The Effect of Modified Ultrafiltration Duration on Pulmonary Functions and Hemodynamics in Newborns and Infants Following Arterial Switch Operation*

Ayda Türköz, MD[1]; Ezgi Tunçay, MD[1]; Şule Turgut Balci, MD[1]; Meltem Güner Can, MD[1]; Dilek Altun, MD[1]; Rıza Türköz, MD[2]; Akif Ündar, PhD[3]

Objectives: Modified ultrafiltration is used to ameliorate the deleterious effects of cardiopulmonary bypass in pediatric cardiac surgery patients. The ideal duration of modified ultrafiltration has not been established yet. We investigated the effects of extended duration of modified ultrafiltration on pulmonary functions and hemodynamics in the early postoperative period in newborns and infants who had transposition of great arteries operations.

Design: Single-center prospective randomized study.

Setting: Pediatric cardiac surgery operating room and ICU.

Patients: Sixty newborns and infants who had been scheduled to undergo transposition of great arteries operation.

Interventions: None.

Measurements and Main Results: Modified ultrafiltration was applied to all patients following the termination of cardiopulmonary bypass (for 10, 15, and 20 min in groups 1, 2, and 3, respectively). Pulmonary compliance, gas exchange capacity, hemodynamic measurements, inotropic support, blood loss, transfusion requirements, hematocrit level, and duration of ventilatory support were measured after intubation, at termination of cardiopulmonary bypass, at the end of modified ultrafiltration, and in the 1st, 6th, 12th, and 24th hours after admission to ICU. The amount of fluid removed by modified ultrafiltration in groups 2 and 3 was larger than that of group 1 ($p < 0.01$). Systolic blood pressure was significantly increased at the end of modified ultrafiltration in group 3 compared to groups 1 and 2 ($p < 0.05$). Hematocrit levels were significantly increased at the end of modified ultrafiltration in groups 2 and 3 compared to group 1 ($p < 0.01$). Therefore, RBCs were transfused less after modified ultrafiltration in groups 2 and 3 compared to group 1 ($p < 0.05$). Static and dynamic compliance, oxygen index, and ventilation index had improved similarly in all three groups at the end of modified ultrafiltration ($p > 0.05$)

Conclusions: Modified ultrafiltration acutely improved pulmonary compliance and gas exchange in all groups. Increased hematocrit and blood pressure levels were also observed in the longer modified ultrafiltration group. However, extended duration of modified ultrafiltration did not have a significant impact on duration of intubation or the stay in ICU. (*Pediatr Crit Care Med* 2014; 15:600–607)

Key Words: arterial switch operation; modified ultrafiltration; newborns and infants; outcomes; pulmonary function

Cardiopulmonary bypass (CPB) affects the clinical outcome of patients by triggering an inflammatory response in the vital organs. Due to small body size, immature organ systems, and long duration of CPB, the inflammatory response becomes more severe in the neonates and infants (1, 2). The decrease of mortality and morbidity in neonates and infants may be associated with reduced multiple organ dysfunctions caused by CPB. Among the new pharmacological and technical strategies of the last decade, modified ultrafiltration (MUF) is an alternative method used in the reduction of nonphysiological response caused by CPB (3–10). MUF improves early-stage symptoms (pulmonary functions and hemodynamics) in patients by concentrating the patient's blood and by reducing myocardial edema, improving pulmonary compliance and gas exchange. It decreases hemorrhage and the need for blood transfusion (3–5, 11, 12). Studies have demonstrated that the MUF technique in neonates and infants during the early stage of post-CBP period not only improves pulmonary function but also ensures a permanent effect in later stages by reducing the mechanical ventilation time and the length of stay in the ICU (13, 14).

***See also p. 670.**

[1]Department of Anesthesiology, Baskent University İstanbul Teaching and Medical Research Center, İstanbul, Turkey.

[2]Department of Cardiovascular Surgery, Baskent University İstanbul Teaching and Medical Research Center, İstanbul, Turkey.

[3]Department of Pediatrics, Surgery and Bioengineering, Penn State Hershey College of Medicine, Pediatric Cardiovascular Research Center, Hershey, PA.

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For information regarding this article, E-mail: aydat@baskent-ist.edu.tr

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MUF termination time varies among the clinics, which could make a difference in its effectiveness (4, 7–9). In general, most clinics terminate the MUF procedures either when the CPB circuit is emptied or when the hematocrit level reaches a reasonable level or after a fixed time period, usually 10–20 minutes (3, 4).

