

Case Report

Bloodless Arterial Switch Operation in a 2.7-kg Jehovah's Witness Patient

Jeffrey L. Burnside, BS, CCP, FPP;* Todd M. Ratliff, BS, CCP, FPP;* Madeleine N. Kelly, BS;†
Aymen N. Naguib, MD;‡ Mark Galantowicz, MD;* Ashley Hodge, MBA, CCP, FPP*

*The Heart Center at Nationwide Children's Hospital, Columbus, Ohio; †SUNY Upstate University, Syracuse, New York; and ‡Department of Anesthesiology and Pain Management, Nationwide Children's Hospital, Columbus, Ohio

Abstract: Bloodless pediatric cardiac surgery requiring the use of cardiopulmonary bypass (CPB) remains a challenge for the entire operating room (OR) team. The amount of circulating blood volume to pump prime volume mismatch of small patients results in hemodilution that frequently results in transfusion of allogeneic blood products. Patients of families of the Jehovah's Witness (JW) faith reject the use of these products because of religious beliefs. Our institution is a referral center for children of JW families because we have developed techniques to minimize blood loss with the hope of performing bloodless pediatric cardiac surgery whenever possible. These techniques include preoperative treatment with erythropoietin, intraoperative acute normovolemic hemodilution, CPB circuit miniaturization, ultrafiltration during and after

CPB, limiting blood gas analyses or other unnecessary blood draws, and using hemostatic agents during and after CPB. We present the case of a 4-day-old patient of the JW faith weighing 2.7 kg with transposition of the great arteries and an intact ventricular septum who underwent an arterial switch operation. The patient received no allogeneic blood product administration throughout the entire hospitalization. The patient's first hematocrit in the OR was 43%, lowest hematocrit on bypass was 15%, and first hematocrit in the cardiothoracic intensive care unit post-procedure was 21%. The patient was discharged on post-op day nine with a hematocrit of 36%. **Keywords:** pediatric cardiac surgery, Jehovah's witness, arterial switch operation, bloodless surgery, neonatal. *J Extra Corpor Technol. 2020;52:142–5*

The avoidance of allogeneic blood use in pediatric cardiac surgery remains a challenge to the entire operating room (OR) team. A close collaboration among the surgeon, anesthetist, cardiac intensive care unit intensivists, and perfusionist is imperative to achieve the goal of avoidance of blood product administration during and after procedures requiring cardiopulmonary bypass (CPB) (1). Many potentially negative risks are associated with the transfusion of blood products including costs, increased risk of infection, increased 30-day mortality, and the incidences of poor outcomes (1,2).

Our institution has endeavored to perform bloodless pediatric cardiac surgery whenever possible. We have

miniaturized circuits, perform zero-balance ultrafiltration (ZBUF), and after CPB perform modified ultrafiltration (MUF) to reduce the prime volume impact on the patient. We also use both acute normovolemic hemodilution (ANH) and retrograde autologous prime (RAP)/venous antegrade prime (VAP) before CPB to minimize hemodilution (1–5).

Our Heart Center is a referral site for children of the Jehovah's Witness (JW) faith who present with congenital cardiac defects that require repair using CPB. JW patients reject allogeneic blood product transfusions based on their religious beliefs; therefore, as an institution, we have protocols in place for this select population. These included the necessity of maintaining a patient's circulating blood volume (CBV) in physical contact with the patient at all times. The CPB circuit fulfills this obligation as the patient's blood circulates in a contiguous loop. ANH removal and readministration were modified so as to be maintained in a constant contiguous circuit with the patient's circulation (4–6).

