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The Novel Use of a Low Prime Modified Ultrafiltration Apparatus in a 13-kg Jehovah's Witness Patient: A Case Report

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Abstract: Modified ultrafiltration (MUF) is used in neonates and infants to reduce volume overload and increase oxygen-carrying capacity post cardiopulmonary bypass (CPB). In addition, it decreases edema, attenuates complementation activation and immunogenic response to CPB. Hemodilution in the pediatric patient has always been a challenge, countered in part by miniaturization of CPB circuits. We describe a case in which we maintained an acceptable hematocrit level greater than 24%, considered the nadir below which the adverse effects of hemodilution can become evident. We performed this by the novel use of an intravenous warming device (enFlow, Vyaire Medical, Mettawa, IL) to reduce the prime volume of our MUF circuit by more than 50%. We present the case and discuss the advantages and disadvantages of using a low-prime MUF circuit. We were able to conduct "bloodless" CPB, with the use of acute normovolemic hemodilution, miniaturization of the CPB and MUF circuits.
Keywords: modified ultrafiltration, cardiopulmonary bypass, Jehovah's Witness, enFlow. *J Extra Corpor Technol. 2018;50:178–83*

OVERVIEW

Pediatric patients whose parents belong to the Jehovah's Witness (JW) faith are a unique challenge to the pediatric cardiac team. In particular, the ability to perform bloodless cardiopulmonary bypass (CPB) poses significant challenges. At our institution, we have miniaturized CPB circuitry to reduce the priming volume by 66% (1). This in turn has reduced intraoperative blood transfusion requirements by 55%. Unlike many pediatric cardiac centers, we do not have all disposables included in a custom pack, giving us the flexibility to mix and match the oxygenator, tubing packs, cardioplegia, and modified ultrafiltration (MUF) setup (Table 1). With low prime volumes in our neonatal patients, a significant portion of "volume steal" existed at the end of the case, when the MUF circuit needed to be primed. Just before terminating pediatric CPB, the amount of volume available to the perfusionist is somewhere between 100 and 200 mL. Needing 60–70 mL to prime the MUF circuit constituted significant "volume steal." This steal was because of the need for priming a large MUF circuit in relation to our CPB circuit.

Outcomes of cardiac surgery on JW patients have been shown to be similar to those of other faiths (2). Blood conservation techniques to support bloodless CPB for JW patients have been previously described (3). Several case reports have been published on bloodless CPB on pediatric JW patients, one on children under 5 kg (4). Current evidence suggests that it is both safe and possible to conduct bloodless CPB for patients of the JW faith.

CASE DESCRIPTION

This case report was written with the permission from our institutional review board (1215332-1). A 2.2-year-old child, weighing 13.5 kg, with the diagnosis of ventricular septal defect (VSD) and interrupted inferior vena cava (IVC) presented for elective surgery. The parents were of the

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Table 1. CPB component selection for various weights categories.

	Neonate (2–7 kg)	Infant (7–15 kg)	Pediatric (15–22 kg)	Child (23–45 kg)	Adult (45–90 kg)	Adult (>90 kg)
Oxygenator	Maquet neo	Maquet neo	Maquet ped	Maquet ped	Capiox FX 15	Medtronic fusion
Tubing (art/ven)	3/16″ × 1/4″	3/16″ × 1/4″	1/4″ × 1/4″	1/4″ × 3/8″	3/8″ × 3/8″	3/8″ × 3/8″
Raceway	1/4″ (small)	1/4″ (large)	3/8″	3/8″	1/2″	1/2″
Prime vol (mL) before RAP	128	148	250	350	500	600

RAP, retrograde autologous prime.

JW faith and refused to consent for blood product transfusions. The patient measured 77.5 cm in length with a body surface area of .51 m^2. A comprehensive intraoperative plan was developed to conduct bloodless CPB per the parents' wishes.

The child received a total of eight doses of 500 μ/kg erythropoietin subcutaneously (Epogen; Amgen, Thousand Oaks, CA), twice a week over a period of 4 weeks before surgery and had an initial hemoglobin (Hb) level of 14.2 g/dL (post treatment and before surgery). Iron supplements were not given. Informed consent was obtained for the use of cell saver blood salvage and for the use of 25% human albumin solution.

