Original Article

Modified Ultrafiltration After Congenital Heart Surgery:
A Veno–Venous Method Using a Dual-Lumen Hemodialysis Catheter

Brian J. LaLone, PhD, CCP,* Mark W. Turrentine, MD;† Ko Bando, MD;‡ Chris C. Frederick, BS, CCP;*
Michael T. Horner, BS, CCP;* Lon H. Richmond, CCP;* Alex P. Bezruczko, BA, BS, CCP;*
Susan M. Morris, BS, CCP;* Deborah L. Frankenberg, MS, CCP;* John W. Brown, MD†

*Sections of Cardiovascular Perfusion and †Cardiothoracic Surgery, James W. Riley Hospital for Children
and Indiana University Medical Center, Indianapolis, Indiana

Keywords: hemofiltration, hemoconcentration, extracorporeal circulation, cardiopulmonary bypass

Presented at the 35th International Conference of the American Society of Extra-Corporeal Technology,
April 3–6, 1997, Phoenix, Arizona

ABSTRACT

Perfusion practice surveys on modified ultrafiltration show most clinicians reporting the use
of arterial to venous cannulation. With an arterial–venous (A–V) approach, the patient’s blood
is accessed in a retrograde direction from the cardiopulmonary bypass aortic cannula, and the
hemoconcentrated blood is returned to a catheter placed at a systemic venous return site. To
avoid possible hazards of these arterial–venous techniques, we developed a veno–venous (V–V)
modified ultrafiltration circuit and method that: (1) uses an 11.5 F dual-lumen hemodialysis catheter placed at a right atrial cannulation site for concomitant pickup and return of the patient’s blood; (2) places the ultrafiltration circuit within the cardioplegia delivery system, enabling the use of the heat exchanger/bubble trap features and also allowing hemoconcentration during cardiopulmonary bypass; and (3) uses an elevated, collapsible transfusion bag within the circuit as a holding reservoir for crystalloid-chased blood from the CPB circuit.

The product literature and our lab testing of the hemodialysis catheter indicates adequate
hemodynamics for modified ultrafiltration in children, and our clinical experience shows
routine completion of the process in about 10–15 min (12.67 ± 1.73 mins; mean ± 1 SD, N = 9). Advantages of this V–V approach compared to A–V access include: (1) no potential aortic air entrainment at the aortic cannula purse-string suture; (2) modified ultrafiltration in patients regardless of aortic size or anatomy; and (3) avoidance of significant arterial to venous shunts during the performance of modified ultrafiltration. The elevated reservoir within the modified ultrafiltration circuit allows: (1) efficient pre- and/or postultrafiltration fluid chasing of blood from the main cardiopulmonary bypass circuit, thereby keeping it safely primed and allowing for the concentration of all circuit contents before and/or following the ultrafiltration method; (2) maintenance of desired patient filling pressures, temperature, and blood oxygen saturation within the ultrafiltration circuit by intermittent addition of warmed, oxygenated blood to the V–V modified ultrafiltration circuit.

Address correspondence to: Brian J. Lalone, CCP
Rm 0515, Indiana University Hospital
550 N. University Boulevard, Indianapolis, IN 46202-5200

THE JOURNAL OF EXTRA-CORPOREAL TECHNOLOGY
Volume 32, Number 2, June 2000
95

Article available at https://j ect.edpsciences.org or https://doi.org/10.1051/ject:2000322095
INTRODUCTION

Modified ultrafiltration (MUF) used components of the extracorporeal circuit to perform hemofiltration of the patient for a brief period immediately upon weaning from cardiopulmonary bypass (CPB). First introduced in 1991 by Naik’s group (1), clinicians using the method for pediatric cardiac surgery report perioperative hematocrit elevations (1–7), reductions in the rise in total body water (1, 2) and IL-8 levels (2, 8), reduced colloid transfusion needs (2, 9), increased blood colloid osmotic pressure (4), reduced blood loss and lower donor blood requirements (2, 9–12), improved hemodynamics (2, 9, 13–16), improved postoperative oxygenation and reduced duration of ventilator support (11), and reductions in the plasma titer of the terminal complement proteins C3a and C5a (6) as well as endothelin 1 (16). These reports of clinical benefit have been accompanied by a more widespread use of MUF following repair of congenital heart defects. In a series of pediatric perfusion practice surveys (17–20) Groom and associates report an increasing use of perioperative hemofiltration methods, with 43% of the programs responding in 1994 reporting the use of MUF (20).

