*Original Article*

# The Efficacy of Low Prime Volume Completely Closed Cardiopulmonary Bypass in Coronary Artery Revascularization

Hideaki Takai, MD, Kiyoyuki Eishi, MD, Shiro Yamachika, MD, Shiro Hazama, MD, Katsuo Nishi, MD, Tsuneo Ariyoshi, MD, Shun Nakaji, MD, and Ichiro Matsumaru, MD

**Purpose: This study was conducted to evaluate and demonstrate the efficacy of low prime volume completely closed cardiopulmonary bypass (LPVP) in arrested coronary artery bypass grafting (CABG). We improved the percutaneous cardiopulmonary support (PCPS) circuit to reduce the deleterious effects of cardiopulmonary bypass (CPB).**

**Methods: Between April 1999 and May 2003, among 228 isolated CABG procedures, 47 procedures using LPVP (group L) and 86 procedures using standard prime volume open CPB (group S) were compared. The LPVP priming volume was 590 mL; the circuit was completely closed with a soft reservoir. Cardiac arrest was obtained by warm blood cardioplegia.**

**Results: The following average values were obtained: packed red blood cell transfusions, 0.88±1.4 U (group L) vs. 2.1±2.5 U (group S); intraoperative lowest hematocrit value, 28.7±4.6% (group L) vs. 22.4±3.3% (group S); blood loss over first 24 hours, 439±242 mL (group L) vs. 599±409 mL (group S); ventilation time, 5.1±3.1 hours (group L) vs. 10.4±14.9 hours (group S).**

**Conclusion: Compared to standard prime volume open CPB, LPVP resulted in fewer deleterious operative effects. Less blood loss, fewer blood transfusions, and earlier patient recovery was noted with LPVP. Thus, LPVP is a very efficient form of CPB. (Ann Thorac Cardiovasc Surg 2004; 10: 178–82)**

**Key words:** cardiopulmonary bypass, coronary artery bypass grafting, on-pump, low prime volume cardiopulmonary bypass

## Introduction

The effects of cardiopulmonary bypass (CPB) have been investigated over the past several decades.[1-3] Various devices, procedures and functions have been developed to reduce the deleterious effects of CPB.[4-8] Recently, in order to avoid the deleterious effects of CPB, off-pump coronary artery bypass grafting (OPCAB) has become more widely used.[9] However, CPB must still be used in cases such as intraoperative hemodynamic instability, critical arrhythmia, small vessels, intramyocardial vessels, or an enlarged heart.[10] Therefore, we designed a new type of CPB (low prime volume completely closed cardiopulmonary bypass: LPVP) that utilizes the characteristics of certain devices in order to reduce the deleterious effects of CPB. For example, in pediatric heart surgery, it has been reported that CPB that combines a centrifugal pump, with a closed circuit and is completely heparin-coated, attenuates the inflammatory response.[11]

We attempted to improve on the existing percutaneous cardiopulmonary support (PCPS) circuit by devising a completely closed circuit with a soft reservoir. In this study, we evaluated the effect of LPVP and standard prime volume open CPB.

## Patients and Methods

We examined 228 isolated CABG procedures occurring between April 1999 and May 2003 in our clinic. Patients were prospectively randomized into two groups. Thus, 47

*From Department of Cardiovascular Surgery, Nagasaki University School of Medicine, Nagasaki, Japan*

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Address reprint requests to Hideaki Takai, MD: Department of Cardiovascular Surgery, Nagasaki University School of Medicine, 1-7-1 Sakamoto-machi, Nagasaki City, Nagasaki 852-8501, Japan.

**Table 1. CPB characteristics**

| | LPVP | Standard prime volume open CPB |
|---|---|---|
| Pump | Centrifugal | Roller |
| Oxygenator | Membrane | Membrane |
| Suction | – | + |
| Venous reservoir | + | + |
| | (Soft reservoir) | (Hard shell cardiotomy reservoir) |
| Priming volume | 590 mL | 1,500 mL |
| Circuit | Completely closed circuit | Open circuit |

procedures using LPVP (group L) and 86 procedures using standard prime volume CPB (group S) were examined and compared. Informed consent was obtained from all the patients studied prior to the operation. Patients with the following conditions were excluded: urgent and emergent cases, renal dysfunction (serum creatinine >1.5 mg/dl), single bypass, OPCAB (16 cases), on-pump beating-heart CABG cases, severe COPD, and uncontrolled asthma.