The following is a case report of a 4-day-old male (2.7 kg, 48 cm, .18 m²) whose parents are of the JW faith and

Received for publication December 4, 2019; accepted March 30, 2020.
Address correspondence to: Jeffrey L. Burnside, BS, CCP, FPP, The Heart Center at Nationwide Children's Hospital, 700 Children's Drive, Columbus, OH 43205. E-mail: Jeffrey.Burnside@NationwideChildrens.org
The senior author has stated that the authors have reported no material, financial, or other relationship with any healthcare-related business or other entity whose products or services are discussed in this paper.

requested no blood products be administered. The neonate was diagnosed with transposition of the great arteries and an intact ventricular septum and presented for an arterial switch operation.

DESCRIPTION

The patient received erythropoietin (EPO) injections (Amgen, Inc., Thousand Oaks, CA) that were administered subcutaneously (500 U/kg) every day for three days before the procedure. The CPB circuit consisted of a Terumo FX-05[®] oxygenator (Terumo Cardiovascular Systems Corporation, Ann Arbor, MI), a 1/8-inch arterial line, 3/16-inch venous line, 3/16-inch arterial boot, and 3/16-inch suckers. For hemofiltration and ZBUF during CPB, a Minntech Hemocor HPH MINI (Minntech, Minneapolis, MN) was used. Because we try to minimize our CPB circuit, a Sorin Cobe CSC-14 Custom 1:1 cardioplegia delivery system (Sorin Group USA Inc., Arvada, CO) was used for the delivery of cardioplegia, as well as to warm the blood in the MUF circuit. A spectrum-level sensor was placed at the manufacturer's suggested minimum operating level, and a bubble detector was placed on the arterial line post-oxygenator. The circuit was primed with Normosol-R[®] (Hospira, Inc., Lake Forest, IL), 5 mEq sodium bicarbonate (Hospira, Inc.), 1,000 IU (1.0 mL) sodium heparin (Sagent Pharmaceuticals, Schaumburg, IL), 1,350 mg 25% mannitol (Hospira, Inc.), and 50 mL 25% albumin (Baxalta US, Inc., Lexington, MA). The family was consulted pre-op and was agreeable to the addition of human albumin to the CPB prime solution. This is a human blood product but is acellular and not considered a foreign blood product. In addition, 54 mg tranexamic acid (Pfizer Inc., New York, NY) were added to the venous reservoir immediately following RAP/VAP. A three-dose regimen is used with 20 mg/kg (with a maximum of 1,000 mg) administered to the patient following the induction of anesthesia, the second dose added to the pump prime, and the third dose given following protamine reversal post-CPB. Finally, 70 mg cefazolin (West-Ward Pharmaceutical Corp., Eatontown, NJ) (20 mg/kg, with a maximum of 1,000 mg) is added to the venous reservoir after RAP/VAP. Patients receive a 20 mg/kg (with a maximum of 2,000 mg) loading dose of cefazolin from anesthesia to post-induction of anesthesia.

A Spectrum heart lung machine (Spectrum Medical, Fort Mill, SC) was used for the case as its design allows for pump configurations that minimize the length of the pump boot, arterial and venous lines, and suckers. The total prime volume of the circuit, cardioplegia, and hemofilter constituents was 140 mL. No baseline laboratory values were drawn preoperatively to conserve blood according to our JW protocol. Baseline blood gas analysis and activated clotting time (ACT) were obtained post-placement of an

arterial blood pressure monitoring line. Any samples removed from this arterial line were accomplished with a two-stopcock technique. The first stopcock is a normal feature to allow for regular blood sampling. An additional stopcock was placed atop this one to allow for the readministration of waste blood drawn to obtain the sample. This assures that the waste blood was not separated from the patient at any time and, therefore, able to be reinfused. Without this configuration, the waste sample would have to be discarded and the red cell volume lost.

Our anticoagulation protocol uses the Heparin Management System Plus (Medtronic, Inc., Minneapolis, MN). Because of the amount of blood necessary to perform all the functions of this assay, only the ACT cartridges are used to monitor anticoagulation throughout cases that involve JW. An empirical dose of 600 IU/kg was administered for the heparin load according to our current institutional protocol.