Following induction of anesthesia and tracheal intubation, arterial and central venous access were obtained. Two-site (cerebral and renal) near-infrared spectroscopy (Covidian, Mansfield, MA) was used. Baseline arterial blood gases and activated clotting time (ACT) were measured. Acute normovolemic hemodilution (ANH) yielded 200 mL of autologous blood (15 mL/kg), collected in a bag containing 26 mL citrate phosphate dextrose with adenosine. Blood pressure was managed with a combination of pressors (Neo-Synephrine) and partial replacement of intravascular volume with normal saline. A heparin dose response test was performed using Hepcon HMS Plus (Medtronic, Minneapolis, MN) with an un-heparinized patient sample. The heparin concentration was set at 3.5 mg/kg. The heparin dose was determined to be 6,000 international units (IU).

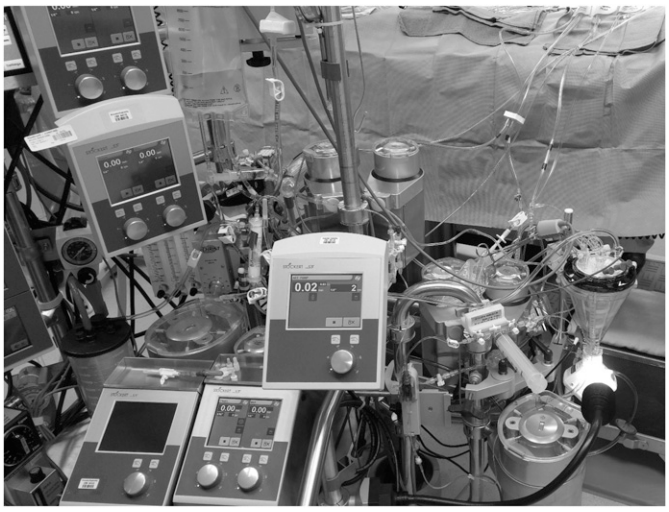

Figure 1. CPB circuitry for the JW patient.

An S5 heart lung machine (HLM) (Livanova, Arvada, CO) was used with a staggered pump configuration (Figure 1). A Quadrox-i neonatal integrated oxygenator (Maquet, Arrlingen, Germany) was set up with a 1/4 × 1/4″ Cortiva-coated tubing pack (Medtronic) and primed with 80 mL Plasmalyte A, 50 mL 25% human albumin, 5 mL sodium bicarbonate, 4 mL cefazolin, 5.4 mL Amicar, and 2000 IU of heparin. A CDI 500 (Terumo, Ann Arbor, MI) arterial sensor and a 1/4″ venous sensor was incorporated into the circuit to measure online blood gas trending. A Livanova CSC 14 cardioplegia pack was set up to administer del Nido cardioplegia solution. A Hemochron Junior (Minntech Corp., Minneapolis, MN) was attached to a 1/8″ line originating from a post-oxygenator port, run through a roller pump and primed. A 55-mL bowl was set up in the Xtra cell saver (Livanova) and directly attached to the patient's intravenous line. The total static prime volume of the CPB circuit was measured at 146 mL.

The patient was heparinized by the surgeon by the direct injection of 6,000 IU of heparin into the right atrium and then purse string sutures were placed. A 12-Fr Bio-Medicus wire–reinforced arterial cannula (Medtronic) was inserted into the aorta and placement was checked by running volume into the aorta from the HLM. Cardiotomy suckers were initiated at an ACT >300 seconds with the final ACT value measured as 609 seconds. Bi-caval cannulation was performed with a 16-Fr curved plastic tip (Edwards Life Sciences, Irvine, CA) in the superior vena cava and an 18-Fr right-angled metal tip venous cannula (DLP; Medtronic) in the IVC.

Retrograde arterial prime (Figure 2) was performed and 40 mL of crystalloid removed. An additional 50 mL of crystalloid was also removed into a bag (Figure 2) before initiating CPB, reducing effective static prime to <100 mL. The patient was cooled to 28°C and a cross clamp applied. Del Nido cardioplegia 20 mL/kg was administered and the VSD was closed with a pericardial patch. Electronic charting was performed through the CONNECT system (Livanova) and blood gases measured at initiation of CPB and roughly every 30 minutes thereafter (Table 2).