The characteristics of the two types of CPB are shown in Table 1.

A CAPIOX EBS oxygenator (Terumo Co., Tokyo, Japan) with a heparin-coated circuit was used for LPVP. A removable soft reservoir of 500 mL capacity was fixed in the middle of the blood removal circuit when setting up the LPVP. The vent circuit, primed with lactate solution without blood, was connected to the middle of the blood removal circuit (Fig. 1). The total priming volume was 590 ml. Suction was provided by the cell saver (Medtronic, Inc., Blood Management Business Electromedics, Parker, CO, USA), which was set up independently. Ordinary wall suction was provided as well. Before driving the LPVP, we drained the priming solution throughout by using a branch of the arterial line. Each patient was given an initial pre-bypass bolus dose of heparin (100 IU/kg). During CPB, activated clotting time (ACT) was maintained at 250-300 seconds, and intravenous doses of heparin were given when needed. Myocardial protection was provided by injecting intermittent warm blood cardioplegia with high potassium according to the protocol of Calafiore et al.[12] After the first injection, cardioplegia was given at every anastomosis. Protamine sulfate was administered at a rate of 100 IU/kg in LPVP.

The Univox Gold oxygenator (Baxter Healthcare Inc., Irvine, CA, USA) with a combined heparin-coated circuit was used in the standard prime volume open CPB circuit. This type of CPB was primed with 1,500 mL of 6% hydroxyethylated starch (10 ml/kg) and Ringer's lactate solution without blood. A Sarns 9000 roller pump (Terumo Cardiovascular Systems, Corp., Ann Arbor, MI, USA) was used. Myocardial protection was provided by injecting intermittent antegrade cold (4°C) cardioplegic solution (St. Thomas's solution). Each patient was given an initial pre-bypass bolus dose of heparin (150 IU/kg). To maintain whole blood ACT greater than 400 seconds during CPB, intravenous doses of heparin were given when needed. Protamine sulfate was administered at a rate of 150 IU/kg in standard prime volume open CPB.

### Statistical analysis

Statistical analysis was performed using the SPSS® software package, version 11.0 (SPSS, Inc., Chicago, IL, USA). All variables are expressed as mean ± standard deviation. The results were examined using the Mann-Whitney U-test to test for significant differences between the two groups. A p value of less than 0.05 was considered to indicate statistical significance.

## Results

Differences between the groups in age, operation time, CPB time, and aortic cross-clamp time were not statistically different. There were also no statistically significant differences between the groups in: the number of branches with lesions, the number of distal anastomoses, and the number of grafts (Tables 2, 3). However, there were statistically significant differences in the following variables: packed red blood cell transfusions (counting only homologous transfusions without autologous transfusions), 0.88±1.4 U (group L) vs. 2.1±2.5 U (group S); blood loss over first 24 hours, 439±242 mL (group L) vs. 599±409 mL (group S); intraoperative lowest hematocrit value, 28.7±4.6% (group L) vs. 22.4±3.3% (group S); ventilation time, 5.1±3.1 hours (group L) vs. 10.4±14.9 hours (group S); dopamine dose at the end of the operation, 4.3±1.9 μg/kg/min (group L) vs. 5.5±2.2 μg/kg/min (group S); perioperative fluid balance, 1,933±663 g (group L) vs. 2,378±794 g (group S); intensive care unit (ICU) stay, 2.9±1.1 days (group L) vs. 4.5±2.0 days (group S); and

**Table 2. Patients'characteristics**

| | Group L | Group S | p value |
|---|---|---|---|
| Age (years) | 69±7.7 | 61±12 | NS |
| Male/female | 36/11 | 66/20 | NS |
| Number of diseased coronary arteries | 2.5±0.74 | 2.7±0.56 | NS |
| Preoperative ejection fraction (%) | 65.8±12.7 | 64.2±14.0 | NS |
| Concomitant disease | | | |
| Diabetes mellitus | 18 (38.3%) | 28 (32.6%) | NS |
| Old myocardial infarction | 16 (34.0%) | 29 (33.7%) | NS |
| Hypertension | 19 (40.4%) | 44 (51.2%) | NS |