In the following study, we investigated the effects of the length of MUF (10, 15, or 20 min) on pulmonary functions and hemodynamics in the early postoperative period. This was performed on newborn and infant patients who underwent operations for transposition of great arteries (TGA).

MATERIALS AND METHODS

Patients

Sixty prospective randomized neonates and infants underwent arterial switch operation for TGA. They were enrolled in the study with the approval of the Ethical Board of the Baskent University, Faculty of Medicine. Informed consent and permissions were obtained from the families of each patient. Infants with a preexisting coagulation disorder, evidence of sepsis, or preexisting pulmonary and renal disease were excluded from the study. Sample size was calculated based on data of the study by Katoni et al (3); 14 cases were required to detect differences in Pao_2/Fio_2, that is, 88, SD 80, power 80%, β 0.20, and α 0.05.

The study was conducted with 20 patients in each group to ensure a proper number in the final result. Treatment assignment was chosen from envelopes. The age, preoperative body weight, gender, cardiac anomaly, and any associated congenital anomalies of the patients were recorded.

Anesthetic Technique

The patients were administered 0.1 mg/kg midazolam, 1 mg/kg dexamethasone, 2–4 mg/kg thiopental IV, 0.6 mg/kg rocuronium IV, and 10 μg/kg fentanyl IV for induction after vascular access. To maintain anesthesia, IV infusions of midazolam 4 μg/kg/min and fentanyl 30–50 μg/kg/min were administered. All patients were monitored both noninvasively and invasively for arterial blood pressures. Five-channel electrocardiography, central venous pressure (CVP), peripheral (Spo_2) and cerebral oxygen saturation ($Scto_2$, FORE-SIGHT), depth of anesthesia (index of consciousness [IOC]) (15) (Morpheus Medical, Barcelona, Spain), oropharyngeal temperature, and hourly urine output were also monitored.

Operative Management

The operations were performed by the same surgeon (R.T.). Following a sternotomy, CPB was initiated using standard aortic and bicaval venous cannulation. The ductus arteriosus was divided and the left and right pulmonary arteries were mobilized as far as the hilar branches. The aorta was cross-clamped and blood cardioplegic arrest was induced. After the aortic cross-clamp was removed, neopulmonary anastomosis was completed. Left atrial and pulmonary artery pressure monitoring catheters and a peritoneal dialysis catheter were inserted.

CPB and Ultrafiltration

The CPB equipment consisted of roller pumps (Terumo, MI) and membrane oxygenators (Terumo). Pump prime solution (total 450 mL) comprised crystalloid solution (Isolyte-S), albumin 20% (100 mL), packed RBCs (to maintain hematocrit about 30% on bypass), sodium bicarbonate, calcium gluconate, mannitol, antibiotic, and heparin.

Pump flow was nonpulsatile and maintained at 150–200 mL/kg/min. Alpha-stat blood gas management was used throughout the procedures. Phentolamine mesylate was routinely administered to the pump circuit at initiation and warming periods of CPB. The body temperature was lowered to 26°C in all cases. Myocardial protection was obtained by infusion of antegrade minicardioplegia technique (16).

In all cases, we used a Gambro 6S 0.6 m^2 polyamide hemofilter (Gambro, Hechingen, Germany). Continuous ultrafiltration (CUF) was performed during rewarming after aortic cross-clamp period. MUF (arteriovenous) was carried out immediately after the completion of the bypass. Blood was drained from the aortic cannula and pumped through the ultrafiltrator. It was then returned to the right atrium via the cardioplegia line, which was attached to a venous cannula as an outflow from the ultrafiltrator. After CPB, group 1, group 2, and group 3 underwent MUF with a flow speed ranging between 30 and 50 mL/kg/min and negative pressure at approximately 30–50 mm Hg for 10, 15, and 20 minutes, respectively.

