Artificial
Organs

Five-Year Experience With Mini-Volume Priming in Infants ≤5 kg: Safety of Significantly Smaller Transfusion Volumes

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doi:10.1111/aor.12241

Received May 2013; revised September 2013.

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Presented in part at the 9th International Conference on Pediatric Mechanical Circulatory Support Systems and Pediatric Cardiopulmonary Perfusion, held May 8–11, 2013 in Hershey, PA, USA.

Abstract: Reducing the cardiopulmonary bypass (CPB) priming volume in congenital cardiac surgery is important because it is associated with fewer transfusions. This retrospective study was designed to compare safety and transfusion volumes between the mini-volume priming (MP) and conventional priming (CP) methods. Between 2007 and 2012, congenital heart surgery using CPB was performed on 480 infants (≤5 kg): the MP method was used in 331 infants (MP group, 69.0%), and the CP method was used in 149 infants (CP group, 31.0%). In the MP group, narrow-caliber (3/16″) tubing was used, and the pump heads were vertically aligned to shorten the tubing lengths. The smallest possible oxygenators and hemofilters were used, and vacuum drainage was applied. Ultrafiltration was vigorously applied during CPB to avoid excessive hemodilution. The mean age and body weight of the patients were 48 ± 41 (0–306) days and 3.8 ± 0.8 (1.3–5.0) kg, respectively. The total priming and transfusion volumes during CPB were lower in the MP group than in the CP group (141 ± 24 mL vs. 292 ± 50 mL, $P < 0.001$, and 82 ± 40 mL vs. 162 ± 82 mL, $P < 0.001$, respectively). In the MP group, the smallest priming volume was 110 mL. However, there was no significant difference in the lowest hematocrit level during CPB between the two groups (22 ± 3% vs. 22 ± 3%, $P = 0.724$). The incidence of postoperative neurological complications was not significantly different between the MP and CP groups (1.8% vs. 2.7%, $P = 0.509$). After adjustment for the Risk Adjustment for Congenital Heart Surgery category, body surface area, and age, MP was not an independent risk factor of postoperative neurological complications or early mortality ($P = 0.213$ and $P = 0.467$, respectively). The MP method reduced the priming volume to approximately 140 mL without increasing the risk of morbidity or mortality in infants ≤5 kg. The total transfusion volume during CPB was reduced by 50% without compromising hematocrit levels. We recommend the use of mini-volume priming, which is a safe and effective method for reducing transfusion volumes. **Key Words:** Cardiopulmonary bypass—Congenital heart defects—Equipment safety—Blood transfusion—Priming volume—Pediatric.

Most patients who undergo surgery for congenital heart defects require cardiopulmonary bypass (CPB) support while the surgeons open their cardiac chambers or major vessels and reconstruct the internal structures. The CPB circuit is usually primed with a mixture of fluids to prevent the abrupt intravascular volume depletion that can be caused by the elongation of the circulatory pathway. In addition, mixing packed red blood cell (pRBC) components with the priming fluid is often necessary to prevent excessive hemodilution. In adult cardiac surgery, a relatively small-volume pRBC transfusion will suffice for maintaining adequate levels of hematocrit (HCT) during CPB. However, in neonates and infants, the volume of the total priming fluid represents 200–300% of their total blood volume. Consequently, the volume of pRBC that is initially mixed with the priming fluid frequently exceeds 50% of the total blood volume.

The adverse effects and potential risks of transfusion have been well documented for decades. An excessive transfusion volume can result in systemic inflammatory response syndrome and increase the risk of infection. Moreover, the immune activation that follows CPB will have synergistic effects with transfusion. Thus, many efforts have been made to reduce the transfusion volume during CPB (1–3). Since 2007, we have adopted several techniques that were introduced in the literature, and we have reported our initial outcomes (4).

With more than 5 years of experience in priming volume minimization methods, we compared the safety and efficacy of mini-volume priming (MP) methods with those of conventional priming (CP) methods.

PATIENTS AND METHODS

Patients

The institutional review board of Seoul National University Children's Hospital approved this research, and a waiver of consent was obtained (IRB No. H-1301-094-458). From July 2007 to December 2012, a total of 480 neonates and infants weighing 5 kg or less underwent initial correctional surgery for congenital heart defects. For CPB, either the Jostra HL30 machine (Jostra, Hirrlingen, Germany) or the Sorin COBE Stroker HLM machine (Sorin, Milan, Italy) was used. Because MP methods could only be applied with the vertically aligned heart–lung machines, the priming methods were determined primarily based on the availability of the Jostra HL30 machine (Fig. 1B). The surgeons decided on the CPB priming methods after discussing the options with perfusionists. The Jostra HL30 was occasionally used for CP methods at the surgeons' discretion. Medical records and CPB charts were retrospectively reviewed, and the baseline patient characteristics are presented in Table 1.