**Table 3. Intraoperative and postoperative data**

| | Group L | Group S | p value |
|---|---|---|---|
| Operation time (min) | 303±45 | 315±74 | NS |
| CPB time (min) | 113±31 | 123±38 | NS |
| AXC time (min) | 69±25 | 79±31 | NS |
| The number of distal anastomoses | 3.1±0.95 | 3.2±1.1 | NS |
| The number of conduits | 2.4±0.73 | 2.5±0.59 | NS |
| Packed red blood cells (U) | 0.88±1.4 | 2.1±2.5 | 0.023 |
| Blood loss in 24 hr (mL) | 439±242 | 599±409 | 0.037 |
| Intraoperative lowest hematocrit (%) | 28.7±4.6 | 22.4±3.3 | <0.01 |
| Ventilation time (hours) | 5.1±3.1 | 10.4±14.9 | <0.01 |
| Weaning time (min) | 22.8±8.4 | 26.2±8.2 | 0.047 |
| Dopamine dose (μg/kg/min) | 4.3±1.9 | 5.5±2.2 | <0.01 |
| Fluid balance (g) | 1,933±663 | 2,378±794 | 0.041 |
| $PaO_2/FiO_2$ ratio | 297±75 | 304±188 | NS |
| Maximum CK-MB | 27.7±10.6 | 24.4±19.9 | NS |
| ICU stay (days) | 2.9±1.1 | 4.5±2 | <0.01 |

NS: no significant difference, CPB: cardiopulmonary bypass, AXC: aortic cross-clamp, CK-MB: creatine kinase-myocardial band, ICU: intensive care unit.

weaning time from CPB, 22.8±8.4 minutes (group L) vs. 26.2±8.2 minutes (group S). No significant differences were noted between the two groups in the pulmonary function ratio ($PaO_2/FiO_2$) measured on postoperative admission to the ICU and the postoperative maximum creatine kinase-myocardial band (CK-MB) value (Table 3).

## Discussion

Compared to standard prime volume open CPB, LPVP reduced the number of transfusions, blood loss and hemodilution. We also found that the patients recovered earlier with the use of LPVP.

LPVP uses a low prime volume and is primed with antegrade autologous blood. Therefore, theoretically, the hemodilution rate is zero, equivalent to autologous blood priming. We were able to keep the hematocrit high during the operation. CABG using LPVP with a centrifugal pump and an artificial lung (the Jostra MECC® system, Jostra AG, Hirrlingen, Germany) has been reported to be less invasive than using standard prime volume open CPB with a roller pump and an artificial lung.[13] The LPVP circuit (Fig. 1) differs from the Jostra MECC® system in the use of a soft reservoir and in the connection of the vent circuit to the blood removal circuit. By installing this soft reservoir, we drained the blood into the soft reservoir. Therefore, we could control the heart size freely and, thus, more easily control the visual field of the target bypass area. When we used LPVP, we needed to prevent volume overload in order to take advantage of the LPVP. We used warm blood cardioplegia as has been described by Calafiore et al.[12] and Hirose et al.[14] They reported that warm blood cardioplegia results in smaller volume changes, reduced postoperative use of catecholamines, and lower CK-MB values than cold crystalloid cardioplegia. Cormack et al.[15] reported that hospital mortality decreases when low hematocrit and renal complications are prevented.

