

Modified Ultrafiltration PostExtracorporeal Membrane Oxygenation

Joseph Deptula, BS, CCP;* Thomas R. Karl, MD;† Dee Ann Griffin, BS, CCP;‡
Sherrie Fogg, BS, CCP*

*The Children's Hospital of Omaha, Omaha, Nebraska; †Children's Hospital, University of California, San Francisco, California;
‡The Children's Hospital of Philadelphia, Pennsylvania

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Abstract: Modified ultrafiltration (MUF) has been widely used for the removal of extracellular water in the immediate postcardiopulmonary bypass (CPB) period. The reported benefits of this technique are improved hematological status and hemodynamic stability post-CPB, as well as a decrease in blood utilization during the operation. MUF has also been associated with improved pulmonary status along with enhanced myocardial performance. With these benefits in mind, we have explored the possible advantages of using MUF following extracorporeal membrane oxygenation (ECMO). The theoretical advantages of

using MUF post-ECMO are the reduction of blood use prior to removal from ECMO for optimization of hemoglobin levels, improved pulmonary compliance decreasing the duration of ventilatory support, improved myocardial function, as well as the other reported benefits described with MUF post-CPB. This report communicates the technique used to perform MUF post-ECMO, as well as a simple MUF circuit design for use in the intensive care unit setting. **Key Words:** extracorporeal membrane oxygenation, modified ultrafiltration, cardiopulmonary bypass, pulmonary function. *JECT 2003;35:203–206*

The introduction of therapies such as high frequency oscillatory ventilation, surfactant therapy, and nitric oxide inhalation have lead to a decline in the number of patients requiring extracorporeal membrane oxygenation (ECMO). ECMO is currently used less frequently for respiratory failure and more frequently for sepsis or pneumonia with significant cardiovascular compromise (1). Over the past decade, there have been no changes seen in mean gestational age, gender, pH, or PaCO₂ before the initiation of ECMO (2). However, there has been a reduction in the proportion with respiratory distress syndrome, with an increase seen in the duration of ECMO. This data may suggest that the patients currently receiving ECMO are at increased risk for morbidity compared to a decade earlier.

According to the University of Michigan Medical Center, outcome indicators such as renal failure, improvement in lung compliance, return of the patient to dry weight,

and the need for inotropes on ECMO may be useful in predicting overall morbidity of ECMO support (3). One modality, which may help to improve the conditions for patients receiving ECMO, may be modified ultrafiltration (MUF) post-ECMO. MUF is used routinely in many pediatric centers postcardiopulmonary bypass (CPB) and has been shown to reduce the plasma concentration of interleukins (4). MUF improves postoperative pulmonary function in children with an increase in PaO₂ and a decrease in A-aDO₂ gradient when compared to controls (5). The increase in capillary permeability as a result of extracorporealization of blood causes an increase in total body water, prolonging ventilatory support. Pulmonary hypertension and poor lung compliance have also been shown to be reversed by MUF (6). Further investigation of this technique showed a marked increase in cardiac index, no change in systemic vascular resistance, and a decrease in heart rate and pulmonary vascular resistance. The use of MUF has been shown to increase myocardial contractility and reduce myocardial wall thickness (7). Studies of the increase in systolic and diastolic pressures have revealed that MUF improves left ventricular function and diastolic compliance, while reducing inotrope requirements in the early postoperative period (8,9).

Address correspondence to: Joseph Deptula Director of Perfusion Services, The Children's Hospital of Omaha, 8200 Dodge Street, Omaha, NE 68114-4113. E-mail jdeptula@chsomaha.org
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When comparing the effects of MUF to the outcome indicators listed by the University of Michigan Medical Center, one may speculate that this technique will decrease the morbidity associated with ECMO when considering the current patient population. This report communicates the technique used to perform MUF post-ECMO, as well as a simple MUF circuit design for use in the intensive care unit setting.

MATERIALS AND METHODS

An A-V ECMO circuit incorporating an ECMO bridge, venous bladder bag, positive and negative regulated pressure roller head, silicone membrane (Medtronic, Inc, Minneapolis, MN), EcmoTherm (Medtronic, Inc, Minneapolis, MN) heat exchanger, arterial and venous cannulae with “T” connector (Luer connector) are used in the standard circuit used for this technique (Figure 1). Patients are separated from ECMO in normal fashion. Should the cannulae not contain a Luer connector, one can be incorporated into the venous line between the cannulae and the bridge once the patient is separated from ECMO. When the patient is off ECMO, the bridge is also clamped and the pump shut off. An empty blood bag should be connected to one of the ports of the bladder bag and a one-liter bag of physiological crystalloid should be attached to the Luer port of the venous cannulae. A clamp is then placed on the venous cannulae, between the patient and the Luer connector, and the venous line drained of blood