Postoperative ICU Period

All patients were connected to the Servo 300 respiratory system in the ICU. Intensivists were blinded to the patient's duration of ultrafiltration. The patients were ventilated at a tidal volume of 10 mL/kg and positive end-expiratory pressure (PEEP) 3–5 cm H_2O in the volume-controlled mode. The respiratory rate was set to achieve end-tidal CO_2 between 35 and 40 mm Hg. The sedation scale was set as (COMFORT scale) (17) less than 3 and morphine (10–30 μg/kg/hr) titrated with midazolam (0.03 mg/kg) were used to provide analgesia and sedation during the stay in the ICU. The patients were extubated after becoming normothermic and having stable respiratory variables, such as acceptable levels of oxygenation ($Pao_2/Fio_2 > 200$), sufficient tidal volume (> 8 mL/kg), and spontaneous respiration of less than 50 breaths/min. Fluids were restricted to 2 mL/kg/hr and the fresh frozen plasma (FFP), thrombocyte, and erythrocyte suspensions (RBC) were administered as needed, depending on the hematocrit level, hemostasis, and the left atrial pressure. In accordance with our standard practice, platelets and cryoprecipitate were transfused as 15 and 10 mL/kg, respectively, after heparin was neutralized with protamine sulfate. RBC was transfused when patient's hematocrit level was lower than 35% during the first 24 hours. FFP was administered to maintain left atrial pressure and to improve hemostasis in the ICU. The duration of mechanical ventilatory support, intensive care, and total hospital stay were recorded.

Measurements

After induction of anesthesia and before surgical incision, hemodynamic and pulmonary measurements were taken.

Repeated measures were obtained after termination of CPB, immediately after MUF, and in the 1st, 6th, 12th, and 24th hours after admission to ICU.

The ventilatory data on maximal inspiratory pressure, plateau pressure, tidal volume, F_{IO_2}, and PEEP which were obtained from the ventilator panel of the Servo Screen 300 (Siemens-Elma AB, Solna, Sweden) and the arterial blood gases analysis results were used to calculate the lung compliance (static and dynamic compliance) and the gas exchange capacity (oxygenation index [OI], respiratory index [RI], and ventilation index [VI]).

Following formulas were used in the calculations:

Static compliance (C_{stat}, mL/cm/kg): $C_{stat} = V_{Texp}/(P_{pause} - PEEP)$, where C_{stat} = static compliance, V_{Texp} = expiratory tidal volume, P_{pause} = plateau pressure, and PEEP = the positive end-expiratory pressure.

Dynamic compliance (C_{dyn}, mL/cm/kg): $C_{dyn} = V_{Texp}/(P_{peak} - PEEP)$, where C_{dyn} = dynamic compliance, V_{Texp} = expiratory tidal volume, and P_{peak} = peak pressure.

Oxygen index (OI): OI = MAP (F_{IO_2}/Pa_{O_2}), where MAP = mean airway pressure, F_{IO_2} = fraction of inspired oxygen, and Pa_{O_2} = partial arterial oxygen pressure.

Ventilation index (VI): VI = RR (PIP – PEEP) × Pa_{CO_2}/1,000, where RR = the respiratory rate, PIP = peak inspiratory pressure, and Pa_{CO_2} = partial arterial carbon dioxide pressure.

Respiratory index (RI): RI = $P(A\text{-}a)_{O_2}/Pa_{O_2}$, where $P(A\text{-}a)_{O_2}$ = (alveolar-arterial oxygen pressure difference).

Hemodynamic measurements, namely, heart rate, systolic arterial pressure (SAP), cerebral tissue oxygen saturation (Sct_{O_2}) (CAS Medical Systems, Branford, CT), CVP, left atrial pressure, inotropic score (dobutamine [μg/kg/min] + dopamine [μg/kg/min] + 100 × epinephrine [μg/kg/min] + 10 × milrinone [μg/kg/min]), mixed venous blood saturation, and glucose, lactate, and hematocrit levels, were recorded.

Other measurements: CUF and MUF volume, urine volume, fluid balance, peritoneal dialysis volume, drained hemorrhagic volume, and the volumes of administered blood and blood products were recorded. Cerebral tissue oxygen saturation (Sct_{O_2}) was monitored during the operation.

Statistical Analysis

SPSS for Windows 15.0 software was used for the statistical analyses performed during the evaluation of the findings obtained from the study. Conformance of the variables with normal distribution was measured using the Kolmogorov-Smirnov test in the evaluation of study data. In addition to descriptive statistical methods (average, SD, etc) used for the evaluation of data, one-way analysis of variance test was employed in the comparison of normally distributed variables in the comparison of quantitative data between groups, and Tukey honest significant difference test was used to determine the group causing the difference. The intergroup comparison of variables without normal distribution was performed using the Kruskal-Wallis test, whereas the group causing the difference was identified through the Mann-Whitney *U* test. The comparison of the normally distributed variables within the group was performed using the paired-sample *t* test, whereas the intragroup variables demonstrating no normal distribution were compared using the Wilcoxon signed rank test. We did not use adjust *p* values for within-group comparisons. Qualitative data were tested using the chi-square test. Significance was evaluated at *p* less than 0.05 level.

