Original Article

The effect of combined conventional and modified ultrafiltration on mechanical ventilation and hemodynamic changes in congenital heart surgery

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Background: Cardiopulmonary bypass is associated with increased fluid accumulation around the heart which influences pulmonary and cardiac diastolic function. The aim of this study was to compare the effects of modified ultrafiltration (MUF) versus conventional ultrafiltration (CUF) on duration of mechanical ventilation and hemodynamic status in children undergoing congenital heart surgery. **Materials and Methods:** A randomized clinical trial was conducted on 46 pediatric patients undergoing cardiopulmonary bypass throughout their congenital heart surgery. Arteriovenous MUF plus CUF was performed in 23 patients (intervention group) and sole CUF was performed for other 23 patients (control group). In MUF group, arterial cannula was linked to the filter inlet through the arterial line, and for 10 min, 10 ml/kg/min of blood was filtered and returned via cardioplegia line to the right atrium. Different parameters including hemodynamic variables, length of mechanical ventilation, Intensive Care Unit (ICU) stay, and inotrope requirement were compared between the two groups. **Results:** At immediate post-MUF phase, there was a statistically significant increase in the mean arterial pressure, systolic blood pressure, and diastolic blood pressure ($P < 0.05$) only in the study group. Furthermore, there was a significant difference in time of mechanical ventilation ($P = 0.004$) and ICU stay ($P = 0.007$) between the two groups. Inotropes including milrinone ($P = 0.04$), epinephrine ($P = 0.001$), and dobutamine ($P = 0.002$) were used significantly less frequently for patients in the intervention than the control group. **Conclusion:** Administration of MUF following surgery improves hemodynamic status of patients and also significantly decreases the duration of mechanical ventilation and inotrope requirement within 48 h after surgery.

Key words: Congenital, hemodynamic, mechanical ventilation, ultrafiltration

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INTRODUCTION

In pediatric open heart surgery, administration of bypass pump has been shown to be associated with an increase in the volume of body fluids. This sudden change in the body fluids volume, in children with low weight and age compared to adults, will be of stronger adverse effects after surgery.[1] Through stimulating the inflammatory system and creating hemodilution at the beginning of the surgery, cardiopulmonary bypass leads to the excessive increase in vascular permeability which in turns results in a severe drop of blood pressure at the beginning of bypass. Furthermore, cardiopulmonary bypass following surgery causes generalized edema throughout the body, especially in the lungs and heart.[2] Destructive effects of bypass on heart lead to interstitial edema and pericardial effusion which influences the cardiac diastolic function and consequently affects the hemodynamic stability of patients at postoperative phase. On the other hand,

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pulmonary capacities and exchange capacity of lung gasses are influenced after placing the patient on bypass pump; consequently, overall pulmonary performance of patients decreases.[3-5] Hemodilution occurring with bypass pump is the sequel of priming solution used to set up the bypass pump. Hemodilution affects children with low weight more pronouncedly than adults. Various strategies have already been used to reduce the side effects of hemodilution through using retrograde autologous priming, medications (diuretics and anti-inflammatory), ultrafiltration, and blood products as prime. In addition, reducing the length of the bypass tubes and minimizing the bypass pump circuit have also been investigated.[6-9] Administration of varied methods of ultrafiltration has been highly regarded in various centers among the various methods of reducing the improper effects of bypass pump hemodilution. The main difference between different methods of ultrafiltration is at the time of their implementation; conventional ultrafiltration (CUF) and modified ultrafiltration (MUF) are performed during bypass pumps and after the end of bypass, respectively. Volumetric limitations in the reservoir during performing the bypass have been shown to reduce the possibility of convenient and efficient ultrafiltration in pediatric patients. Thus, the use of MUF is widely used at the end of bypass.[10,11]

In the literature, there is a large controversy whether to use any of these interventions. While numerous studies conducted in the past have shown that the use of MUF at the end of bypass improves brain, lung, and heart function in the period after the open heart surgery and also reduces the need for blood products, length of postoperative ICU stay through reducing the amount of body fluids and hence the tissue edema.[4,12,13] A number of studies have reported no significant improvement in the clinical conditions of patients, in which MUF has been implemented.[14-16] In this study, we aimed to examine the effects of combined CUF and MUF on mechanical ventilation and hemodynamic changes in pediatric cardiac surgery.