Inclusion criteria

1 Neonates and infants (≤5 kg in body weight) who underwent surgery for congenital heart defects with CPB support from July 2007 to December 2012 in Seoul National University Children's Hospital;
2 Operations conducted by four pediatric cardiac surgeons with more than 5 years of experience as independent operators.

Exclusion criteria

1 Previous history of chest surgery, including Blalock–Taussig shunt without CPB support;
2 Patients with severe systemic congenital anomalies, such as chromosome defects.

Priming methods

The differences between the MP and CP methods are presented in Table 2 and Fig. 1A. The major modifications in the MP methods can be summarized as follows:

1 Oxygenators and hemofilters with small priming volumes were used (Table 3);
2 Pump heads were vertically aligned to shorten the circuit lengths;
3 Venous reservoirs were located at the same height as the patient's heart to enable vacuum-driven venous drainage;
4 Venous circuit tubing with a diameter of 3/16″ was used.

Circuit tubing of 3/16″ and 1/4″ diameters have 1.78 and 3.17 mL of filling volume per 10-cm length, respectively (3). The heart–lung machine was located very close to the operative field. Due to the vertical alignment setup, the arterial pump could be placed next to the oxygenator. During the study period, arterial line filters were not included in the circuit, and only roller pumps were used in both groups (3). A sodium bicarbonate ($NaHCO_3$) solution of 5 + 1 mEg/kg was mixed with the priming fluid. The volume of pRBC used for priming fluid was calculated based on the initial HCT level that was obtained through point-of-care arterial blood gas analysis (ABGA) before skin incision, as follows:

$$\begin{aligned}&\text{Initially mixed pRBC volume}\\&= [\{(\text{body weight (kg)} \times 80) + \text{priming volume}\\&\quad \text{except pRBC (mL)}\} \times \text{target HCT (30\%)}]\\&\quad - \{(\text{body weight (kg)} \times 80) \times \text{initial HCT (\%)}\}\end{aligned}$$

Conduct of CPB support

In both groups, alpha stat strategies were used. However, the airflow to the oxygenator was adjusted in accordance with the cerebral oximeter values. Initial dose of heparin for bypass was 300 units/kg. Activated clotting time was maintained above 480 s during bypass. The initial venous reservoir volume was 15 mL, and the perfusionists on duty took care of maintaining minimum reservoir volume. No low level sensor was used. Cardioplegia was administered every 30–40 min. Point-of-care ABGA was obtained during the following time points:

1 After the initiation of full CPB support
2 Immediately after ultrafiltration following the aortic cross-clamping and cardioplegia infusion