When first incorporating MUF into clinical practice, perfusion teams have several considerations to weigh in deciding upon the approach that best suits their patients’ needs. Chief among these concerns is safety. Because MUF necessitates CPB circuit modifications, a fundamentally safe MUF circuit design (4) and operational protocol (5) are important issues. Safety concerns also drive the decision-making process addressing which MUF cannulation method to use, and what safety devices to incorporate into the MUF circuit (21).

Most clinicians report the use of arterial–venous (A–V) cannulation for MUF (20, 21). With A–V MUF, the patient’s blood is accessed in a retrograde direction from the CPB aortic cannula, and the hemofiltered blood is usually returned to a catheter placed in the right atrium. In a 1994 survey (20), 36% of respondents used an A–V method and only 7% of pediatric open-heart centers reported using an A–V approach. Darling and colleagues (21) surveyed 50 North American pediatric perfusion practices in 1996 and reported that of the 22 centers utilizing MUF, 86% were using an A–V approach.

Despite this predominant use of A–V methods, there are several theoretical disadvantages to the use of the CPB aortic cannula as a blood access for MUF. Using this method creates an arterial–venous shunt; which, in hemodynamically compromised patients, may not be well tolerated. In newborns, the aortic cannula is relatively large and can be obstructive to native cardiac output following some surgical corrections; possibly impairing MUF usage. Also, because of occasional malposition during retrograde flow, the tip of the aortic cannula can capture the aortic wall tissue resulting in negative pressures within the MUF circuit and aortic cannula; causing potential aortic air entrainment at the cannula purse-string suture when capture is released, and/or air entry into the MUF circuit either across the oxygenator membrane or by cavitation.

To potentially address these last concerns regarding air, an A–V MUF circuit can include safety devices such as a pump servo-controlled by circuit pressure and a bubble trap device (4, 5). Alternatively, the use of a V–V cannulation method for MUF would avoid all of the above problems. However, because the ultrafiltration process necessarily removes dissolved oxygen and, thus, desaturates the blood, the V–V method has been suggested to be potentially harmful (3, 22) by presenting to the lungs a blood so desaturated as to cause pulmonary vasoconstriction.

This report presents our experiences in the establishment of a V–V MUF method in our pediatric perfusion practice. The MUF circuit and protocol addresses the concern for an appropriate oxygen saturation of MUF blood returning to the patient and as well, incorporates other safety and cost-minimizing features.

MATERIALS AND METHODS

This work was conducted in two phases: preclinical and clinical. For the preclinical trials, we conducted both an in vitro and an in vivo study.

PRECLINICAL MATERIALS AND METHODS

In the in vitro bench testing, we studied three separate and identical circuits with outdated human bank blood to help define optimal operational parameters and protocol before conducting animal tests. These MUF circuits contained 1⁄4-in ID tubing throughout, except for a 1⁄4-in ID section of pump raceway tubing that was coupled to an ultrafilter (Minntecha HPH400). In these tests, the MUF circuit pick-up and return tubings were connected to a dual-lumen catheter that was inserted into the needle port of a 1000 mL IV bag filled with diluted bank blood.

One in vitro circuit was used to test the time required to hemoconcentrate diluted bank blood to a 40-plus hematocrit comparing two dual-lumen subclavian access hemodialysis catheters (Medcompb #T114C and Cookc #C-PU10. OD-NT-9-NS-DDS). These were identified from the literature (23, 24) as potentially acceptable for MUF use on the basis of the reported flow ranges (200–400 mL/min), outside diameter (10–12 F), and low recirculation rates (~9%). In this test, MUF pump flow was set at 200 mL/min and postultrafilter pressure was set at 400 mmHg by adjustment of a distally placed tubing screw clamp.