RESULTS

The study was planned for 60 infants, ranging between 3 and 67 days of age, operated between 2009 and 2011. Of these, 56 patients met the inclusion criteria. One patient in group 1 was excluded from the study due to a change in the intraoperative surgical application. Three patients died in the early postoperative period (one patient in group 1 and two patients in group 2). Pulmonary compliance measurements were not obtained in patients who had delayed sternal closure.

The demographic details of the patients are given in **Table 1**. The depth of anesthesia (IOC value) was similar in all three groups (51 ± 7, 53 ± 6, and 48 ± 10, respectively, $p > 0.05$). All patients were administered fentanyl and midazolam infusion throughout the operation, and no additional anesthesia was required for any patient. In the beginning of CPB, Sct_{O_2} was increased in all three groups compared to the earlier induction values (54 ± 7, 59 ± 4, 56 ± 8, and 64 ± 5, 74 ± 4, 67 ± 5, respectively, $p < 0.05$). At the end of the operation, the values returned to their previous levels (**Figure 1**).

Compared to the CPBend values, static and dynamic pulmonary compliance were increased at the end of the MUF in all three groups ($p < 0.05$) as well as in the 6th, 12th, and 24th hours in the ICU ($p < 0.05$) (**Table 2**).

Oxygenation index, ventilation index, and respiratory index were not different between the three groups (**Table 2**). However, the oxygenation index decreased at post-MUF period ($p < 0.05$) and it increased in the first hour in the ICU and decreased again in 12th and 24th hours in the ICU in all three groups. The ventilation and respiratory indices were also increased in the first hour in the ICU compared to CPBend ($p < 0.05$) (Table 2).

SAP was similar in all three groups throughout the study period, except immediately after MUF. SAP significantly increased at the end of MUF in group 3 compared to groups 1 and 2 (60 ± 8, 62 ± 10, and 66 ± 12 mm Hg, respectively) ($p < 0.05$). Likewise, the hematocrit levels were similar in all three groups except at the end of MUF, when they were significantly higher in groups 2 and 3 (41% ± 4%, 41% ± 6%, and 36% ± 5%, respectively) ($p < 0.01$) than in group 1(**Table 3**). Heart rate, central venous pressure, left atrial pressure, inotropic score, mixed venous blood saturation, and lactate level were not statistically different between the groups.

The volume status of all three groups is shown in **Table 4**. The volume obtained at the end of MUF was higher (170 ± 67, 197 ± 137, and 113 ± 46 mL, respectively, $p < 0.01$) in group 2 and group 3 than that of group 1. The volume of the RBCs

TABLE 1. Clinical Characteristics of Patients

Characteristics	Group 1 Mean ± SD	Group 2 Mean ± SD	Group 3 Mean ± SD	p^a
Age (d)	17 ± 14	21 ± 14	22 ± 15	0.550
Body surface area (m^2)	0.21 ± 0.0	0.22 ± 0.0	0.21 ± 0.0	0.944
Cardiopulmonary bypass time (min)	167 ± 17	170 ± 39	179 ± 33	0.058
Cross-clamp time (min)	89 ± 10	92 ± 12	97 ± 20	0.064
Ventilation time (hr)	95 ± 77	87 ± 45	99 ± 84	0.797
Length of ICU stay (d)	7 ± 4	7 ± 3	9 ± 8	0.620
Length of hospital stay (d)	15 ± 10	11 ± 5	16 ± 10	0.270
	n (%)	*n* (%)	*n* (%)	p^b
Gender (male)	9 (50)	10 (56)	11 (55)	0.764
Ventricular septal defect	7 (39)	11 (61)	13 (65)	0.098
Preop ventilation	4 (22)	2 (11)	5 (25)	0.806
Delayed sternal closure	1 (6)	5 (28)	4 (20)	0.138
Reintubation	0	1 (6)	2 (10)	0.180
Complications				
Diaphragm paresis	1 (6)	1 (6)	0	0.353
Sepsis	0	1 (6)	0	0.965
Bleeding	1 (6)	0	1 (5)	0.421

[a]One-way analysis of variance test and Kruskal-Wallis test.
[b]Chi-square test.

transfused at the end of the operative procedure was less (73 ± 35, 70 ± 28, and 91 ± 43 mL, respectively, $p < 0.05$) in groups 2 and 3 than in group 1. CUF volume, urine volume, fluid balance, peritoneal dialysis volume, blood loss, and the amount of administered platelets, FFP and cryoprecipitate were not statistically different between the groups (Table 4).