Baseline cerebral saturations were measured and are depicted with Hb values in Table 2. We were able to wean from CPB after a cross clamp time of 45 minutes and a bypass time of 76 minutes. Hematocrit (Hct) measured

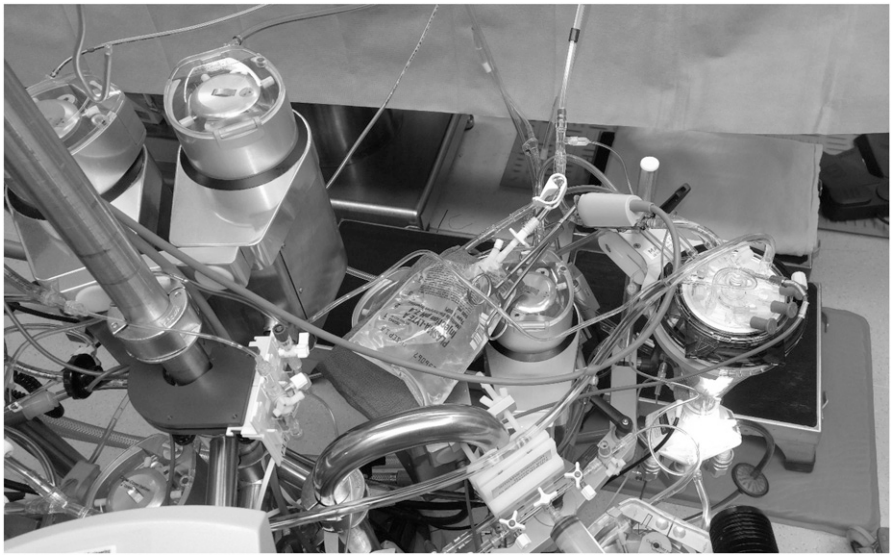

Figure 2. RAP—retrograde autologous priming.

Table 2. Hemodynamic and blood gas parameters on CPB.

Time	Cerebral Oxygen Saturation (%)	Hb (g/dL)	HCT (%)	Lactate mmol/L	Pump Flow (mL/kg)	MAP (mmHg)	Venous Oxygen Saturation (%)
Baseline	68/59	14.3	42	1.4	–	61	–
CPB 13 minutes	95/58	10.5	31	2.6	102	38	75
CPB 51 minutes	66/70	9.2	27	2.4	95	40	73
CPB 72 minutes	53/70	8.2	24	2.1	101	41	69
Post-CPB	70/65	10.2	30	2.2	–	53	–

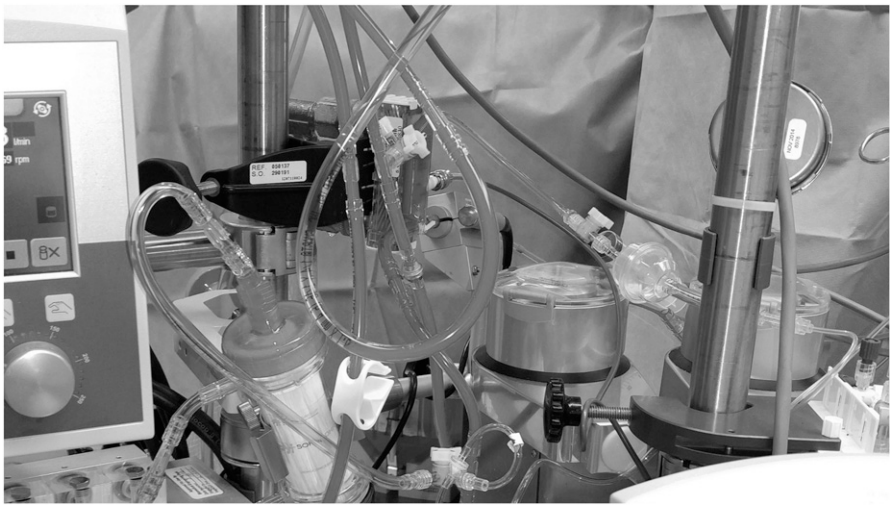

Figure 3. Old MUF circuit with CSC 14 and DHF 02 hemoconcentrator.

before termination of CPB was 24%. A partial bowl was washed in the cell saver, resulting in packed red cells with a Hct of 30%. This volume was transfused to the patient. The Hct of the patient increased to 30% after performing 10 minutes of MUF and transfusion of the autologous blood after protamine administration. We did not measure the Hct post-MUF and pre-ANH, and thus could not determine the efficacy of both separately. During the case, 200 mL of crystalloid was removed via conventional ultrafiltration and an additional 250 mL removed via MUF. At the end of CPB, the patient's estimated fluid balance was negative 3 mL.

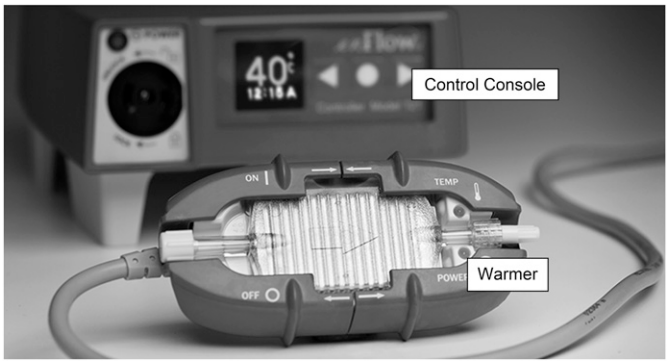

Figure 4. The Enflow fluid warmer with control console (courtesy: Vyaire Medical).