into the empty bag on the venous bladder, by opening the venous line and the crystalloid bag. The venous line is kept free of air and fluid filled, should there be a need to re-institute ECMO. A MUF circuit should be crystalloid primed using 1/8 inch standard IV tubing connected to 3/16 inch roller pump boot tubing to the inlet of the hemofilter. The outlet of the hemofilter should be connected to 3/16 inch tubing, incorporating a screen bubble filter and then to standard 1/8 inch IV tubing. A single roller head can be placed onto a mobile cart for use as the MUF pump and situated next to the ECMO pump for simultaneous manipulation of the rates of each pump for patient volume control (Figure 2). The inlet to the hemofilter is then connected to the platelet port, situated between the oxygenator and the heat exchanger. The outlet of the hemofilter is connected to the Luer port on the venous line, removing the crystalloid bag, and displacing any residual air into the venous line. Once the connection has been deaired, the clamp between the venous cannulae and the Luer connection is removed and replaced between the Luer connector and ECMO bridge (Figure 3). MUF is initiated by running the filtration pump at a rate tolerated by the patient, usually 10–30 mL/kg/min. The volume removed from the patient is replaced by slowly running the ECMO pump head to displace the volume from the A-V circuit into the MUF circuit. Once the venous line blood bag is emptied it should be replaced with a bag of crystalloid solution, chasing the residual blood volume through the ECMO circuit. When the patient requires volume, the filtration

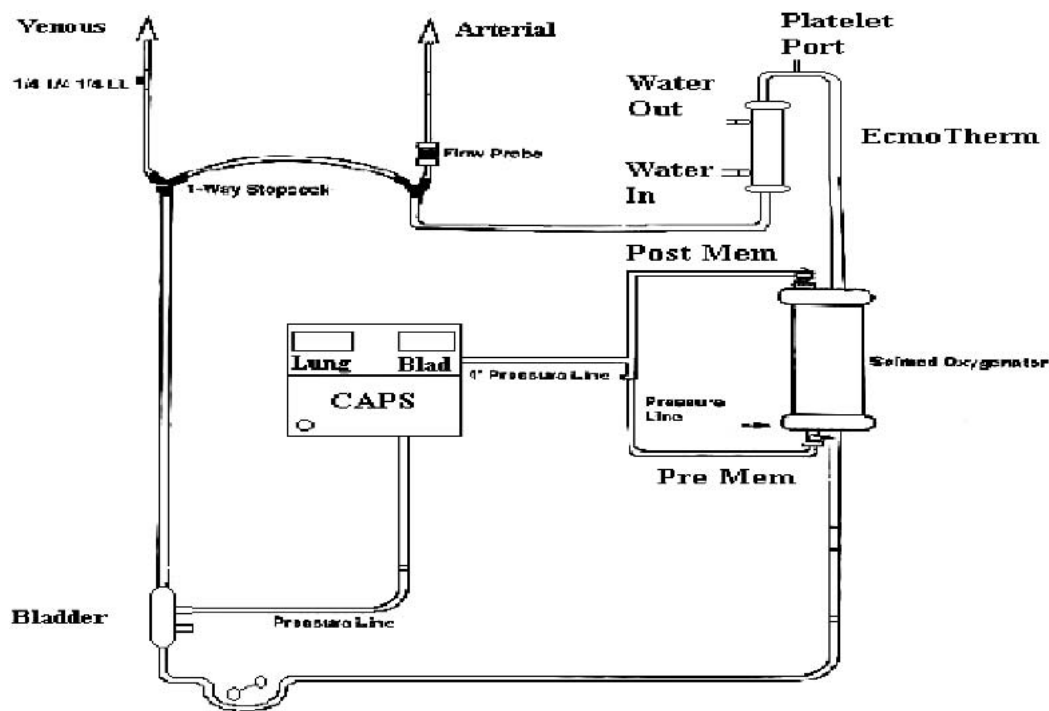


Figure 1. A-V ECMO circuit with roller pump and computer aided perfusion system (CAPS).