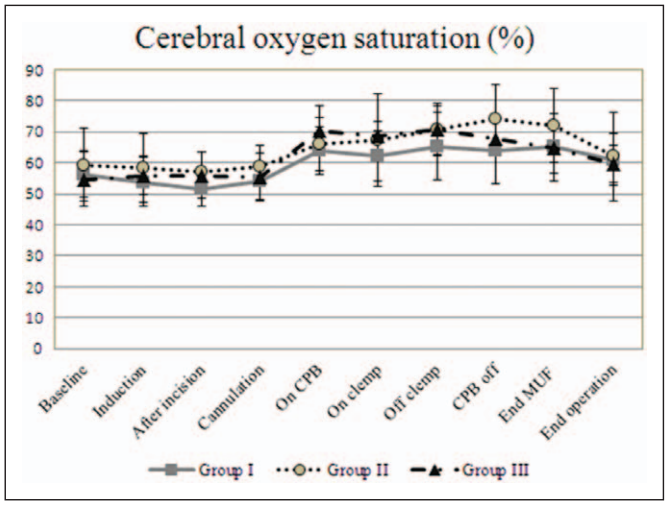

Figure 1. Intraoperative cerebral oxygen saturation (%). In the groups; paired-sample *t* test. CPB = cardiopulmonary bypass, MUF = modified ultrafiltration.

DISCUSSION

In 56 subjects who underwent arterial switch operation, the pulmonary dysfunction manifested by reduced pulmonary compliance and poor pulmonary gas exchange after CPB acutely improved after MUF in all three groups (10, 15, and 20 min). However, this improvement observed immediately after MUF was not sustained in the first hour after admission to ICU. Reimprovement was observed in all three groups between 6 and 24 hours of follow-up in the ICU. In addition, the intraoperative blood transfusion requirements decreased in groups 2 and 3 while this positive effect was not observed in any of the three groups during the initial 24 hours in the ICU. The length of MUF did not alter the extubation time, stay in the ICU, and time of discharge.

Ultrafiltration used to remove the excess water from the patient's body is operated by hydrostatic pressure gradient. There are three methods for the application of ultrafiltration, namely, conventional, high volume zero balance of modification of CUF and MUF. Collective use of CUF and MUF is more effective in the reduction of inflammatory response (9, 10). Removing larger amounts of water improves pulmonary compliance and gas exchange and increases hematocrit, thereby reducing the need for blood transfusion. It improves hemodynamics. Hence, it reduces the need for inotropes. Consequently, it may also shorten the ventilation period and the duration of intensive care and hospital stay.

TABLE 2. Effect of the Length of MUF on Lung Compliance and Gas Exchange Capacity

