contact. A major goal of the CardioVention system is to minimize this inflammatory response.

This small-scale trial has several limitations. Future studies should be better powered, and all patients should undergo full neurocognitive testing preoperatively as well as at designated postoperative time points. Nevertheless, the new hybrid technology represented in the CardioVention system is promising and has comparable safety to the standard CPB technology, as seen in this small pilot study. Postoperative DWMRI showed a trend toward a greater incidence of ischemic events following traditional on-pump surgery, even in a small number of patients. These preliminary findings justify a larger trial to confirm these subclinical ischemic changes and to correlate them with long-term neurocognitive changes. Hybrid pump technology may benefit not only short-term neurocognitive function but other areas as well, and further investigation into its potential value is warranted.

ACKNOWLEDGMENT

Funding for this study was generously provided by a grant from the Miami Heart Research Institute, which has no affiliation with CardioVention.

REFERENCES

Diegeler A, Hirsh R., Schneider F, et al. 2000. Neuromonitoring and neurocognitive outcome in off-pump versus conventional coronary bypass operation. Ann Thorac Surg 69:1162-6.

Mongero LB. 2003. Size is at the heart of the matter: update on advanced circulatory support technology. Heart Surg Forum 6:112-3.

Mueller XM, Jegger D, Augstburger M, Horisberger J, Godar G, von Segesser LK. 2002. A new concept of integrated cardiopulmonary bypass circuit. Eur J Cardiothorac Surg 21:840-6.

Mueller XM, Tevaearai HT, Jegger D, von Segesser LK. 2003. Air filtering capacity of an integrated cardiopulmonary bypass unit. ASAIO J 49:365-9.

Puskas JD, Williams WH, Duke PG, et al. 2003. Off-pump coronary artery bypass grafting provides complete revascularization with reduced myocardial injury, transfusion requirements, and length of stay: a prospective randomized comparison of two hundred unselected patients undergoing off-pump versus conventional coronary artery bypass grafting. J Thorac Cardiovasc Surg 125:797-808.

Restrepo L, Wityk RJ, Grega MA, et al. 2002. Diffusion- and perfusion-weighted magnetic resonance imaging of the brain before and after coronary artery bypass grafting surgery. Stroke 33:2909-15.

Roach GW, Kanchuger M, Mangano CM, et al. 1996. Adverse cerebral outcomes after coronary bypass surgery. N Engl J Med 335:1857-63.

Rubens FD, Ruel M, Lavallee G, et al. 1999. Circuits with surface modifying additive alter the haemodynamic response to cardiopulmonary bypass. Eur J Cardiothorac Surg 15:353-8.

Taylor KM. 1998. Brain damage during cardiopulmonary bypass. Ann Thorac Surg 65(suppl):S20-6.

van Dijk D, Jansen EWL, Hijman R, et al. 2002. Cognitive outcome after off-pump and on-pump coronary artery bypass surgery: a randomized trial. JAMA 287:1405-12.

Zamvar V, Williams D, Hall J, et al. 2002. Assessment of neurocognitive impairment after off-pump and on-pump techniques for coronary artery bypass graft surgery: prospective randomized controlled trial. British Med J 325:1268-72.