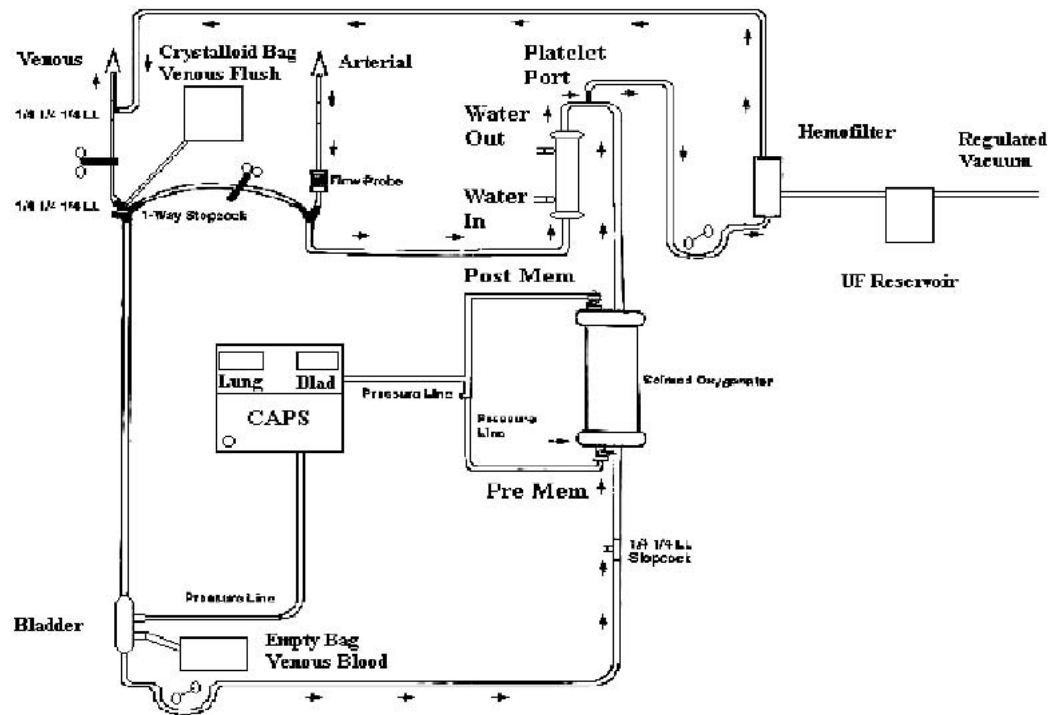


Figure 2. MUF circuit incorporated into an A-V ECMO circuit.

pump rate is lowered and the arterial pump head rate increased, transferring volume to the patient. MUF is continued until an adequate amount of volume is removed, roughly the priming volume of the ECMO circuit. The residual volume in the circuit is thus concentrated into the patient.

ANALYSIS AND DISCUSSION

With the decrease in the number of ECMO patients and the necessity for caution in selecting patients to be considered for MUF, we have only performed this technique in four patients; therefore, data is insufficient for comparison and analysis. Observations show an increase in mean arterial pressure, more importantly in diastolic coronary perfusion pressure, with a decrease in patient fluid volume signified by a reduction in central venous pressure, visual removal of free hemoglobin in the ultrafiltrate, and an increase in hematocrit between pre and post-MUF levels. Care should be taken not to over concentrate these patients as their hemoglobin levels can be drastically increased when a patient is removed from ECMO at hematocrits of 40% or higher. Often patients are transfused with packed red blood cells (PRBCs) just prior to removal from ECMO, optimizing the hemoglobin for hemodynamic stability and in preparation for any blood loss associated with decannulation. With the ECMO circuit being a closed system without blood returning back from the suckers, as in

conventional CPB, there is less of a recirculation phenomena and an ability to concentrate the entire residual blood volume of the ECMO circuit into the patient. With this in mind, one may consider not transfusing PRBCs just prior to coming off ECMO. Frequent blood gas monitoring is also helpful to monitor the hematocrit levels. A goal should be decided upon and once this level has been achieved then MUF should be terminated. Total protein levels should also be monitored. Since protein is not readily removed by the hemofiltration process, protein levels will continue to rise in these patients. Care should be taken in these patients not to create a hyperoncotic state.

The time to perform this technique and the amount of residual ECMO circuit volume able to be concentrated and transfused will be dependent upon the size of the patient. The flow rate of the ECMO circuit will be dependent on the amount of arterial blood able to be safely removed per minute without causing hemodynamic instability, usually 10–30 cc/kg/min. The larger the patient the faster the MUF pump can be run and the more fluid removed per minute. The amount of residual ECMO circuit volume, which can safely be concentrated and reinfused into the patient, will also be strictly patient-size dependent. In the neonate, the ECMO circuit volume to patient volume is high and therefore the ability to infuse residual circuit volume will be lower compared to a pediatric patient where the ECMO circuit volume to patient circuit volume is lower.

The physiological process of ECMO in the intensive care unit and cardiopulmonary bypass in the operating room are quite different. Cardiopulmonary bypass in the operating room is an acute process and therefore immune system activation is usually fulminate, seeing that the patients have only recently been placed on bypass. The levels of complement and activated immune system intermediate levels are more elevated than seen in the ECMO patient who has been on bypass for days to weeks where the acute phase immune system response may no longer be an issue. Interleukins and activated complement components will be higher in the post bypass patient in the operating room compared to the ECMO patient in the intensive care unit and therefore their level of removal will correlate to the level of circulating levels.