MATERIALS AND METHODS

Procedures followed in this study were in accordance with the ethical standards of the responsible committee on human experimentation (institutional or regional) and with the Helsinki Declaration of 1975, as revised in 2000 (available at http://www.wma.net/e/policy/17-c_e.html). Before starting the study, it was reviewed and confirmed with the institutional Ethics Committee. Informed written consent was obtained from the parents of the participants. The ethical standards of this trial are in accordance with the guidelines provided by the CPCSEA and World Medical Association Declaration of Helsinki on Ethical Principles for Medical Research Involving Humans for studies involving experimental animals and human beings, respectively.

Study design

Our study was a single-center, prospective, randomized trial with planned enrollment of 46 pediatric patients for congenital heart surgery under cardiopulmonary bypass in 2014. We used online random allocation software (http://www.graphpad.com/quickcalcs/randomize2/) and passed the randomization list to a third person (colleague) that was out of the study and he kept all allocations "concealed" until the end of the study and the time of statistical analyses. Inclusion criteria were gestational age >37 weeks, postnatal age younger than 24 months, weight between 5 and 10 kg, and patients scheduled for open congenital heart surgery. Exclusion criteria were emergency operation, redo operation, preexisting pulmonary disease, use of extracorporeal membrane oxygenation after surgery, active noncardiac disease affecting recovery after the surgery, and arrest and having received shock during the surgery. According to Aggarwal *et al*.[1] study and considering $\alpha = 0.05$, $\beta = 0.1$, and mean systolic blood pressure (SBP) values and differences $S_p = 38$, $\mu_1 = 101$ mmHg, $\mu_2 = 139$ mmHg and the formula:

$$n=\frac{2\left(Z_{1-\frac{\alpha}{2}}+Z_{1-\beta}\right)^2 \times \left(S_p\right)^2}{\left(\mu_1-\mu_2\right)^2}$$

Sample size was calculated $n = 21$ for each group. Authors finally considered $n = 23$ in each group.

Patients were randomized at the time of surgery into either the control group (received CUF during cardiopulmonary bypass [CPB]) or intervention group (received CUF during CPB and MUF immediately after CPB). Operative management was standardized. No changes in surgical or anesthetic techniques were made for the purpose of the study. Our standard pediatric perfusion protocol was used in all patients, through aortic and bicaval cannulation and flow rates of 125–200 ml/kg/min, depending on weight, to maintain mixed venous oxygen saturations of 60%–70%. Blood prime was used, with priming volume determined by the sizes of arterial and venous tubing. Blood cardioplegia solution was used during aortic cross-clamping. Circulatory arrest was not used. A composition of 300 U/kg heparin was added to the patients' blood before the cannulation to prevent the blood clots during CPB, and the added heparin in surgery was used to maintain activated clotting time (ACT) over 480 s, if necessary. The alpha-stat method was used to maintain the acid-base balance for all patients. To perform ultrafiltration technique, Hemocor HPH 400 Minntech hemofilter (Minntech Corporation, Minneapolis, MN, USA) was used. The CUF was used for patients in both groups during the surgery and also the MUF was used for patients in the intervention group by taking blood from the aortic cannula and returning blood to the right atrium through the venous cannula after the end of CPB.

A line was linked from oxygenator outlet to the filter inlet, and a line was returned from venous reservoir to filter outlet in the CUF method. The arterial cannula was linked to the filter inlet through the arterial line, and for 10 min, 10 ml/kg/min of blood was filtered by patient blood pressure monitoring.[14] Cardioplegia cannula was linked to the filter outlet and finally blood was returned from the cardioplegia line to the right atrium in MUF method [Figure 1]. Then, protamine with the initial dose 1 mg/kg was administered to patients after the end of MUF and removing the arterial and venous cannulas, and the next doses were prescribed if the ACT was not at the desired levels.