Another in vitro circuit was used to study pressure-flow relationships of the MUF circuit when using a Medcomp

a Minntech Corp., Minneapolis, MN
b Medcomp, Inc., Harleysville, PA
c Cook, Inc., Bloomington, IN
T114C catheter. For this test, MUF circuit pump flow was set at 113 and 196 mL/min, and pressures were measured at the luer inlet and outlet catheter connection sites during the start (hemodiluted, hematocrit = 14) and completion (hemocent- 
trated, hematocrit = 36) of the hemocentrination period. A third in vitro MUF circuit was connected to our standard pediatric CBP circuit and used to define necessary further circuit modifications and to conduct perfusionist orientation sessions.

In the in vivo preclinical studies, seven dogs weighing 8.4 to 26 kg (15.4 ± 7.8 kg) were placed on CPB after being anesthetized and paralyzed using guidelines according to “Guide for the Care and Use of Laboratory Animals,” (NIH Publication No. 85-23, revised, 1985). These animals were part of ongoing myocardial protection and pulmonary valve replacement studies. MUF was performed post-CPB to evaluate the appropriateness of the earlier bench findings, define necessary modifications in the MUF circuit, and associated procedures, conduct perfusionist troubleshooting and orientation sessions, finalize operational protocols, and familiarize the surgeons, anesthesiologists, and nurses with the MUF procedure.

Two different MUF circuit designs were used in the in vivo studies. In the first animal, a two-pump process for MUF was studied. In this circuit, V→V MUF was performed by one pump, and as ultrafiltrate was formed, the animal’s filling pressures were maintained with volume from the oxygenator by transfusion to the MUF circuit loop by the arterial CPB pump. For the remaining six animals studied, a one-pump MUF process was performed using the MUF circuit design employed in the clinical phase.

CLINICAL MATERIALS AND METHODS

Figure 1 illustrates the basic MUF circuit that was developed through the preclinical studies and applied to patients following congenital heart surgery. The MUF circuit was introduced into the main CPB circuit just distal to the arterial filter (Terumo® Capiox Pediatric #CX*AF02, or Medtronic® Intersept Pediatric #1338). This was the normal position occupied within our CPB circuit for the take-off of blood into a 4:1 blood

---

Dashed lines indicate the MUF circuit, with arrows denoting blood flow direction. Tubing clamps are positioned as during conduct of modified ultrafiltration during the postcardiopulmonary bypass period (see Table 1, step #6). Letters within circles (A through J) define potential position(s) of tubing clamps for the various uses of the circuit. Numbers 1 and 2 within circles define alternate stopcock attachment points of the ultrafiltered blood recirculation line. Asterisks denote the location of oxyhemoglobin sensor cuvettes placed within the circuit for five patients. Abbreviations: cm, centimeters; CPS, cardioplegia solution; IVC, inferior vena cava; MUF, modified ultrafiltration; RA, right atrium; UF, ultrafiltered.
The MUF circuit consisted of an ultrafilter (Minntech\textsuperscript{b} HPH400, or Baxter\textsuperscript{b} Hemocon 0.3), an 11.5 F dual-lumen hemodialysis catheter (Mecomp\textsuperscript{b} Duo-flow\textsuperscript{™} XTP #T114C) and a 1000 mL transfusion bag (Baxter\textsuperscript{b} Clintec\textsuperscript{®} Viaflex\textsuperscript{®} Container #2B8004). The MUF circuit tubing set was custom made (Gish\textsuperscript{g}, Cat. #8666 Riley Children’s V–V MUF Circuit) with a \(\frac{1}{8}\)-in ID pump boot and the remainder made from \(\frac{1}{8}\)-in ID tubing and appropriate connectors. With the transfusion bag (MUF supplement bag reservoir) empty, the total MUF circuit volume was 170 mL with the \(\frac{1}{8}\)-in MUF pickup and return table lines holding 35 mL.

Figure 1 shows tubing clamps positioned for the MUF procedure, with the perioperative events surrounding the MUF procedure schematized in Table 1. Parameters for MUF generally included a pump flow rate set at 10–30 mL/min/kg and a MUF circuit back pressure at the hemoconcentrator (transmembrane pressure, TMP) set to about 450 mmHg with a partial occluding (Hoffman) screw clamp (screw clamp H).