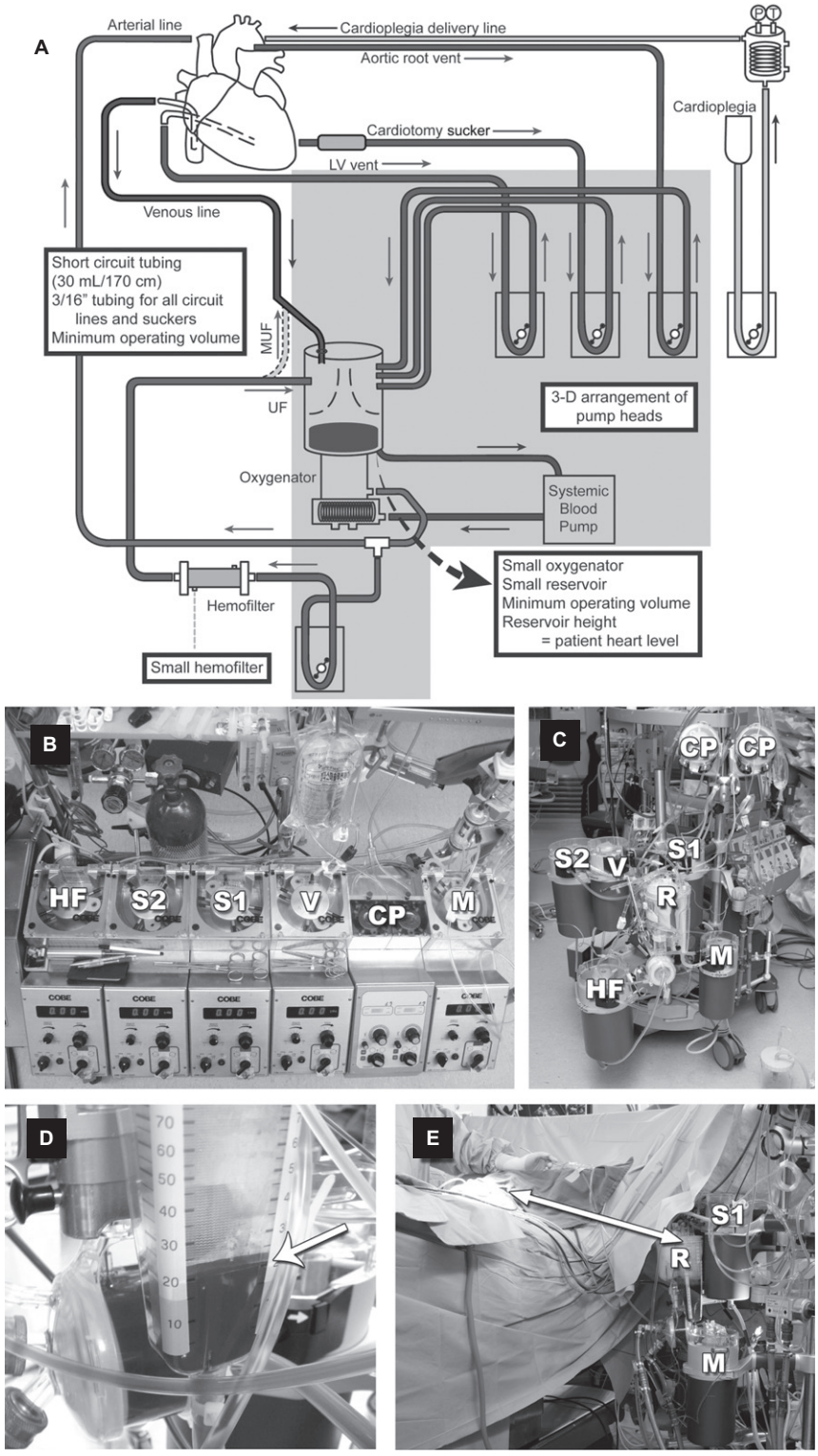

FIG. 1. (A) Summary of mini-volume priming methods is shown. (B) Horizontally aligned heart–lung machine (Sorin COBE Stroker HLM). The heart–lung machine with horizontal alignment is not suitable for circuit length minimization. (C) Vertically aligned heart–lung machine (Jostra HL30). Pump heads were three-dimensionally aligned to shorten the tubing lengths. (D) The minimum operating venous reservoir volume was maintained (arrow). (E) The reservoir was located at the same level as the patient's heart (arrow). UF, modified ultrafiltration; MUF, modified ultrafiltration; CP, cardioplegia head; S1–2, cardiotomy sucker heads; V, vent head; M, main (arterial) pump; R, reservoir; HF, pump head for the hemofilter.

TABLE 1. *Baseline patient characteristics*

	Mini-volume priming group (n = 331)	Conventional priming group (n = 149)	P value	Total (n = 480)
Age (days), mean (range)	44.0 ± 38.8	57.7 ± 45.4	0.001	48.4 ± 41.4 (0–306)
Weight (kg), mean (range)	3.7 ± 0.8	4.1 ± 0.7	<0.001	3.8 ± 0.8 (1.3–5.0)
BSA (m^2), mean (range)	0.22 ± 0.04	0.25 ± 0.03	<0.001	0.23 ± 0.04 (0.11–0.37)
RACHS category, n (%)			<0.001	
1	4 (1.2)	5 (3.4)		9 (1.9)
2	146 (44.1)	104 (69.8)		250 (2.0)
3	68 (20.5)	30 (20.1)		98 (20.4)
4	104 (31.4)	10 (6.7)		114 (23.8)
5	0 (0.0)	0 (0.0)		0 (0.0)
6	9 (2.7)	0 (0.0)		9 (1.9)
Preoperative neurological complications, n (%)	11 (3.3)	1 (0.7)	0.115	12 (2.5)

3 Every 30–60 min during the main surgical procedure
4 Immediately after declamping the aorta
5 Once or twice during CPB weaning

The mean number of ABGAs performed during CPB was 3.9 ± 1.4. Perfusionists added pRBC to the CPB circuit when necessary to maintain a HCT above 20% (5). Target HCT value was 28% at the point-of-care test ABGA. Ultrafiltration was frequently applied to avoid excessive hemodilution during CPB.