Hemodynamic variables (systolic blood pressure, diastolic blood pressure, mean blood pressure, heart rate, and central venous pressure) were measured before anesthesia induction) baseline), the start of bypass pump, the end of bypass pump, 15 min after bypass pump (end of MUF), the time entering the Intensive Care Unit (ICU), and 2, 4, 6, 8, 10, 12, 24, and 48 h after the surgery. Comparison between patients who received MUF + CUF and those who received CUF was conducted with respect to the duration of mechanical ventilator support, duration of ICU stay, and duration of hospitalization. Total number and dose of inotropes during stay in the ICU were calculated by the doses of 5–10 μg/kg/min for dopamine, 5–7 μg/kg/min for dobutamine, 0.05–0.15 μg/kg/min for epinephrine, and 0.5–0.75 μg/kg/min for milrinone.[15] We use an institutional protocol for vasoactive drug usage as: epinephrine 0.01–0.15 μ/kg for SBP <65 mmHg for neonates, SBP <70 for infants (1 <age <18 month), and SPB <75 for children >18 months).

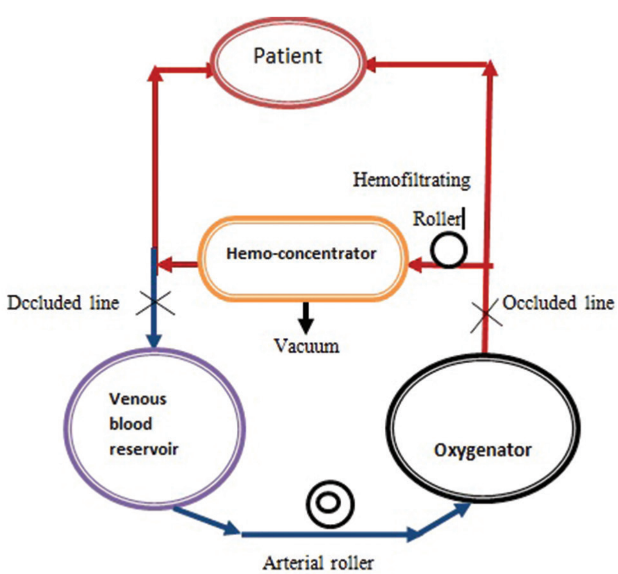

Figure 1: MUF circuit

Data analysis was performed using the SPSS version 19 software (SPSS Inc, Chicago, IL). The descriptive statistics including indicators of central tendency and dispersion (mean and standard deviation) and frequency distribution were used to describe the specifications of research units in both groups. All variables were tested for normality. Chi-square test was used for comparing categorical variables such as gender, operation type, and inotrope drug administration. Comparison of demographic and operation data, duration of mechanical ventilation and ICU stay, and time of the consumption of inotrope drugs between groups were determined using the independent-samples *t*-test for paired data. Furthermore, hemodynamic changes at various time intervals in two groups were determined by analysis of variance for repeated measures. $P < 0.05$ considered statistically significant.

RESULTS

The results obtained from this study indicate that 43.47% ($n = 10$) of individuals were boys and 56.53% ($n = 13$) were girls in the group MUF + CUF. There were 12 (52.17%) boys and 11 (47.82%) girls in the group CUF; these differences were statistically insignificant. Operations performed in MUF + CUF and CUF groups included repair of ventricular septal defect ($n = 8$ vs. $n = 6$), repair of ventricular septal defect and atrioventricular septal defect ($n = 6$ vs. $n = 5$), repair of ventricular septal defect and atrioventricular septal defect with pulmonary hypertension ($n = 4$ vs. $n = 5$), repair of total anomalous pulmonary venous connection ($n = 3$ vs. $n = 4$), and repair of ventricular septal defect with pulmonary hypertension ($n = 2$ vs. $n = 3$), respectively. Mean volume of ultrafiltrate separated during CUF was not significantly different in two groups. Demographic characteristics of the patients including age, weight, height, and body surface area, as well as the priming volume, time of aortic cross-clamping, time of bypass pump, and urinary output were compared between two groups [Table 1]. Clinical status of patients at the postoperative period in both groups has been presented in Table 2. Duration of mechanical ventilation and length of ICU stay for two groups showed a significant difference [Table 2]. However, there was no significant difference in the patients' overall length of stay in hospital. Alterations of mean arterial blood pressure in both groups were investigated at 13 different times from before the induction of anesthesia to 48 h after the surgery; the mean arterial blood pressure in the intervention group increased from 63.14 (4.98) mmHg to 72.14 (8.43) mmHg. However, the mean arterial blood pressure remained almost unchanged from 63.09 (9.30) to 63.52 (12.66) without any significant change in the control group; a significant difference was observed between the groups ($P = 0.03$). There was also a significant difference in the mean arterial blood pressure between the groups on time entering the ICU ($P = 0.04$), 2 ($P = 0.038$), 4 ($P = 0.024$), 6 ($P = 0.01$), and 8 ($P = 0.016$) h after the surgery.