### Table 1: Routine sequence of steps for modified ultrafiltration at Riley Hospital for children

<table>
<thead>
<tr>
<th>Step # and approximate running time</th>
<th>Perioperative event</th>
<th>Team goals and procedures</th>
<th>Tubing clamp(s) on position(s)</th>
<th>MUF Pump, arterial pump and circuit characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 00:00</td>
<td>Off cardiopulmonary bypass, patient stable, and venous cannulae just removed</td>
<td>Begin pre-MUF circuit preparatory procedures</td>
<td>A–J</td>
<td>CPB and MUF circuits de-aired and blood-filled</td>
</tr>
<tr>
<td>2. 00:05</td>
<td>Perfusionist seeks and receives permission to chase venous line blood to oxygenator</td>
<td>Crystalloid chase of venous line blood from saline-filled basin</td>
<td>Clamp A briefly released to allow fluid chase</td>
<td></td>
</tr>
<tr>
<td>3. 00:20</td>
<td>Surgeon initiates MUF cannulation sequence</td>
<td>Perfusionist crystalloid-chases oxygenated, warmed blood in CPB circuit (venous reservoir through arterial filter) to MUF supplement bag reservoir</td>
<td>A, B, D, F, G, I, J</td>
<td>Arterial pump used for fluid chase procedure</td>
</tr>
<tr>
<td>4. 00:40</td>
<td>Surgeon asks perfusionist to fill MUF cannula lumens by gravity from MUF supplement bag</td>
<td>De-air MUF cannula lumens and connectors prior to cannulation</td>
<td>A–C; F, J</td>
<td>As surgeon taps cannula, 25–35 mL of blood is drained from MUF supplement reservoir</td>
</tr>
<tr>
<td>5. 01:00</td>
<td>Surgeon completes MUF cannulation through existing purse string suture in RA</td>
<td>Placement of cannula tip near inferior caval-atrial junction to pickup IVC blood</td>
<td>A–J</td>
<td></td>
</tr>
<tr>
<td>6. 01:30</td>
<td>Begin MUF procedure</td>
<td>Maintenance of appropriate right heart filling pressures as ultrafiltrate is lost from circulation</td>
<td>A–C; D or E; F</td>
<td>Intermittent placement of tubing clamp at location D or E enabling small aliquot addition of MUF supplement reservoir blood to V–V MUF circuit</td>
</tr>
<tr>
<td>7. 9:30 to 14:30</td>
<td>Perfusionist announces completion of MUF procedure</td>
<td>Perfusionist completes MUF procedure when MUF supplement reservoir is empty or desired hemoglobin is achieved</td>
<td>A–J</td>
<td></td>
</tr>
<tr>
<td>8. 15:00</td>
<td>Surgeon removes MUF catheter from RA</td>
<td></td>
<td>A–J</td>
<td></td>
</tr>
</tbody>
</table>
saturation cells (Gish g STATSAT, #SS2500) were placed in
monitor (Software version 4.0) and calibrated before the ter-
noted in Figure 1. These cells were connected to the STATSAT
the MUF IVC-pickup and RA-return lines at the locations
printer coupled to the RS232 dataport of the STATSAT moni-
and these values were continuously recorded during MUF by a
loop. Meter saturation data were updated at 3.3-sec intervals,
blood past the cells through a closed, shunted MUF circuit
-tested the ability of this method to augment the hemoglobin
al from the supplement bag reservoir. In five patients, we
mittent addition of oxygenated blood to the veno–venous cir-
determinations following each protamine dose.
the patients following transfusion of the concentrated pump
into the ultrafiltrate. Supplemental protamine was also given to
during the hemofiltration process very little heparin crosses
that the heparin reversal dose of protamine be given.
clamps at DEIJ, crystalloid tubing in raceway, and UF
recirculation line at stopcock position #2: see Figure 1).
While off bypass during pre- and post-MUF periods, the
MUF circuit can be used to concentrate blood from the main
cardiopulmonary bypass circuit (venous line through arterial
filter). This is accomplished by first using the arterial pump to
crystalloid-chase that portion of the circuit’s contents to the
MUF supplement bag (clamps at ABDFGHIJ, see Figure 1).
Next, the contents of the MUF bag can be hemoconcentrated
(clamps at ABCDFHI, crystalloid tubing out of raceway, UF
blood recirculation line at stopcock position #2: see Figure 1).
Following MUF cannula removal, the CPB circuit contents
were concentrated as described above when the surgeon re-
quested that the heparin reversal dose of protamine be given.
Because use of a hemofilter to concentrate residual pump con-
tents results in a significant concentration of heparin (25–28),
the protamine dose was calculated with the assumption that
during the hemofiltration process very little heparin crosses
into the ultrafiltrate. Supplemental protamine was also given to
the patients following transfusion of the concentrated pump
blood. The effectiveness of the initial and supplemental prot-
amine doses were assessed by activated coagulation test (ACT)
determinations following each protamine dose.
During MUF, patient volume was maintained by the inter-
mittent addition of oxygenated blood to the veno–venous cir-
cuit from the supplement bag reservoir. In five patients, we
tested the ability of this method to augment the hemoglobin
oxygen saturation of the MUF circuit blood returning to the
right atrium. For these patients, two ¼-in hemoglobin oxygen
saturation cells (Gish® STATSAT, #SS2500) were placed in
the MUF IVC-pickup and RA-return lines at the locations
noted in Figure 1. These cells were connected to the STATSTAT
monitor (Software version 4.0) and calibrated before the ter-
mination of CPB with a 5 min recirculating of CPB circuit
blood past the cells through a closed, shunted MUF circuit
loop. Meter saturation data were updated at 3.3-sec intervals,
and these values were continuously recorded during MUF by a
printer coupled to the RS232 dataport of the STATSTAT moni-
tor. The STATSTAT system digital electronics and software
provide a accuracy and responsiveness that allow it to report an
oxygen saturation change as small as 0.2% in 3 sec (29). For
each 3.3-sec interval update, a saturation difference was com-
puted between the MUF blood returning to the right atrium
(return) and the saturation of blood picked up at the cannula
lumen (pickup) in the IVC.