Our initial hematocrit in the OR was 43%, so the decision was made to remove 20 mg/kg of whole blood through ANH. This whole blood removal would result in a calculated CPB hematocrit of >20%, which is in accordance with our protocol. The ANH was drawn up in a continuous fluid-filled loop and kept in unbroken circuit with the patient at all times (described previously by Burnside et al. (5)). A 60-mL syringe with 8 mL of anticoagulant citrate dextrose (ACD) (Fenwal Inc., Lake Zurich, IL) was attached to the double stopcock on the arterial line; 52 mL of autologous blood was drawn into the syringe and mixed with the 8-mL ACD. This blood was then transferred to a blood administration bag previously connected to the same stopcock. One of the two ports on the bag was attached to a blood administration kit (Primary Y-Type blood set, Hospira, Inc.), which was subsequently connected to the patient's central venous line (CVL). The blood administration kit includes a filter, so the ANH blood may be filtered before readministration according to the *American Association of Blood Banks Standards for Perioperative Autologous Blood Collection and Administration*, 7th edition (Standard 5.4.5.1) (7). The ANH draw line was detached from the arterial blood monitoring line only after connection of the blood bag to the CVL, thus ensuring physical contact with the patient during the procedure.

During ANH, anesthesia maintained hemodynamic stability with the administration of phenylephrine (Quva Pharma, Bloomsbury, NJ) and, if necessary, 25% albumin to maintain acceptable cerebral saturations (CrO₂) and blood pressure, and prevent adverse electrocardiographic (EKG) changes. CrO₂ saturations ranged from 69% to 71% (baseline CrO₂ 64%), and no adverse EKG changes were noted. During ANH, the anesthetist administered one dose phenylephrine 10 µg (PharMEDium, LLC, Memphis, TN) for low MAP (no albumin was necessary) to maintain hemodynamic stability. Our ANH protocol states that a

decrease of cerebral saturation $\leq 20\%$ of the patient's baseline is considered significant and ANH is terminated. This threshold was not reached with this patient.

A median sternotomy was performed, and heparin 1,600 IU was administered by the surgeon directly into the right atrium. An 8-Fr DLP Medtronic arterial cannula (Medtronic Inc.) was placed in the ascending aorta. RAP was initiated during the placement of the single 16-Fr venous cannula (Medtronic, Inc.) followed by VAP. After RAP/VAP and the addition of tranexamic acid and cefazolin to the venous reservoir, CPB was initiated at the surgeon's request. The anesthesiologist administered 110 μg phenylephrine during RAP/VAP to maintain hemodynamic stability. Flow was increased to a cardiac index of 2.2 L/min/m², which is considered full flow at our institution. Cooling was initiated, at the surgeon's request, to a core temperature of 26°C, and an initial blood gas analysis was performed. An aortic cross-clamp was applied, and the first dose of antegrade cardioplegia was administered to the aortic root using the Sorin CSC-14 Custom 1:1 delivery system (Liva Nova USA, Inc., Arvada, CO) for a dose of 15 mL/kg. Subsequent cardioplegia doses were administered directly into the coronary ostia using a 2-mm arteriotomy cannula (Medtronic, Inc.). Cardioplegia was re-dosed at approximately every 30 minutes while cross-clamped. A final dose was administered to the neo-aorta for a total of 4 doses of cardioplegia. ZBUF was initiated following the initial dose of cardioplegia and continued throughout the case, Normosol-R[®] was used for fluid replacement during ZBUF with 20 mEq/L sodium bicarbonate, and 200 mg/L calcium chloride (International Medication Systems, LTD., So. El Morte, CA) was added to buffer the solution and prevent hypocalcemia. Blood gases and anticoagulation were monitored approximately every 60 minutes. After 115 minutes, the aortic cross clamp was removed, and 1,350 mg of mannitol 25% and 500 mg magnesium chloride were administered to the pump. The patient was rewarmed to a core temp of 37°C, blood gases and electrolytes were corrected to normal, and CPB was terminated.