SBP in the intervention group increased from 88.19 (32.06) mmHg to 96.28 (16.66) mmHg at the end of MUF and decreased in the control group from 89.43 (28.11) mmHg to 87.73 (14.51) mmHg. A significant difference was observed between the two groups in this regard ($P = 0.01$). There was also a significant difference in SBP between the groups on time entering the ICU ($P = 0.02$), 2 ($P = 0.04$), 4 ($P = 0.001$), and 6 ($P = 0.015$) h after the surgery. Diastolic blood pressure in the intervention group increased from 47.28 (3.33) mmHg to 54.80 (4.22) mmHg; however, the diastolic blood pressure remained almost unchanged from 49.28 (8.00) to 49.90 (5.20). There was also a significant difference between the groups in this regard ($P = 0.02$). There was also a significant difference in diastolic blood pressure between the groups on time entering the ICU ($P = 0.034$), 2 ($P = 0.011$), 4 ($P = 0.047$), 6 ($P = 0.02$), and 8 ($P = 0.001$) h after the surgery [Figure 2]. Within 48 h after the surgery, heart rate demonstrated better stability in the intervention group and the heart rate at 2, 4, and 6 h after surgery was 127.00 (18.02) vs. 135.61 (15.02) bpm [$P = 0.04$], 126.04 (4.48) vs. 135.52 (16.77) bpm [$P = 0.021$], and 130.71 (10.51) vs. 142.52 (14.41) bpm [$P = 0.001$], respectively, in the intervention and control groups.

Within 48 h after the surgery, the excessive increase of central venous pressure was prevented in the intervention group by performing MUF; central venous pressure on time entering the ICU, 2, 4, and 6 h after surgery was 10.09 (1.70) vs. 15.80 (4.97) cmH_2O [$P = 0.033$], 10.28 (1.61) vs. 16.90 (3.64) cmH_2O [$P = 0.01$], 10.85 (1.76) vs. 16.00 (1.89) cmH_2O [$P = 0.047$], and 12.07 (1.35) vs. 17.52 (3.84) cmH_2O [$P = 0.008$], respectively, in the intervention and control groups.

Number and amount of the administered inotropes during the patients' ICU stay have been presented in Table 3. Accordingly, the number of patients for which milrinone and dopamine were used was equal in both groups. However, the number of patients who required epinephrine or dobutamine in ICU was lesser in the intervention group ($P = 0.03$). Milrinone, epinephrine, and dobutamine were used significantly less frequently for patients in the intervention group than the control group in terms of $P < 0.05$; however, no significant difference was observed between the two groups in terms of dopamine requirement ($P = 0.239$).