We timed the MUF procedure outlined in Table 1 in nine
consecutive patients to assess the time required to perform
MUF in our patients. In 12 separate patients, we examined the
ability of MUF to augment the patient’s hematocrit by per-
foming hematocrit determinations on radial artery blood
samples drawn immediately before and following the MUF
procedure.

Saturation, time of MUF, and hematocrit data were entered
into an Excel® database and analyzed for statistical significance
using analysis of variance (ANOVA) and paired r-tests. All
values were expressed as mean ± one standard deviation of the
mean.

RESULTS

PRECLINICAL STUDIES

In our in vitro test of the hemodialysis catheters, both
showed an ability to hemoconcentrate 1000 mL of buffered,
dilated bank blood from a 15 to a 40-plus hematocrit in less
than 10 min. The Medcomp® catheter was selected for clinical
use on the basis of a thinner wall thickness and the presence of
multiple side holes at the pickup and return sites.

The hemodynamics of the Medcomp catheter coupled to our
MUF circuit was examined at two blood flow levels and at two
different hematocrits in one in vitro circuit. At a flow of 113
mL/min, pressure at the return inlet to the cannula (postpump)
ranged from 29 to 33 (mean = 30.7) mmHg at a hematocrit of
14, and from 57 to 74 (mean = 65.5) mmHg at a hematocrit of
36. When pump flow was placed at 196 mL/min, pressure at
the cannula inlet ranged from 39 to 52 (mean = 45.2) mmHg at
a hematocrit of 14, and from 89 to 121 (mean = 105) mmHg at
a hematocrit of 36. At a flow of 113 mL/min, pressure at
the pickup arm of the cannula outlet (prepump) ranged from −8 to
16 (mean = 7) mmHg at 13 hematocrit, and from −42 to −2
(mean = −22) mmHg at a hematocrit of 36. When pump flow
was set to 196 mL/min, pressure at cannula outlet ranged from
−32 to 11 (mean = −21) mmHg at 13 hematocrit, and from
−48 to −20 (mean = −29) mmHg at a hematocrit of 36.