Operative risk and outcome evaluation

Due to the nonrandomized design of this study, we used Risk Adjustment for Congenital Heart Surgery (RACHS-1) categories as a variable for the purposes of statistical adjustment (Table 1) (6). The primary end points were operative mortality (within 30 days) from any cause and postoperative neurological complications (newly developed neurological manifestations confirmed by pediatric neurologists). Secondary end points were the total priming volume, initially mixed pRBC volume, pRBC volume added during CPB support, and lowest HCT level obtained during CPB support.

Statistical analysis

Statistical analysis was performed with SPSS 18.0 software (SPSS, Inc., Chicago, IL, USA). Student's t-tests or Mann–Whitney U-tests were used for con-

TABLE 2. *Composition of cardiopulmonary bypass system*

		Mini-volume priming methods (n = 331)		Conventional priming methods (n = 149)	
Heart–lung machine		Jostra HL30		Sorin COBE Stroker HLM/Jostra HL30	
Oxygenator		D-901	17 (5.1%)	D-901	77 (51.7%)
		Minimax Plus	1 (0.3%)	D-902	1 (0.7%)
		SAFE-micro	13 (3.9%)	SAFE-micro	63 (42.3%)
		SAFE-mini	1 (0.3%)	SAFE-mini	1 (0.7%)
		RX-05	298 (90.0%)	RX-05	7 (4.7%)
		Quadrox neonate	1 (0.3%)		
Height of reservoir		Same as heart level		80 cm below heart level	
Hemofilter		DHF-02	61 (18.4%)	DHF-02	51 (34.2%)
		FH22H	102 (30.8%)	FH22H	59 (39.6%)
		Junior	14 (4.2%)	Junior	1 (0.7%)
		HPH400	3 (0.9%)	HPH400	1 (0.7%)
		D150	151 (45.6%)	D150	37 (24.8%)
Vacuum drain		Vacuum drainage only (–20 to –40 mm Hg)		Gravity drainage	
Circuit tubing size	Arterial line	3/16″		3/16″	
	Venous line	Mainly 3/16″ and 1/4″		1/4″	
	Cardiotomy	3/16″		3/16″	
Arterial line filter		Not used			
Bubble detector		Not used			
Cardioplegic solution		Basically crystalloid, mixed with small amount (<20 mL) of whole blood			
Ultrafiltration		Applied			
Modified ultrafiltration		Applied			
Content of priming solution		Plasma solution Voluven 20% albumin $NaHCO_3$ Packed red blood cells			

TABLE 3. *Priming volumes of oxygenators and hemofilters*

	Manufacturer	Model name	Priming volume (mL)	Maximal flow rate (L/min)	Fiber surface area (m^2)
Oxygenator	Terumo	RX-05	43	1500	0.5
	Sorin	D-901	60	800	0.34
		D-902	105	2300	0.64
	Medtronic	Minimax Plus	149	2300	0.8
	Maquet	SAFE-micro	46	800	0.33
		SAFE-mini	90	2300	0.66
		Quadrox neonate	38	1500	0.38
Hemofilter	Sorin	DHF-02	30	—	0.25
	Gambro	FH22H	12	—	0.2
	Minntech	Minntech Junior	8	—	0.09
		HPH400	34	—	0.3
	Medica	D150	19	—	0.25

tinuous variables, and χ^2 or Fisher's exact tests were used for categorical variables. Multivariable logistic regression, adjusted for age, body surface area (BSA), and RACHS category, was used to compare the 30-day mortality and postoperative neurological complications between the two groups. Continuous variables are presented as means ± SD, and ranges are also presented in parentheses when necessary. Categorical variables are expressed as numbers or frequencies of occurrence. A *P* value of less than 0.05 was considered statistically significant.

RESULTS

Baseline patient characteristics are presented in Table 1. Mini-volume priming methods were applied in 331 cases (69.0%, MP group), and CP methods were applied in 149 cases (31.0%, CP group). Age, body weight, BSA, and RACHS category were significantly different between the groups. In contrast, the prevalence of preoperative neurological problems was not significantly different between the groups.