Table 1: Demographic and operation data in two groups

Variable	MUF + CUF (*n*=23)	CUF (*n*=23)	*P*
Age (month)	15 (4.2)	17 (6.3)	0.62
Weight (kg)	8.1 (1.4)	8.5 (1.2)	0.25
Height (cm)	78.6 (7.1)	81.3 (6.5)	0.74
BSA (m^2)	0.48 (0.15)	0.43 (0.22)	0.46
Priming volume (ml)	422.5 (180.1)	454.8 (151.3)	0.35
Cross clamp (min)	76.9 (7.1)	75.7 (6.1)	0.64
CPB time (min)	101.3 (10.5)	99.6 (8.7)	0.41
Urine output (ml)	132.7 (41.5)	140.5 (39.8)	0.48
Volume of CUF (ml)	172.6 (61.2)	163.2 (56.8)	0.75
Volume of MUF (ml)	156.2 (41.3)	-	

Values are expressed as mean (SD), CUF = Conventional ultrafiltration; MUF = Modified ultrafiltration; BSA = Body surface area; CPB = Cardiopulmonary bypass; SD = Standard deviation

Table 2: Comparison duration of mechanical ventilation and Intensive Care Unit stay in two groups

Variable	MUF + CUF (*n*=23)	CUF (*n*=23)	*P*
Duration of MV (h)	12.3 (6.3)	34.3 (12.5)	0.004*
Duration of ICU stay (days)	4.4 (3.4)	7.4 (3.5)	0.007*
Duration of hospital stay (days)	9.3 (4.1)	11.7 (5.6)	0.14

**P*<0.05, independent-samples *t*-test. Values are expressed as mean (SD). SD = Standard deviation; MV = Mechanical ventilation; ICU = Intensive Care Unit; CUF = Conventional ultrafiltration; MUF = Modified ultrafiltration

Table 3: Comparison of the number and time of the consumption of inotrope drugs in two groups

Variable	MUF + CUF (*n*=23)	CUF (*n*=23)	*P*
Milrinone			
Number	23/23	23/23	1
Time (h)	36.6 (28.5)	64.1 (47.8)	0.04
Epinephrine			
Number	8/23	12/23	0.008**
Time (h)	72.7 (32.5)	131.6 (29.3)	0.001*
Dopamine			
Number	5/23	5/23	0.943
Time (h)	62.4 (26.1)	81.6 (21.4)	0.239
Dobutamine			
Number	2/23	9/23	0.03**
Time (h)	26.0 (22.6)	86.4 (16.7)	0.002*

**P*<0.05, independent-samples *t*-test; ***P*<0.05, Chi-square test. Values are expressed as mean (SD). SD = Standard deviation; CUF = Conventional ultrafiltration; MUF = Modified ultrafiltration

DISCUSSION

In the present study, effects of MUF on the hemodynamic status of patients and duration of mechanical ventilation were studied. Information obtained from the hemodynamic status of patients in this study showed that there is a significant difference in central venous pressure and heart rate changes between the two groups before and after MUF. Administration of MUF in the intervention group significantly reduced the central venous pressure and heart rate. Furthermore, systolic and diastolic blood and mean arterial pressure in the intervention group patients were significantly higher compared with the control group. In the study of Schlünzen *et al.*, beneficial effects including reducing the heart rate and increasing the mean arterial pressure were noted.[16] At the end of MUF in our study, patients in group CUF + MUF showed an increase of 8% in the mean SBP compared to the 1.1% decrease in the mean