The Hct of the patient was 34% on admission to the intensive care unit postoperatively and 35% on post-op day 1. The patient was discharged on the third post-op day with a Hct of 34%.

COMMENTS

The MUF circuit at our institution until November of 2017 consisted of a Livanova CSC 14 with a static prime of 31 mL with a Hemocor high performance hemoconcentrator (HPH) Junior (Minntech Corp.) with a static prime of 8 mL (Figure 3). The total MUF circuit static prime, including the 1/8″ inlet line from oxygenator outlet and a 1/8″ delivery table line was approximately 60 mL. After cross clamp release this cardioplegia circuit was flushed with blood from the systemic circuit and comprised a large volume steal. In most instances the volume of blood available to the perfusionist in the venous reservoir of a neonatal/infant circuit was between 100 and 200 mL.

In December of 2017, we transitioned to a smaller MUF circuit, replacing the 31 mL CSC 14 heat exchanger with an IV blood warmer, enFlow (Vyaire Medical), with a static prime of 4 mL (Figure 4). The routine use of the enFlow for MUF at our institution is off-label. The MUF circuit consisted of a 1/8″ line running from the outlet of the oxygenator, through a 3/16″ raceway tubing into a HPH junior and then into an enFlow cartridge (Figure 5). The total static prime of this circuit was approximately 20 mL, reducing the blood steal from the systemic circuit by more than 60%. The concept of blood flow during MUF is represented in a schematic (Figure 6).

The enFlow was originally designed for the military for heating transfused blood in extreme conditions (5). It has a lightweight controller (9.7 oz) and a disposable cartridge, which heats the blood in seconds when loaded on the warmer to 40°C. The high temperature is designed to offset heat loss. A long extension cord assists in easy placement for transport or mounting on the HLM. With a prime volume of 4 mL, it is an ideal disposable to use for MUF. The enFlow has an overheat audible alarm at 41°C, and the cartridge has a safety feature in that it will not heat unless loaded onto the warmer cassette. Once the cassette is closed a green light turns on confirming warming. This light is blue if the temperature of the cassette goes below 35°C, yellow when above 43°C, and red at 45°C. In many instances, the patient is warm enough that we do not have to use the warming function, so cartridge is placed onto the warmer, but the cassette is not closed, thus, disabling the warming feature. An extension pigtail comes with the cartridge, but we recommend using a 1/8″ pigtail, post hemoconcentrator. The maximum flow detailed in the instructions for use manual is 200 mL/min. We have