Parameters related to CPB are presented in Table 4. The duration of CPB, the number of total circulatory arrest (TCA) cases, and the number of regional perfusion cases were significantly different between the groups. In the priming fluid, the amount of every component in the MP group was significantly less than that in the CP group. The smallest priming fluid volume in the MP group was 110 mL. In

TABLE 4. *Cardiopulmonary bypass parameters and postoperative outcomes*

	Mini-volume priming group (n = 331)	Conventional priming group (n = 149)	*P* value
CPB data			
CPB time (min)	151 ± 60	133 ± 68	0.003
ACC time (min)	77 ± 45	71 ± 41	0.181
TCA applied cases	2 (0.6%)	9 (6.0%)	0.001
TCA time (min)	29 ± 27	37 ± 17	0.600*
Regional perfusion cases	51 (15.4%)	5 (3.4%)	<0.001
Regional perfusion time (min)	27 ± 12	26 ± 12	0.579*
Lowest rectal temperature (°C)	26.1 ± 2.8	26.5 ± 3.6	0.976
Hematocrit at CPB termination (%)	26 ± 3	26 ± 4	0.878
Total urine output during CPB (mL)	106 ± 144	108 ± 149	0.901
Hemofiltration during CPB (mL)	429 ± 231	407 ± 189	0.263
Modified ultrafiltration (mL)	168 ± 96	174 ± 111	0.524
CPB priming			
Plasma solution (mL)	30.6 ± 18.1	78.1 ± 39.1	<0.001
Voluven (mL)	28.2 ± 27.4	57.0 ± 36.8	<0.001
20% Albumin (mL)	48.8 ± 24.8	62.4 ± 24.6	<0.001
pRBC (mL)	33.6 ± 17.2	94.6 ± 42.3	<0.001
Total priming volume (mL)	141.3 ± 23.8	292.1 ± 49.5	<0.001
pRBC added during CPB (mL)	48.2 ± 33.6	69.2 ± 63.3	<0.001
Lowest hematocrit during CPB (%)	21.9 ± 3.1	21.8 ± 3.0	0.724
Total transfusions via CPB (mL)	81.6 ± 39.6	162.3 ± 82.3	<0.001
Postoperative neurological complications	6 (1.8%)	4 (2.7%)	0.509
Operative mortality (≤30 days)	21 (6.3%)	2 (1.3%)	0.019

*Mann–Whitney *U*-test.
ACC, aortic cross-clamp; TCA, total circulatory arrest.

particular, the volume of initially mixed pRBC in the MP group was approximately 36% of that in the CP group. The volume of total transfusion by CPB was significantly less in the MP group. Nevertheless, there was no significant difference in the lowest hematocrit levels between the groups. Additionally, there were no bypass-related accidents in the study population. During the study period, the priming volume in the MP group remained constant (Fig. 2B).

The incidence of postoperative neurological complications was not significantly different between the groups, but the MP group showed significantly higher operative mortality rates (≤30 days). The information about operative mortality is summarized in Table 5. Considering the difference in age, BSA, and RACHS category distribution between the groups, we performed two multivariable logistic regression analyses to compare the incidence of postoperative neurological complications and operative mortality (Table 6, Fig. 2A). Age and BSA were independent predictors of postoperative neurological complications ($P = 0.004$, OR 1.02, 95% CI 1.01–1.03; $P = 0.031$, OR 0.00, 95% CI 0.00–0.13, respectively). Only the RACHS category was an independent predictor of operative mortality ($P < 0.001$, OR 2.23, 95% CI 1.42–3.50). In contrast, the application of MP methods was not a significant risk factor for postoperative neurological complications or operative mortality ($P = 0.213$ and $P = 0.467$, respectively).

DISCUSSION

A vertically aligned heart–lung machine was first introduced into our hospital in 2007. Because the vertically aligned heart–lung machine enabled our perfusionists to organize the system in a more customized manner, we began to apply MP methods in congenital cardiac surgery at that point. With our accumulated experience, we are convinced that MP methods are safe and effective. In this study, we retrospectively evaluated the safety and efficacy of MP methods. Our main interest was whether we could significantly reduce the number of transfusions without compromising safety.

Reducing the number of or avoiding transfusions is one of the main concerns of cardiac surgery. Thus, there have been reports about reducing the priming volume in congenital cardiac surgery. Several of these reports focused on priming without transfusion or even congenital cardiac surgery without transfusion (7–9). However, in most cases, the sample size was insufficient, or the lowest hematocrit level was not presented (10,11). Without the lowest hematocrit during CPB being stated, it cannot be known whether the safety of patients was compromised. In the reports on nonhemic congenital cardiac surgeries, the surgeons and perfusionists frequently accepted the risk of excessive hemodilution because the patients and families were Jehovah's Witnesses. In such cases, the surgeon should be extraordinarily cautious to minimize bleeding. These potentially dangerous attempts remain experimental and cannot be considered for everyday use. Jonas et al. reported that excessive hemodilution during CPB can result in neurological deterioration after congenital cardiac surgery (5). Because the safety of the patient is the highest priority, we reduced the priming volume, but we did not accept extremely low hematocrit levels during CPB.