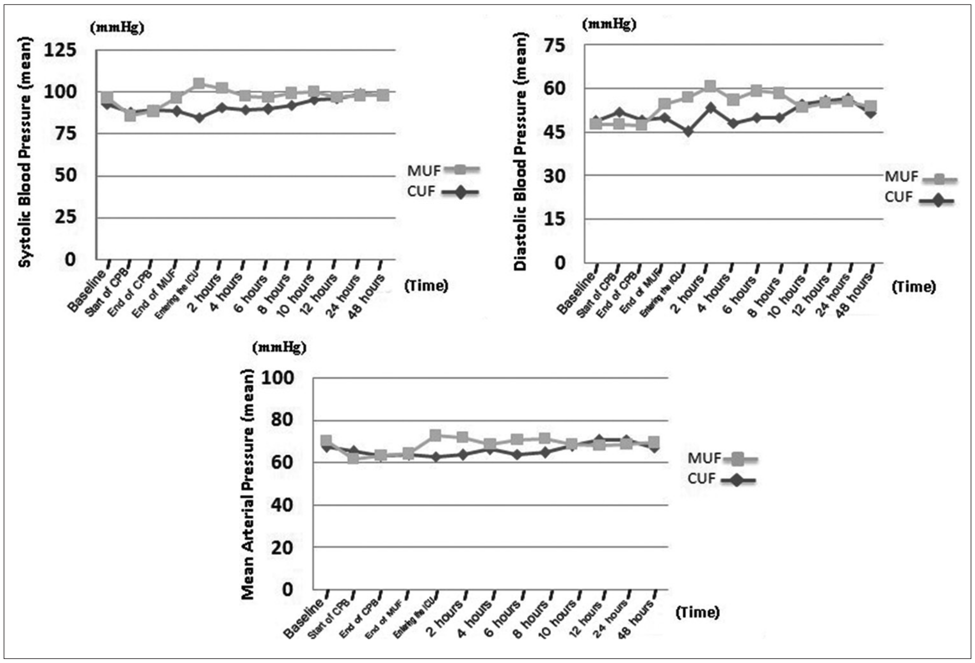

Figure 2: Hemodynamic changes at different times in two groups

SBP in group CUF ($P = 0.01$). Increase in SBP was reported in most previous studies. Furthermore, Kotani *et al*., in their study on infants with congenital cardiac problem of transposition of the great arteries, stated that the use of MUF could increase the systolic and diastolic blood pressure of patients without a significant change in central venous pressure and left atrial pressure.[17] In another prospective randomized study, Torina *et al*.[13] studied the effects of using MUF in adult patients scheduled for coronary artery bypass grafting surgery and showed that using MUF had no significant effect on the hemodynamic status of patients; in contrast, using MUF at the end of CPB improved the blood pressure and heart rate in the present study. It seems that the difference in the results obtained from these two studies represents a beneficial effect of using MUF in pediatric patients. Through evaluating the children weighing <15 kg and with congenital malformations undergoing surgery, Thompson *et al*.[18] reported that using sole MUF was unable to increase the blood pressure and improve the heart rate of patients. Nevertheless, in the intervention group of our study, hemodynamic status of patients showed a great improvement.

Examining the adult patients undergoing open heart surgery, Sahoo *et al*.[19] reported that using combined CUF and MUF is associated with improved stability in heart rate and central venous pressure of patients in the 24-h postoperative period which is in line with the results obtained from our study.

Duration of mechanical ventilation was significantly lower in the intervention group of our study compared to the control group. Similar results were obtained in the study of Mohanlal *et al*. and Meliones *et al*., reduction in duration of mechanical ventilation may be due to the removal of excess water from the body, especially the lungs, which could improve the lung function more quickly.[14,20] Beneficial effects of using MUF in reducing the duration of mechanical ventilation and length of stay in the ICU have been pointed out in various studies most of which, similar to the present study, have used CUF and MUF together;[21-25] nonetheless, only have a limited number of studies using MUF failed to report a significant change in the duration of mechanical ventilation in patients after surgery.[4,18,19]

In the present study, inotropes requirement was independently studied. A significant difference was observed in terms of the number of patients and also the amount of the used epinephrine and dobutamine between the groups. In a similar study conducted by Javadpour *et al*.,[22] using MUF generally reduced inotrope requirement in the postoperative period. In their study, the administration of dopamine in the 24 h after surgery was significantly lower in the MUF group; however, no significant difference in the administration of epinephrine was observed between the groups. Administration of epinephrine was different between the groups of our study; yet, the amount of administered dopamine was of no significant difference. Maybe, this difference is due to the different types of used inotropes or different surgeon and anesthesiologist views. Of note, inotrope administration was generally decreased after surgery in both studies.

In another study on infants undergoing the arterial switch surgery, Kotani *et al*. reported that the duration of inotrope administration decreased from 95 to 80 h using MUF, but there was no significant difference between groups.[17] However, in our study, the number and duration of inotropes were significantly different between groups.