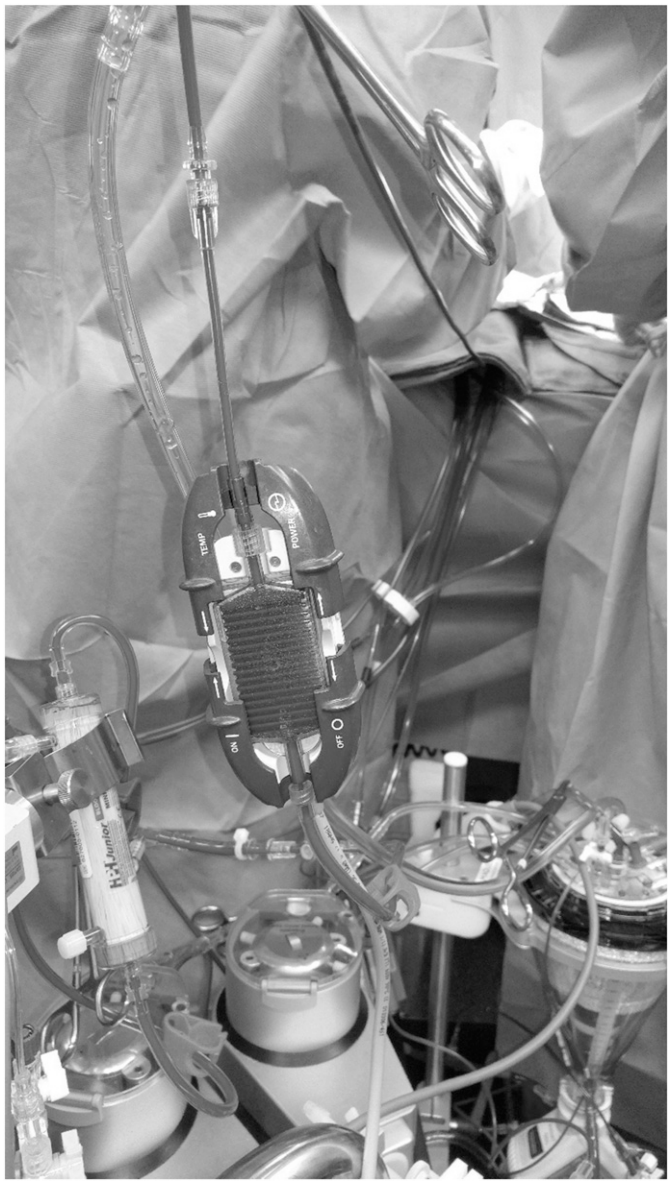

Figure 5. Enflow cartridge in place with hemoconcentrator.

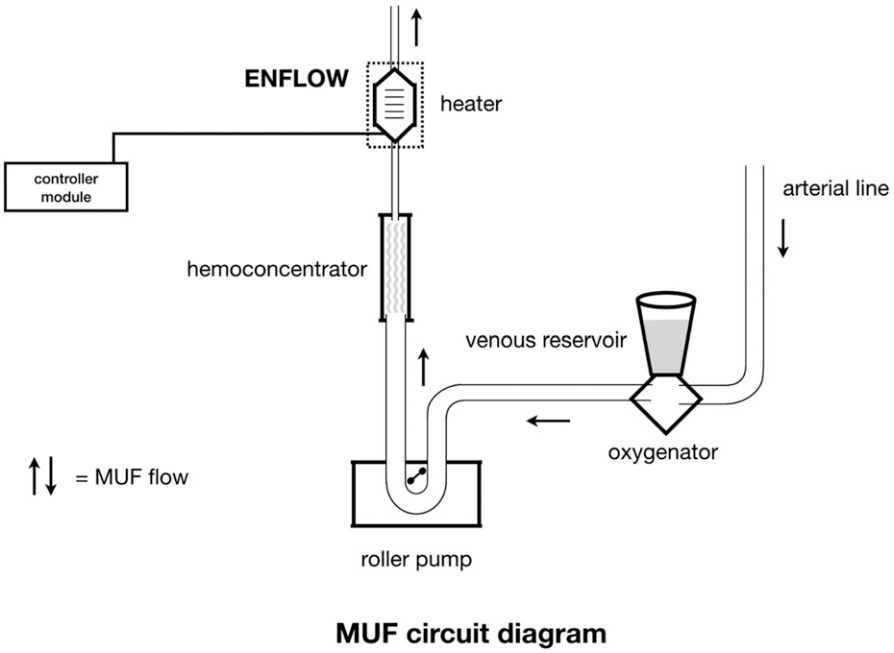

Figure 6. MUF circuit diagram.

used flows up to 250 mL/min with a Minntech junior hemoconcentrator and 300 mL/min with the larger Sorin DHF 02 (Livanova) hemoconcentrator. System pressures measured in both scenarios did not exceed 250 mmHg.

Another alternative available to us was the Sarns Conducer (Terumo), with a prime volume of 7 mL (6). This alternative was not an option because of the need for an additional de-airing circuit, thereby, increasing the static prime of the proposed new MUF circuit.

The nadir Hct, below which end organ dysfunction can manifest, is considered to be 30% in adults (7,8). In this case, the lowest recorded Hct was 24%, considered to be the corresponding nadir in pediatric CPB (9). Transfusion trigger on patients undergoing cardiac surgery is a controversial issue. In adults undergoing cardiac surgery, a transfusion trigger at a Hb of 7.5 g/dL or HCT of 21% is accepted practice (10). In pediatric cardiac surgery, this trigger is 8 g/dL for single-ventricle patients and lower for two-ventricle patients (11).

Our patient precluded transfusion. The ethics of consent for transfusion in mentally incompetent adults and underage children are unclear. Parents can provide consent for children, provided the following criteria are met: consent is voluntary, the patient has the capacity, consent is specific to the person/treatment, and the consent is informed (12). Possessing the ability to perform bloodless CPB would give cardiac teams the added advantage of significant cost savings, improved outcomes, and avoid the ethical/legal considerations surrounding blood transfusion.

CONCLUSION

Miniaturization of the MUF circuit is important in addition to miniaturization of the CPB circuit to perform bloodless CPB in neonates and infants. A team-centered philosophy of preoperative preparation, ANH, minimal sampling, innovative CPB circuit design, and meticulous surgical technique contributed to the successful bloodless operation in this patient.

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