There were several factors that contributed to the reduction of priming volume in our study. First, we gave preference to oxygenators and hemofilters with small priming volumes. Second, small-diameter circuit tubing was used, and heart–lung machines were positioned near the operative field. Roller pump heads were three-dimensionally aligned so that the distance between the arterial pump and the oxygenator could be minimized. Importantly, the venous reservoir was located at the same height as the patient's heart, draining venous blood with vacuum assistance (12). Merkle et al. wrote that they could not position the venous reservoir at the same height as the patient's heart due to possible vacuum failure (10). However, we could depend solely on vacuum drainage because we have not experienced vacuum failure over the last decade. The arterial line filter was excluded from the circuit because we do not believe that it is essential; however, pediatric cardiac surgeons do not uniformly agree on the necessity of the arterial line filter (3). The minimum reservoir volume was maintained at approximately 15–25 mL, but we experienced no problem without a low level detector. Nevertheless, this study was not intended to show the safety of CPB without an arterial line filter or low level detector. We want the readers to understand that arterial line filter and low level detector are valuable options for CPB safety. During CPB, we frequently applied ultrafiltration to concentrate the circuit fluid. We believe that vigorous ultrafiltration is essential for the reduction of transfusion during CPB (13).

As a result, the volume of initially mixed pRBC in the MP group was approximately 36% of that in the CP group. Additionally, the volume of the total transfusion via CPB was reduced by 50% in the MP group. Nevertheless, the lowest hematocrit level was almost the same in the two groups. This result demonstrates our strict adherence to patient safety. Additionally,