In evaluating the effect of MUF on left ventricle function, Davies *et al*.,[15] in another study announced that the use of MUF immensely reduced the number and dose of the inotrope use during 24 h after the pediatric heart surgery. Dopamine was used for most patients in their study which might have contributed to the insignificant difference; epinephrine and milrinone were used in their study for patients of control group in addition to dopamine and dobutamine which represents the increased inotrope requirement for patients, in which MUF was not administered. Inotropes requirement generally declined in both studies; it seems that the difference in types of inotropes used in two studies is due to the different hospital routines.

Limitations

The major limitation of our study was the small sample size (n = 23), and the present study was performed only in one hospital and multicenter studies with more patients might yield more powerful results.

CONCLUSION

Results of this study showed that administration of CUF method during surgery and MUF after surgery generally improve the hemodynamic status of the pediatric patients during their ICU stay compared to the sole CUF administration method during surgery. Furthermore, duration of mechanical ventilation and overall inotrope requirement during the period of 48 h after surgery significantly decreased.

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Conflicts of interest

There are no conflicts of interest.

AUTHORS' CONTRIBUTION

- MZ contributed in the conception of the work, conducting the study, revising the draft,approval of the final version of the manuscript, and agreed for all aspects of the work.
- AA contributed in the conception of the work and agreed for all aspects of the work
- NA contributed in the conception of the work and agreed for all aspects of the work
- PR contributed in the conception of the work and she worked on the definition of intellectual content, literature search, clinical studies, and experimental studies.
- GM contributed in the conception of the work and he worked on the definition of intellectual content, literature search, clinical studies, and experimental studies.
- SG contributed to the manuscript preparation, manuscript editing, and manuscript review
- MF contributed in the conception of the work, conducting the study, cooperated in data acquisition, data analysis, and statistical analysis, approval of the final version of the manuscript, and agreed for all aspects of the work.
- FG contributed in the conception of the work, conducting the study, cooperated in data acquisition, data analysis, and statistical analysis, and agreed for all aspects of the work.

REFERENCES

1. Aggarwal NK, Das SN, Sharma G, Kiran U. Efficacy of combined modified and conventional ultrafiltration during cardiac surgery in children. Ann Card Anaesth 2007;10:27-33.
2. Marenzi G, Lauri G, Grazi M, Assanelli E, Campodonico J, Agostoni P. Circulatory response to fluid overload removal by extracorporeal ultrafiltration in refractory congestive heart failure. J Am Coll Cardiol 2001;38:963-8.
3. Boodhwani M, Hamilton A, de Varennes B, Mesana T, Williams K, Wells GA, *et al*. A multicenter randomized controlled trial to assess the feasibility of testing modified ultrafiltration as a blood conservation technology in cardiac surgery. J Thorac Cardiovasc Surg 2010;139:701-6.
4. Mahmoud AB, Burhani MS, Hannef AA, Jamjoom AA, Al-Githmi IS, Baslaim GM. Effect of modified ultrafiltration on pulmonary function after cardiopulmonary bypass. Chest 2005;128:3447-53.
5. Ziyaeifard M, Alizadehasl A, Massoumi G. Modified ultrafiltration during cardiopulmonary bypass and postoperative course of pediatric cardiac surgery. Res Cardiovasc Med 2014;3:e17830.
6. Allen M, Sundararajan S, Pathan N, Burmester M, Macrae D. Anti-inflammatory modalities: Their current use in pediatric cardiac surgery in the United Kingdom and Ireland. Pediatr Crit Care Med 2009;10:341-5.
7. Leyh RG, Bartels C, Joubert-Hübner E, Bechtel JF, Sievers HH. Influence of modified ultrafiltration on coagulation, fibrinolysis and blood loss in adult cardiac surgery. Eur J Cardiothorac Surg 2001;19:145-51.
8. Ootaki Y, Yamaguchi M, Oshima Y, Yoshimura N, Oka S. Effects of modified ultrafiltration on coagulation factors in pediatric cardiac surgery. Surg Today 2002;32:203-6.
9. Perrotta S, Lentini S. Ministernotomy approach for surgery of the aortic root and ascending aorta. Interact Cardiovasc Thorac Surg 2009;9:849-58.
10. Chew MS, Brix-Christensen V, Ravn HB, Brandslund I, Ditlevsen E, Pedersen J, *et al*. Effect of modified ultrafiltration on the inflammatory response in paediatric open-heart surgery: A prospective, randomized study. Perfusion 2002;17:327-33.
11. Steffens TG, Kohmoto T, Edwards N, Wolman RL, Holt DW. Effects of modified ultrafiltration on coagulation as measured by the thromboelastograph. J Extra Corpor Technol 2008;40:229-33.