MUF was initiated immediately after the cessation of CPB. The former cardioplegia circuit was flushed of crystalloid before the end of CPB and was modified for use as the MUF circuit. The former cardioplegia cannula was placed in the right atrium for return of the concentrated circuit contents. The concentrated blood was warmed as it passed through the cardioplegia heat exchanger. The venous cannula was removed, and this volume was hemoconcentrated and returned to the patient. MUF was discontinued after 10 minutes, resulting in a removal of 200 mL of effluent from the circuit and patient.

Following MUF, 21 mg protamine sulfate (APP Pharmaceuticals, LLC, Schaumburg, IL) was administered by anesthesiologist over several minutes. When the protamine dose was complete, the ANH was readministered to the patient through the CVL with the filtered blood administration kit. Immediately following the ANH administration, recombinant factor VIIa (NovoSeven; Novo Nordisk Inc., Plainsboro, NJ) was given in congruence with our JW protocol. The arterial and venous lines, as well as all the sucker and vent lines, were rinsed with Normosol[®] into the venous reservoir. This volume was then transferred to a Fresenius continuous auto transfusion system (Terumo Cardiovascular Group, Ann Arbor, MI). This volume was processed, and 85 mL of concentrated red blood cells were returned to the patient through the pre-connected CVL, also through the filtered blood administration kit. Normosol-R[®] was used for the wash solution during red cell processing as it produces the most physiologically normal product (8).

The lowest hematocrit on bypass was 15% with a corresponding lactate value of 3.4 mmol/L. The hematocrit immediately preceding cessation of CPB was 17%. Following MUF and the administration of the ANH and cell saver blood, the hematocrit on leaving the OR was 21%, with a corresponding lactate value of 4.2 mmol/L (Table 1).

After the repair was complete, hemostasis was achieved, the chest was closed, and the patient was deemed hemodynamically stable, and extubation occurred. The patient

Table 1. Patient laboratory values from baseline until hospital discharge.

	ACT (seconds)	Hct (%)	Hgb (g/dL)	Lactate (mmol/L)	Glucose (mg/dL)	Sodium (mmol/L)	Potassium (mmol/L)	Calcium (mg/dL)
Baseline 0815	131	43	14.6	2.5	126	138	2.4	1.25
S/p heparin 0923	>999	38	12.9	2.5	148	140	2.3	1.13
1st on CPB 0937	>999	22	7.5	3	136	139	2.1	0.9
2nd on CPB 1035	>999	20	6.8	3.2	276	137	2.9	1.04
Last on CPB 1200	>999	17	5.8	4.2	274	137	3.2	1.47
Off CPB 1240	403	21	7.1	4.2	231	142	2.4	.91
1st in CTICU	N/A	21	7.1	4.2	231	142	2.4	1.19
CTICU s/p 24 hours	N/A	22	7.5	3.5	105	137	3.3	1.22
POD 2	N/A	24	8.2	1.2	N/A	N/A	N/A	N/A
POD 3	N/A	23	7.8	1.4	N/A	N/A	N/A	N/A
Discharge (POD 9)	N/A	36	11.2	N/A	N/A	N/A	N/A	N/A

N/A, assay not performed.

was subsequently placed on a nasal cannula at 2 L/min and transferred to the cardiothoracic intensive care unit (CTICU).

EPO 1,400 units subcutaneously per day (500 unit/kg), along with the addition of ferrous sulfate (Mead Johnson, Glenview, IL) 6 mg by mouth three times a day, was restarted in the CTICU POD 1. The patient was also started on Lasix (Fresenius Kabi, Bad Homburg, Germany) 3 mg (1 mg/kg) twice a day for the first 5 days post-op and then decreased to once a day for the remainder of the hospital stay. The patient continued to show improvement and was transferred to the cardiac step down unit on postoperative day (POD 3), with a hematocrit of 23% and a lactate value of 1.4 mmol/L. The patient was discharged home from the cardiac step down unit on POD 9, with a hematocrit of 36% (Table 1).