As with MUF post-CPB, there are complications to consider. Hypothermia during the MUF period, and entrainment of air into the CPB circuit (on the arterial side, across the membrane of the oxygenator or from around the cannula) have been reported. In smaller patients, there have been reports of arterial cavitation caused by obstruction of the aortic cannula by the aortic wall during extraction, as well as aortic obstruction by the arterial cannula itself (10). Air in the ECMO circuit is more easily removed through the bridge than during conventional MUF, although one still must be aware of the possibility of air in the arterial line. Air in the ECMO circuit is more easily removed through the bridge than during conventional MUF, although one still must be aware of the possible presence in the arterial line. Air emboli can best be avoided by recirculating the ECMO circuit after the MUF technique has been performed, should there be a need to reinstitute ECMO. We did not encounter any of these complications in the patients where this technique was performed.

Anticoagulation during the MUF period should also be closely monitored. MUF postbypass in the operating room setting is performed on blood fully heparinized (>400 sec). However, MUF performed post-ECMO is performed on blood only partially heparinized (<220 sec). Activated clotting time levels during ECMO are similar to that of continuous arteriovenous or venovenous hemofiltration where circuit and membrane clotting are not an issue. Singer and colleagues showed that unbound, free heparin does cross the hemofilter membrane yet, in an amount inconsistent to measure (11). However, since protein is not readily removed during hemofiltration, heparin bound to protein is concentrated in the patient, which may suggest that activated clotting levels would rise during and imme-

diately post-MUF. Care should be taken post-MUF to monitor the patient for excessive bleeding, which may be directly related to this phenomena where protamine reversal of heparin may be indicated.

CONCLUSION

Considering the patient population presently undergoing ECMO and the factors for outcome measures presented by the University of Michigan Medical Center, the use of MUF post-ECMO may be a way to reduce the morbidity associated with this technique. MUF may improve pulmonary function, reduce pulmonary hypertension, increase cardiac output and decrease heart rate and pulmonary vascular resistance, and improve left ventricular function and diastolic compliance while reducing inotropic requirement in post-ECMO patients as seen post-CPB. Further studies examining the benefit of this technique should be performed before any conclusions can be drawn in this patient population.

REFERENCES

1. Hintz SR, Suttner DM, Sheehan AM, Rhine WD, Van Meurs KP. Decreased use of neonatal extracorporeal membrane oxygenation (ECMO): How new treatment modalities have affected ECMO utilization. *Pediatrics*. 2000;106:1339-43.
2. Roy BJ, Rycus P, Conard SA, Clark RH. The changing demographics of neonatal extracorporeal membrane oxygenation patients reported to the Extracorporeal Life Support Organization (ELSO) Registry. *Pediatrics*. 2000;106:1334-8.
3. Swaniker F, Kolla S, Moler F, et al. Extracorporeal life support outcomes for 128 pediatric patients with respiratory failure. *J Pediatr Surg*. 2000;35:197-202.
4. Skogby M, Adrian K, Friberg LG, Mellgren G, Mellgren K. Influence of hemofiltration on plasma cytokine levels and platelet activation during extracorporeal membrane oxygenation. *Scand Cardiovasc J*. 2000;34:315-20.
5. Onoe M, Oku H, Kitayama H, Matsumoto T, Kaneda T. Modified ultrafiltration may improve postoperative pulmonary function in children with a ventricular septal defect. *Surg Today*. 2001;31:586-90.
6. Gaynor JW. Use of modified ultrafiltration after repair of congenital heart defects. *Semin Thorac Cardiovasc Surg Pediatr Card Surg Annu*. 1998;1:81-90.
7. Millar AB, Armstrong L, van der Linden J, et al. Cytokine production and hemofiltration in children undergoing cardiopulmonary bypass. *J Thorac Cardiovasc Surg*. 1993;56:1499-502.
8. 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.
9. Chaturvedi RR, Shore DF, White PA, et al. Modified ultrafiltration improves global left ventricular systolic function after open-heart surgery in infants and children. *Eur J Cardiovasc Surg*. 1999;15:742-6.
10. Darling E, Nanry K, Shearer I, Kaemmer D, Lawson S. Techniques of paediatric modified ultrafiltration: 1996 survey results. *Perfusion*. 1998;13:93-103.
11. Singer M, McNally T, Sreaton G, Mackie I, Machin S, Cohen SL. Heparin clearance during continuous veno-venous haemofiltration. *Intensive Care Med*. 1994;20:212-15.