12. Gaynor JW. The effect of modified ultrafiltration on the postoperative course in patients with congenital heart disease. Semin Thorac Cardiovasc Surg Pediatr Card Surg Annu 2003;6:128-39.
13. Torina AG, Silveira-Filho LM, Vilarinho KA, Eghtesady P, Oliveira PP, Sposito AC, *et al*. Use of modified ultrafiltration in adults undergoing coronary artery bypass grafting is associated with inflammatory modulation and less postoperative blood loss: A randomized and controlled study. J Thorac Cardiovasc Surg 2012;144:663-70.
14. Mohanlall R, Adam J, Nemlander A. Venoarterial modified ultrafiltration versus conventional arteriovenous modified ultrafiltration during cardiopulmonary bypass surgery. Ann Saudi Med 2014;34:18-30.
15. Davies MJ, Nguyen K, Gaynor JW, Elliott MJ. Modified ultrafiltration improves left ventricular systolic function in infants after cardiopulmonary bypass. J Thorac Cardiovasc Surg 1998;115:361-9.
16. Schlünzen L, Pedersen J, Hjortholm K, Hansen OK, Ditlevsen E. Modified ultrafiltration in paediatric cardiac surgery. Perfusion 1998;13:105-9.
17. Kotani Y, Honjo O, Osaki S, Kawabata T, Ugaki S, Fujii Y, *et al*. Effect of modified ultrafiltration on postoperative course in neonates with complete transposition of the great arteries undergoing arterial switch operation. Circ J 2008;72:1476-80.
18. Thompson LD, McElhinney DB, Findlay P, Miller-Hance W, Chen MJ, Minami M, *et al*. A prospective randomized study comparing volume-standardized modified and conventional ultrafiltration in pediatric cardiac surgery. J Thorac Cardiovasc Surg 2001;122:220-8.
19. Sahoo TK, Kiran U, Kapoor PM, Choudhary SK, Choudhury M. Effects of combined conventional ultrafiltration and a simplified modified ultrafiltration in adult cardiac surgery. Indian J Thorac Cardiovasc Surg 2007;23:116-24.
20. Meliones JN, Gaynor JW, Wilson BG, Kern FH, Schulman SR, Shearer IR, *et al*. 762-3 Modified ultrafiltration reduces airway pressures and improves lung compliance after congenital heart surgery. J Am Coll Cardiol 1995;25:271A.
21. Bando K, Turrentine MW, Vijay P, Sharp TG, Sekine Y, Lalone BJ, *et al*. Effect of modified ultrafiltration in high-risk patients undergoing operations for congenital heart disease. Ann Thorac Surg 1998;66:821-7.
22. Javadpour H, Siddiah V, Redmond M. Effects of modified ultrafiltration in children undergoing repair of complete atrioventricular canal defect. J Cardiovasc Thorac Res 2009;1:1-4.
23. Journois D, Israel-Biet D, Pouard P, Rolland B, Silvester W, Vouhe P, *et al*. High-volume, zero-balanced hemofiltration to reduce delayed inflammatory response to cardiopulmonary bypass in children. J Am Soc Anesthesiol 1996;85:965-76.
24. Sever K, Tansel T, Basaran M, Kafali E, Ugurlucan M, Ali Sayin O, *et al*. The benefits of continuous ultrafiltration in pediatric cardiac surgery. Scand Cardiovasc J 2004;38:307-11.
25. Huseyin S, Yuksel V, Guclu O, Turan FN, Canbaz S, Ege T, *et al*. Comparison of early period results of blood use in open heart surgery. J Res Med Sci 2016;21:28.