DISCUSSION

The transfusion of allogeneic blood products is often necessary during pediatric cardiac surgery procedures, requiring the use of CPB. The extreme hemodilution effect resulting from the priming solution of these circuits may result in increased morbidity and mortality if left untreated. This effect is inconsequential for adult cardiac surgical procedures as their large CBVs are less affected by the CPB prime. However, a CPB circuit for a neonate or infant can often be nearly half or more of the patient's CBV, resulting in excessive hemodilution (9–11). The benefits of blood product transfusions in these situations are obvious, but the benefits must be weighed against their associated risks and costs.

Our institution is a referral center for JW patients as our cardiac surgery team has developed techniques to minimize the use of blood products for all of our patients. As reported recently by Naguib et al., our cardiac team is successful in performing bloodless cardiac procedures in patients weighing >6 kg, with 59.6% of these patients requiring no blood product transfusion during their entire hospitalization (1). However, the challenge remains with

our patients weighing <6 kg as all of these patients included in this study received allogeneic blood transfusions (1).

Neonatal and infant JW patients often present with higher preoperative hematocrits because of pretreatment with EPO and iron supplementation. In addition, lower hematocrits during and after CPB are often tolerated as long as the patient remains hemodynamically stable and without signs of low cardiac output, decreased urine output, decreased cerebral saturations, and metabolic acidosis. These considerations along with close coordination of all members of the cardiac OR team working make it possible to achieve completely bloodless pediatric cardiac hospitalization.

REFERENCES

1. Naguib A, Winch P, Tobias J, et al. A single-center strategy to minimize blood transfusion in neonates and children undergoing cardiac surgery. *Ped Anesth*. 2015;25:477–86.
2. Kneyber MCJ, Hersi MI, Twisk JWR, et al. Red blood cell transfusion in critically ill children is independently associated with increased mortality. *Intensive Care Med*. 2007;33:1414–22.
3. Olshove V, Preston T, Gomez D, et al. Perfusion techniques toward bloodless pediatric open heart surgery. *J Extra Corpor Technol*. 2010; 42:122–7.
4. Ratliff T, Hodge A, Preston T, et al. Bloodless pediatric cardiopulmonary bypass for a 3.2-kg patient whose parents are of Jehovah's witness faith. *J Extra Corpor Technol*. 2014;46:173–6.
5. Burnside J, Ratliff T, Hodge A, et al. Bloodless repair for a 3.6 kilogram transposition of the great arteries with Jehovah's witness faith. *J Extra Corpor Technol*. 2017;49:307–11.
6. Boettcher W, Dehmel F, Redlin M, et al. Complex cardiac surgery on patients with a body weight of less than 5 kg without donor blood transfusion. *J Extra Corpor Technol*. 2017;49:93–7.
7. AABB. Standards for Perioperative Autologous Blood Collection and Administration. Bethesda, MD: AABB;2016:22.
8. Ratliff T, Burnside J, Hodge A, et al. The impact of three different wash solutions on autotransfusion products. *J Extra Corpor Technol*. 2018;50:113–6.
9. Boettcher W, Merkle F, Huebler M, et al. Transfusion-free cardiopulmonary bypass in Jehovah's witness patients weighing less than 5 kg. *J Extra Corpor Technol*. 2005;37:282–5.
10. Huebler M, Habazetti H, Boettcher W, et al. Transfusion-free complex cardiac surgery with use of deep hypothermic circulatory arrest in a preterm 2.96-kg Jehovah's witness neonate. *Tex Heart Inst J*. 2011; 38:562–4.
11. Huebler M, Boettcher W, Koster A, et al. Transfusion-free complex cardiac surgery with cardiopulmonary bypass in a 3.55-kg Jehovah's witness neonate. *Ann Thorac Surg*. 2005;80:1504–6.