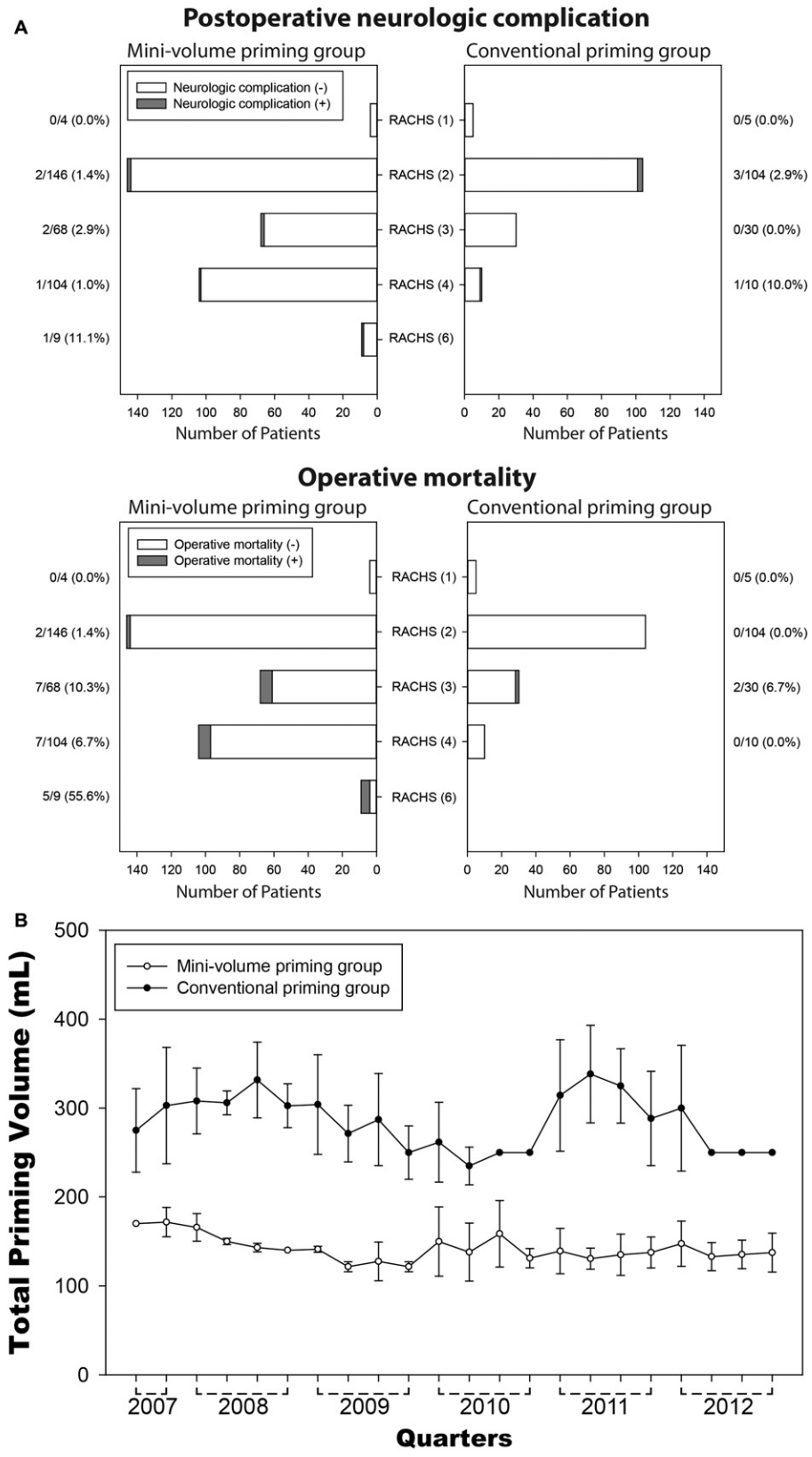

FIG. 2 (A) Postoperative neurological complications and operative mortality, stratified by RACHS category. (B) Change in priming volumes during the study period. Error bars indicate standard deviations.

TABLE 5. *Summary of operative mortality*

	Number	Diagnosis/operation	Cause of death
Conventional priming group (n = 2)	CP#1	TGA-VSD/arterial switch operation	POD #9, septic shock
	CP#2	TGA-VSD/arterial switch operation	POD #2, progression of heart failure
Mini-volume priming group (n = 21)	MP#1	HLHS/Norwood-type operation	POD #1, progression of heart failure
	MP#2	HLHS/Norwood-type operation	POD #3, progression of heart failure
	MP#3	HLHS/Norwood-type operation	POD #29, progression of heart failure
	MP#4	HLHS/Norwood-type operation	POD #8, progression of heart failure
	MP#5	HLHS/Norwood-type operation	POD #7, progression of heart failure
	MP#6	PA-IVS, TR, MR, large PDA/mitral valve repair, BT shunt	POD #30, neonatal sepsis
	MP#7	Complete AVSD, Ebstein anomaly (type C), severe MR, severe LV enlargement and poor systolic function, hypoplastic and thin RV/(emergency operation) RA reduction plasty, PAB, repair of atrioventricular valve	POD #15, progression of heart failure
	MP#8	PA-VSD/total correction	POD #30, RV dysfunction
	MP#9	PA-VSD/BT shunt, PDA division	POD #1, shunt occlusion POD #10, hypoxic brain damage
	MP#10	PA-VSD, severe LV dysfunction/BT shunt, PDA division, pulmonary artery angioplasty	POD #1, progression of heart failure
	MP#11	TGA-IVS, ASD/arterial switch operation, ASD patch closure, PDA division	POD #7, neonatal sepsis
	MP#12	Multiple VSD (large PM and apical muscular)/VSD patch closure	POD #1, sudden cardiac arrest, ECMO support POD #19 progression of heart failure
	MP#13	PA-VSD/BT shunt, PDA division, pulmonary artery angioplasty	POD #1, sudden cardiac arrest
	MP#14	PA-IVS, ASD, severe TR, PDA, tracheal and bronchus stenosis/palliative RVOT widening, pulmonary valvectomy, RV infundibular muscle resection, ASD patch closure with fenestration, PDA ligation, RA reduction plasty	POD #7, progression of heart failure
	MP#15	Right isomerism, unbalanced AVSD, TAPVR (supracardiac, obstructive), severe AVVR, PS, PDA, ventricular dysfunction/TAPVR repair, PDA division, PAB, ECMO support	POD #9, progression of heart failure
	MP#16	DCMP, severe MR/mitral valve repair, PFO primary closure	POD #16, progression of heart failure, sepsis
	MP#17	TGA with unusual coronary artery, PM VSD, ASD, PDA/arterial switch operation, VSD patch closure, ASD patch closure, PDA division	POD #1, progression of heart failure
	MP#18	Right isomerism, RV type single ventricle with pulmonary atresia, TAPVR (infracardiac, obstructive), PDA/TAPVR repair, BT shunt, PDA division, ECMO support	POD #11, progression of heart failure
	MP#19	Premature birth (1.2 kg, 29 + 3 weeks), PM VSD, ASD, PDA, severe pulmonary hypertension/VSD patch closure, ASD primary closure, PDA ligation	POD #19, progression of heart failure
	MP#20	DORV (Fallot type), subaortic VSD, valvular PS, ASD, PDA, severe coarctation of aorta with diffuse aorta wall thickening, diffuse arch vessel hypoplasia, ascending aorta aneurysm/coartoplasty (extended end-to-end anastomosis), ascending aorta aneurysm resection and primary closure, PDA division	POD #7, progression of heart failure
	MP#21	Coarctation of aorta, diffuse arch hypoplasia, large VSD (mimicking HLHS)/coartoplasty (extended end-to-end anastomosis), PAB, PFO primary closure, PDA division, ECMO support	POD #23, progression of heart failure