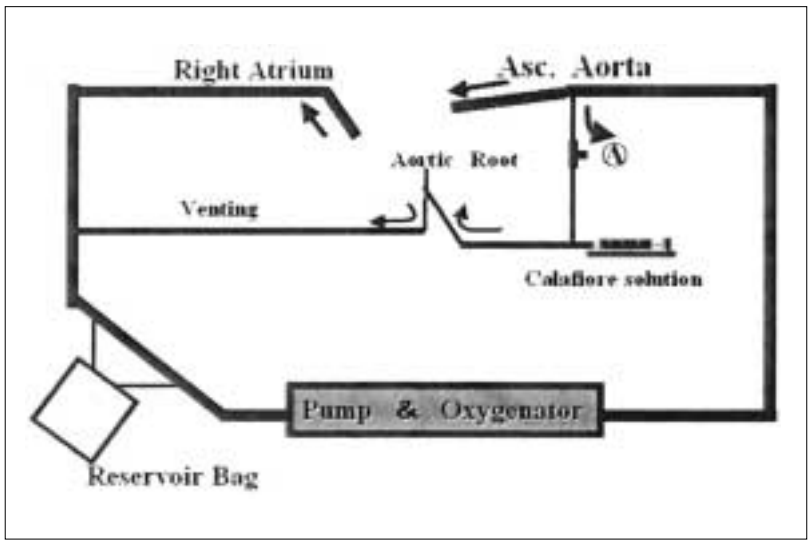


**Fig. 1.** Schema of the circuit we improved.
The tube size (I.D.) of this circuit is 3/8 inches. We use an arterial infusion cannula (7.0 mm I.D.) and 27-Fr venous cannula (two stages). A needle vent is placed in the aortic root and is connected to the vent circuit and the cardioplegic solution circuit. The soft reservoir bag is connected to the middle of the blood removal circuit. Maximum pump flow is 7.0 L/min. Before starting LPVP, we drain the priming solution through Ⓐ.

The LPVP circuit was heparin-coated. Examining our data, we hypothesized that the low dose of heparin helped prevent prolonged postoperative bleeding. However, Weiss et al. reported that postoperative drainage from chest tubes is not related to intraoperative heparin doses.[11] Metz and Keats reported that there is no tendency for patients with lower ACT to bleed more easily than patients with high ACT, and that the bleeding is not dependent on the heparin dose.[16]

To assess respiratory status, we examined the intubation time (ventilation time) and pulmonary function ($PaO_2/FiO_2$ ratio) on admission to the ICU. There was no statistical difference between the two groups in the $PaO_2/FiO_2$ ratio, but the difference in intubation time was statistically significant. Intraoperative volume overload may result in pulmonary edema. There was a significant difference in the intraoperative fluid balance. With cold crystalloid cardioplegia, the one-time infusion volume was approximately 1,000 mL, whereas with warm blood cardioplegia, it was only approximately 5 mL. This large difference in volumes resulted in a minimal change in the intraoperative hematocrit and in the quantity of packed red blood cells that were transfused. In the present study, there was an approximately 400 mL difference in the average fluid balance between group L and group S. The significant difference in intubation times that were observed indicate that early extubation was possible with the use of LPVP.

Based on the data, we found that the recovery from cardiac arrest after using the LPVP circuit was smoother than that after the use of the standard prime volume open CPB circuit. As well, myocardial protection in LPVP was similar to standard prime volume open CPB. The dose of dopamine required at the end of surgery with the LPVP circuit was statistically less than that required after standard prime volume open CPB. Weaning time was measured from aortic cross-clamp removal to CPB stop. After postoperative systemic circulating blood volume was adjusted, the radial artery systolic pressure was maintained at 100 to 120 mmHg. Operative CK-MB values in patients receiving warm blood cardioplegia are significantly lower than those in patients receiving cold crystalloid cardioplegia. Furthermore, intermittent warm blood cardioplegia causes little myocardial cell injury and has little influence on organ function post-CPB performed at a normal temperature, as was reported by Jaquet et al.[17] They also reported that the value of CK-MB in patients receiving intermittent antegrade warm blood cardioplegia was lower than in patients receiving cold crystalloid cardioplegia. However, in the present study we found no significant difference in maximum postoperative CK-MB values between the two groups.

In conclusion, compared to standard prime volume open CPB, we believe that LPVP is a very useful CPB approach, because the use of the LPVP circuit results in fewer adverse operative effects and earlier patient recovery. Further investigation with a large number of patients is warranted, and such investigation should include an assessment of molecular biological inflammatory mediators such as interleukin-6, TNF-alpha and others. Such a continued effort is required so as to improve the methods and tools used with CPB so as to reduce the deleterious effects of CPB.

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