In the first animal studied, we rejected the use of a two-
pump model for MUF as too cumbersome and confirmed the
utility of the concept of a MUF supplement bag reservoir in the
subsequent six animals studied. Animal studies also confirmed
that by frequent intermittent addition from the supplement bag,
the apparent blood oxygen saturation (as determined by view-
ing the “brightness” of the blood) of hemoconcentrated MUF

i Microsoft Corp., Redmond, WA
blood returning to the right atrium could often be maintained at a higher saturation than the IVC pickup blood.

**CLINICAL STUDIES**

Patient use began in July, 1996 and through October 1998, 487 of 637 patients received MUF following cardiopulmonary bypass. There were no patient complications from the use of the MUF technique. Our total MUF clinical experience can be separated into two sequential periods: early and recent. In our early experience (July 1, 1996 through January, 1997) patients were considered for MUF treatment on the basis of patient entry into risk-stratified, randomized prospective trials studying the mechanisms of patient improvement following MUF and the utility of on-pump hemofiltration and MUF treatment. Portions of these studies and their results have been presented elsewhere (11, 16).

In our recent clinical experience (February 1, 1997 through October, 1998), 444 of 508 patients received MUF following cardiopulmonary bypass. MUF patients ranged in age from 1 day to 21 years (787 ± 935 days); weight varied from 2.2 to 152 kg (10.7 ± 9.7 kg). Of the 64 patients not selected for MUF during this period: 52 were large (weight greater than approximately 35 Kg, with no other indications such as preoperative pulmonary hypertension, pulmonary edema, renal failure); nine were transferred directly from cardiopulmonary bypass to long-term extracorporeal membrane oxygenation (ECMO) support; and three died immediately upon separation from cardiopulmonary bypass following surgical correction. The MUF ultrafiltrate volume ranged from 300 to 3200 mL (816 ± 297 ml). Indexed to body weight, the MUF fluid loss ranged from 19 to 431 mL/kg (106 ± 59 mL/kg).

In a consecutive group of MUF patients treated in February, 1997 (N = 9); the time required to accomplish the V–V MUF technique as outlined in Table 1 was 12.7 ± 1.73 min. In 12 other MUF patients treated before February, 1997, the patient hematocrit was elevated 56.4 ± 27.7% by MUF from 20.1 ± 4.4 to 30.9 ± 5.5 (p = .00008).

The oxygen hemoglobin saturation data from five patients are displayed in Figure 2. As illustrated by the oxygen hemoglobin saturation difference (Figure 2, lower panel), the MUF blood returning to the patient was augmented with oxygen in 760 of the 762 STATSAT meter updates throughout the duration of MUF. The saturation difference ranged from −0.1% + 48.3%; whereas, time of MUF varied between 5.3 to 14.5 min. The mean saturation data (Figure 2, upper panel) demonstrates that this veno–venous MUF method consistently elevates the oxygen hemoglobin saturation of the MUF blood returning to the patient’s right atrium. For the entire duration of MUF in these five patients, the IVC pickup blood averaged 59.5 ± 8.6% and was augmented to 78 ± 8.6% upon return to the patient’s RA, 18.6 ± 9.1% difference (p < .00001).

In an attempt to reduce cost and increase utility, we incorporated the MUF circuit into the cardioplegia circuit and included a bag reservoir to enable postpump processing of circuit

---

**Table 2: Disposables cost difference for use of MUF compared to post-CPB centrifugal cell salvage and 4:1 blood cardioplegia delivery**

<table>
<thead>
<tr>
<th>MUF replaces post-CPB cell salvage of CPB circuit contents*</th>
<th>MUF replaces post-CPB cell salvage of CPB circuit contents and 4:1 blood cardioplegia*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat exchanger in MUF circuit</td>
<td>Bubble trap in MUF circuit</td>
</tr>
<tr>
<td>$89.40</td>
<td>$34.80</td>
</tr>
<tr>
<td>$6.72</td>
<td></td>
</tr>
</tbody>
</table>

*Assumes hemoconcentrator use during CPB on all cases.
contents. Thus, our MUF method was employed without the concurrent use of a centrifugal cell salvage device for post-MUF processing of the extracorporeal circuit blood. As illustrated by the cost data of Table 2, our experience shows an approximate additional cost of $7 to perform MUF on pump cardioplegia cases; with higher costs incurred on cases in which cardioplegia is delivered by the surgeon.