POD, postoperative day; TGA, transposition of great arteries; VSD, ventricular septal defect; HLHS, hypoplastic left heart syndrome; PA, pulmonary atresia; IVS, intact ventricular septum; ASD, atrial septal defect; TR, tricuspid regurgitation; MR, mitral regurgitation; PDA, patent ductus arteriosus; BT, Blalock–Taussig; AVSD, atrioventricular septal defect; LV, left ventricle; RV, right ventricle; RA, right atrium; PAB, pulmonary artery banding; AVVR, atrioventricular valve regurgitation; PS, pulmonary stenosis; PFO, patent foramen ovale; TAPVR, total anomalous pulmonary venous return; ECMO, extracorporeal membrane oxygenation; DORV, double outlet right ventricle.

TABLE 6. *Multivariable analyses of primary end points*

	Variable	*P* value	OR (95% CI)
Postoperative neurological complications	Age*	0.004	1.02 (1.01–1.03)
	BSA*	0.031	0.00 (0.00–0.13)
	RACHS category	0.381	1.37 (0.68–2.74)
	Mini-volume priming	0.213	2.59 (0.58–11.6)
Operative mortality (≤30 days)	Age	0.566	1.00 (0.98–1.01)
	BSA	0.097	0.00 (0.00–9.02)
	RACHS category*	<0.001	2.23 (1.42–3.50)
	Mini-volume priming	0.467	0.56 (0.12–2.66)

*Independent predictor.

there was almost no learning curve; thus, the beginning perfusionists could easily learn the MP methods under the supervision of more experienced perfusionists (Fig. 2B).

Despite the many previous reports about priming volume minimization, surgeons and perfusionists have been reluctant to apply MP methods because they are not convinced of their safety. However, from a safety perspective, no CPB-related accidents occurred in either group. The multivariable analysis revealed that the application of MP methods was not a significant risk factor for the incidence of postoperative neurological complications or operative mortality. We initially considered performing a propensity-score-matched analysis. However, the complexity and risk of congenital heart surgery, which is the most important variable, was too diverse. Even with RACHS categories, we were not certain that we could appropriately match the patients. The patients who were in the same RACHS category could have different comorbidities. We think that the patients in the mini-volume priming group had an obviously higher preoperative risk.

Even with these favorable results, there are several limitations to our study. Above all, this study did not follow a randomized controlled design, and the baseline patient characteristics were not identical between the groups. This was mainly because one of the four surgeons in our institute adopted MP methods first. Initially, the surgeon and experienced perfusionists took great caution to safely establish the MP methods. Recently, other surgeons at our institute began accepting the MP methods, as the perfusionists were accustomed to them and these methods did not increase the operative risk. Currently, the application of MP methods is one of our routine practices. Although this is not a randomized controlled study, we compared the outcomes in 480 (331 vs. 149) neonates and infants ≤5 kg with the use of multivariate analyses. In addition, transfusion could not be completely avoided, even with MP methods. However, we think that the need for some degree of transfusion is inevitable because we did not accept excessive hemodilution. Our CPB circuit composition is similar to those described in previous reports of nonhemic congenital cardiac surgery. Finally, we did not analyze the humoral aspects of the use of fewer transfusions. Based on this evidence that the application of MP methods does not compromise patient safety, however, further study of the benefits of MP methods is definitely warranted.

CONCLUSION

In congenital cardiac surgery for neonates and infants, we were able to significantly reduce the priming volume (mean 141 mL vs. 292 mL) with mini-volume priming methods, and the cardiopulmonary bypass-related transfusion volume was dramatically reduced (mean 82 mL vs. 162 mL). Additionally, there was no evidence that the application of MP methods is related to the increased risk of postoperative neurological complications or operative mortality. MP methods are easy, safe, and highly effective in reducing the number of transfusions. We hope that pediatric cardiac surgeons and perfusionists utilize these methods in their clinical practice.

Acknowledgment: Perfusionist Kyung-Hoon Lee contributed to the development of mini-volume priming methods.

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