Variables	Group 1 Mean ± SD	Group 2 Mean ± SD	Group 3 Mean ± SD	*p*[a]
Static compliance (mL/cm/kg)				
Preop	2.5 ± 1	2.6 ± 2	2.6 ± 1	0.168
CPBend	2.0 ± 1	2.0 ± 2	2.1 ± 1	0.178
MUFend	2.2 ± 1[b]	2.4 ± 1[b]	2.4 ± 1[b]	0.099
ICU1	2.0 ± 1	2.2 ± 1	2.2 ± 1	0.210
ICU6	2.4 ± 1[b]	2.6 ± 1[b]	2.6 ± 1[b]	0.107
ICU12	2.5 ± 1[b]	2.4 ± 1[b]	2.5 ± 2[b]	0.264
ICU24	2.3 ± 1[b]	2.4 ± 2[b]	2.5 ± 1[b]	0.099
Dynamic compliance (mL/cm/kg)				
Preop	2.4 ± 1	2.8 ± 2	2.4 ± 1	0.451
CPBend	2.0 ± 1	2.3 ± 1	2.1 ± 1	0.695
MUFend	2.2 ± 1[b]	2.5 ± 1[b]	2.4 ± 1[b]	0.425
ICU1	2.1 ± 1	2.2 ± 1	2.2 ± 1	0.488
ICU6	2.3 ± 1[b]	2.5 ± 1[b]	2.5 ± 1[b]	0.812
ICU12	2.5 ± 1[b]	2.5 ± 1[b]	2.4 ± 1[b]	0.978
ICU24	2.3 ± 1[b]	2.4 ± 1	2.3 ± 0	0.463
Oxygen index				
Preop	19 ± 10	20 ± 10	18 ± 10	0.385
CPBend	11 ± 5	11 ± 4	11 ± 5	0.960
MUFend	8 ± 4[b]	8 ± 6[b]	9 ± 6[b]	0.683
ICU1	14 ± 13[b]	13 ± 8[b]	14 ± 10[b]	0.697
ICU6	10 ± 6	10 ± 9	10 ± 9	0.064
ICU12	9 ± 5[b]	8 ± 6[b]	8 ± 7[b]	0.102
ICU24	8 ± 5[b]	7 ± 4[c]	8 ± 5[b]	0.155
Ventilation index				
Preop	19 ± 7	20 ± 4	18 ± 6	0.673
CPBend	22 ± 6	23 ± 6	24 ± 7	0.441
MUFend	20 ± 8	21 ± 9	22 ± 6	0.783
ICU1	25 ± 9[b]	27 ± 16[b]	26 ± 12[b]	0.492
ICU6	20 ± 7	24 ± 16	22 ± 9	0.347
ICU12	19 ± 2	21 ± 12	21 ± 10	0.233
ICU24	18 ± 8	18 ± 9	17 ± 10	0.345
Respiratory index				
Preop	8 ± 4	7 ± 3	8 ± 4	0.969
CPBend	4 ± 4	4 ± 3	3 ± 3	0.699
MUFend	4 ± 4	3 ± 3	3 ± 3	0.650
ICU1	6 ± 5[b]	5 ± 3	6 ± 3[b]	0.758
ICU6	4 ± 4	4 ± 2	4 ± 3	0.188
ICU12	4 ± 4	3 ± 2	3 ± 2	0.303
ICU24	3 ± 3	2 ± 1	3 ± 2	0.370

CPB = cardiopulmonary bypass, MUF = modified ultrafiltration.
Between the groups: [a]One-way analysis of variance test and Kruskal-Wallis test.
In the groups: paired-sample *t* test ([b]$p < 0.05$, [c]$p < 0.01$).
CPB end was taken as the baseline in the groups.

TABLE 3. Hematocrit and Systolic Arterial Pressure Results

Variables	Group 1 Mean ± SD	Group 2 Mean ± SD	Group 3 Mean ± SD	p^a
Hematocrit (%)				
Preop	35±3	36±6	35±5	0.109
CPBend	32±5	34±3	33±5	0.454
MUFend	36±5[a,b]	41±4[c]	41±6[c]	0.019
ICU1	32±4	33±5	34±4	0.987
ICU6	34±4	35±5	34±5	0.592
ICU12	34±4	35±5	33±5	0.414
ICU24	32±3	34±3	33±3	0.165
Systolic arterial pressure (mm Hg)				
Preop	70±15	72±20	68±15	0.796
CPBend	52±8	53±10	54±15	0.865
MUFend	60±8+	62±10[b]	66±12[a,b]	0.002
ICU1	64±13[b]	64±12[b]	65±18[b]	0.789
ICU6	72±16[b]	68±13[b]	70±11	0.650
ICU12	74±16[b]	77±13[b]	74±11[b]	0.306
ICU24	81±11[b]	78±10[b]	77±17[b]	0.406

CPB = cardiopulmonary bypass, MUF = modified ultrafiltration.
Between the groups: [a]One-way analysis of variance test and Kruskal-Wallis test.
In the groups: paired-sample *t* test ([b]$p < 0.05$, [c]$p < 0.01$).
CPB end was taken as the baseline in the groups.

The study by Mahmoud et al (6) compared the effects of CUF and MUF on the pulmonary functions after CPB in children. They found a better pulmonary compliance and gas exchange with MUF. This effect disappeared at the end of sixth hour, and MUF did not change the extubation and ICU periods (6). The study (6) did not include neonates or patients with long CPB and cross-clamp times. However, it is well that CPB-induced adverse effects and organ dysfunction are much greater in neonates than in older children.