DISCUSSION

Our experiences with the dual-lumen hemodialysis catheter indicate that although MUF hemodynamics were satisfactory, improvements are needed in the catheter design to optimize it for MUF. This catheter was designed for a Seldinger guidewire insertion via a subclavian or femoral stick (24). Accordingly, it has a sharper tip than is desired for placement at the inferior cavoatrial junction. In addition, being designed for longer-term use than a 10–15 min MUF treatment, the materials of construction are necessarily more expensive than may be required for MUF.

It is noteworthy that although we experimented with a dual cannulation technique for V–V MUF in the animal lab setting, we have no clinical experience using this modality. With practiced technique, it is reasonable to expect that the cost of the dual-lumen cannula could be eliminated by instead using two cannulae (i.e., a vent catheter and a small venous cannula) already opened on the operative field. An important feature of the particular dual-lumen cannula chosen for our work, is that it’s inherent design limits the recirculation rate to a nominal amount (24). As discussed by Darling and colleagues (21), one potential disadvantage of a veno–venous method that both accesses and returns blood to the right atrium is the possibility of considerable recirculation. Because we found that MUF can be accomplished in a reasonably short period of time with the use of the chosen dual lumen catheter, our studies suggest that recirculation effects are minimal.

The veno–venous approach avoids the risks of aortic-cannula related arterial air embolism that may accompany a negative pressure event with arterial-venous methods. Although servo-control of the arterial–venous pump may reduce the likelihood of such embolisms, this technology is not available from all pump manufacturers. It is important to note that negative pressure is present within the IVC pickup arm of our MUF circuit during routine operation. Accordingly, within our protocol we have a mandatory check of a tubing clamp placed on the MUF access line to the main CPB circuit (position C, Figure 1), preventing air entry across the membrane oxygenator.

The method reported here illustrates the utility of including an in-line reservoir within the MUF circuit. Circuit blood contents can be translocated to the reservoir enabling a hemoconcentrated blood product for later transfusion, thus avoiding the use of centrifugal cell processing with its attendant loss of platelets, clotting factors, and other plasma proteins. In addition, by semicontinuous addition of the warm supplement reservoir blood to the V–V MUF circuit, the patient’s filling pressures and blood temperature can be easily maintained.

This study indicates that while supplement bag blood is added to the circuit, the hemoconcentrated MUF blood returning to the right atrium has an approximate 18% higher blood oxygen saturation than that blood entering the MUF circuit from the IVC. Elliott has suggested that the benefits of MUF may partially derive from the delivery of an oxygenated blood to the lungs (8). In this regard, one group reports abandonment of V–V MUF (nonoxygen supplemented) in a patient when pulmonary hypertension was observed (3). In our own experience, this has not been found. Rather, in a prospective study using the particular veno–venous method reported herein, patients with preoperative pulmonary hypertension receiving V–V MUF have a reduced incidence of perioperative pulmonary hypertension compared to the control group not receiving MUF (16). Other benefits accompanying MUF usage in our patients included a decreased need for blood transfusion and a reduced duration of ventilatory support with an improved postoperative oxygenation (11).

Our experience, like that of others working with arterial–venous methods, shows a marked rise in hematocrit through the use of modified ultrafiltration. In addition, this method is generally performed in less than 15 min and is accompanied with improved hemodynamics. Results to date indicate that the technique has great promise.

ACKNOWLEDGMENTS

The authors gratefully acknowledge Lisa Fisher, Randy Bills, Kim Sun M.D., and Jeff Morelock, M.D. for their assistance in the conduct of the animal studies. We also thank Palaniswamy Vijay Ph.D. and Thomas G. Sharp M.D. for their guidance and support in this work. For their assistance in the provision of some disposable products in the conduct of these studies, we acknowledge the support of the Minntech Corporation, Medcomp Inc., and Specialized Medical Systems.

REFERENCES