The improvement in pulmonary function may have greater clinical significance in selected patients with complex congenital heart disease, such as those with preoperative pulmonary hypertension or small neonates and patients who require prolonged CPB (12–14). In a study performed by Keenan et al (11) on 38 infants, pulmonary compliance was improved in patients who underwent MUF versus the control group. However, these improvements were not sustained past the immediate postultrafiltration period and did not lead to a decrease in the duration of mechanical ventilation and length of stay in the ICU (11). Kotani et al (3) showed that MUF shortened the ICU stay but did not change the duration of ventilatory support for patients with TGA undergoing arterial switch operation. Although neonates were included and the duration of CPB was longer in our study, the positive effects of MUF on pulmonary compliance and gas exchange disappeared in the first hour in intensive care, while the improvement reappeared and continued increasingly during the subsequent periods of follow-up in 6th and 24th hours.

Although there was no difference between the intraoperative CUF volumes in the groups in our study, the fluid volume obtained at the end of MUF led to nearly a two-fold difference between groups 1 and 3. This caused an elevation in the hematocrit value to 36% and 41%. Extending the duration of MUF from 15 to 20 minutes did not yield any additional benefits for the ICU monitoring of neonates and infants who underwent arterial switch operation. Prolonged MUF was not able to change pulmonary and hemodynamic variables, blood gas measurements, or total blood loss. The delayed sternal closure was more in groups 2 and 3. This also emphasizes that prolonging the MUF time does not decrease the need for delayed sternal closure. Kuratani et al (18) reported a meta-analysis of randomized controlled trials comparing clinical outcome variables and the advantage of MUF over conventional ultrafiltration. This comparison proved significant improvements in clinical conditions in the immediate post bypass period, but the postoperative outcome was not significantly influenced.

Limitations

The focus of this clinical study was to measure clinical outcomes; therefore, the level of inflammatory mediators was not measured.

TABLE 4. Continuous Ultrafiltration and Modified Ultrafiltration Volume, Urine Volume, Fluid Balance, Peritoneal Dialysis Volume, Blood Loss and Administered Platelets, Fresh Frozen Plasma, Cryoprecipitate, and Body Weight Results

Variables	Group 1 Mean ± SD	Group 2 Mean ± SD	Group 3 Mean ± SD	*p*
Continuous ultrafiltration volume[a] (mL)	330 ± 213	384 ± 114	425 ± 179	0.240
Modified ultrafiltration volume[a] (mL)	113 ± 46[c]	170 ± 67	197 ± 137	0.001
Urine output[a] (mL)				
End operation	76 ± 13	80 ± 13	69 ± 13	0.404
ICU24	291 ± 155	332 ± 189	281 ± 181	0.661
Balance[b] (mL)				
End bypass	−54 ± 43	−73 ± 26	−82 ± 53	0.189
ICU24	−57 ± 50	−65 ± 48	−62 ± 60	0.345
Peritoneal dialysis[a] (mL)				
ICU24	141 ± 72	114 ± 70	135 ± 76	0.533
Blood loss[a] (mL)				
End operation	41 ± 23	53 ± 35	50 ± 28	0.678
ICU24	107 ± 62	122 ± 107	109 ± 110	0.840
Packed red cell[b] (mL)				
End operation	91 ± 43[a]	73 ± 35	70 ± 28	0.041
ICU24	147 ± 110	146 ± 102	130 ± 100	0.228
Platelets[b] (mL)				
End operation	59 ± 20	66 ± 41	60 ± 21	0.229
ICU24	61 ± 20	78 ± 40	67 ± 24	0.699
Cryoprecipitate[b] (mL)				
End operation	40 ± 20	48 ± 21	42 ± 21	0.812
Fresh frozen plasma[b] (mL)				
ICU24	100 ± 80	99 ± 78	109 ± 87	0.764
Body weight[a] (kg)				
Before induction	3.5 ± 0.5	3.4 ± 0.9	3.4 ± 0.4	0.760
End operation	3.8 ± 0.4	3.7 ± 0.9	3.9 ± 0.6	0.810
ICU24	3.8 ± 0.5	4.0 ± 1.3	3.8 ± 0.6	0.702

Between the groups ([a]One-way analysis of variance test and [b]Kruskal-Wallis test).

CONCLUSIONS

In this study, MUF acutely improved the pulmonary compliance and gas exchange in all three groups and when MUF lasted longer than 10 minutes acutely increased hematocrit levels and blood pressure measurements. However, there were not any additional contributions to the pulmonary, hemodynamic, and clinical measurements in the ICU. Furthermore, it did not reduce the mechanical ventilation time or the length of stay in the ICU.

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