Case Report

Use of the Aquadex™ system for ultrafiltration therapy in a hemodynamically unstable pediatric patient

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Abstract. In this case report, we describe the use of the Aquadex™ system for ultrafiltration therapy in the pediatric cardiac intensive care setting in a patient with fluid overload and acute kidney injury after congenital heart surgery. The patient is an 11-year-old, 25 kg male with complex single ventricle anatomy who underwent a one and a half ventricle repair. The patient experienced multiple organ dysfunction syndrome including acute kidney injury in the early post-operative period secondary to low cardiac output syndrome and tachyarrhythmia. Ultrafiltration using the Aquadex™ system was utilized to treat fluid overload in the setting of acute kidney injury and hemodynamic instability. Negative fluid balance was safely achieved. It was subsequently possible to wean ventilatory and inotropic support. We conclude that the use of ultrafiltration therapy is feasible in hemodynamically unstable pediatric patients with significant fluid overload in the setting of acute kidney injury following congenital heart surgery.

Keywords: Ultrafiltration, acute kidney injury, congenital heart defects, heart failure, cardiopulmonary bypass, cardiac surgery

1. Introduction

Fluid overload in the early postoperative period after pediatric cardiac surgery is a well described phenomenon that is independently associated with increased morbidity and mortality [1–5]. Factors contributing to this process include low cardiac output syndrome and systemic inflammatory response after cardiopulmonary bypass, due to reperfusion injury

with ischemia, oxidative stress, and release of antidiuretic hormone. A subset of these patients develops acute kidney injury (AKI) as part of multiorgan dysfunction syndrome [2, 3]. In those patients who develop AKI in the postoperative period, morbidity and mortality is high, particularly in those who experience higher amounts of fluid overload [2–4].

Since the 1980s, ultrafiltration has been used as an alternative mechanism of fluid removal in adult patients with congestive heart failure [6]. Numerous clinical trials have demonstrated advanced ultrafiltration devices, such as the Aquadex™ system, to be safe and effective, while maintaining hemodynamic stability, avoiding global electrolyte imbalance, and

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achieving symptomatic relief of congestive heart failure [1, 6–9]. The less invasive, low flow capability of this type ultrafiltration makes it an attractive option for fluid removal in patients who may not be stable enough to tolerate other more invasive means of fluid removal, such as continuous veno-venous hemofiltration (CVVH). This type of ultrafiltration has not been reported in the pediatric population. We describe the successful use of ultrafiltration in a hemodynamically unstable pediatric patient following congenital cardiac surgery.

2. Case report

The patient is an 11-year-old, 25 kg male with complex single ventricle anatomy including an unbalanced right dominant atrioventricular canal defect, who underwent multiple palliative procedures in infancy and subsequently underwent a bidirectional superior cavopulmonary anastomosis at 2 yr of age. Due to persistent pulmonary vein stenosis, he was not felt to be a candidate for a Fontan palliation. The patient presented to our institution for a one-and-a-half ventricle repair. He underwent a repair of his atrioventricular canal defect, as well as left ventricle to aortic baffle, and placement of a right ventricle to pulmonary artery conduit. The patient's initial post-operative course was complicated by a low cardiac output syndrome and tachyarrhythmia causing multiorgan dysfunction syndrome with AKI, acute hepatic failure, acute respiratory failure, and significant fluid overload. The patient also developed ventricular septal defect patch dehiscence and severe mitral valve regurgitation. He subsequently underwent re-operation for ventricular septal defect closure and placement of a mechanical mitral valve. The post-operative course was complicated by persistent multi-system organ failure and profound fluid overload.

The patient was initially treated with conventional diuretics and fenoldopam but a negative fluid balance could not be achieved. He continued to have significant hemodynamic instability and became progressively oliguric with elevation in blood urea nitrogen and creatinine. This was associated with worsening ventilation and oxygenation secondary to progressive pulmonary edema.

Given the patient's tenuous hemodynamic status, we did not feel that he would tolerate conventional forms of dialysis/ultrafiltration and thus, therapy was initi-

ated using the Aquadex™ system. Prior to initiation of therapy, a 6 French (Fr), 15 cm, double lumen, reinforced, peripherally inserted central catheter (PICC) was placed in the right lower extremity. The patient was therapeutically anticoagulated with unfractionated heparin prior to initiation of ultrafiltration for mechanical valve thromboprophylaxis. This was continued throughout the duration of ultrafiltration therapy. His dose was titrated between 28 and 32 U/kg/hr to maintain an activated partial thromboplastin time of 60–80 sec.

Blood flow rates were initially set low in order to assess patient tolerance at the commencement of therapy. Based on the filter type, blood flow rates could range from 10–40 mL/min, with ultrafiltration rates ranging between 10–500 mL/hr. On the first day of therapy, the patient was started at a blood flow rate of 10 mL/min and gradually increased to 40 mL/min. Similarly, he was initially started at a net ultrafiltration rate of 10 mL/hr and was increased to 20 mL/hr. The patient did experience some mild hypotension requiring administration of crystalloid and albumin, as well as an increase in vasopressor support, within the first few hours of therapy. Fluid restriction was attempted, but in light of numerous infusions, the patient's total hourly fluid input was approximately 75% maintenance.

After the first 24 hr of use, an ultrafiltration of approximately 450 mL was achieved. Over the 9 days of treatment, the ultrafiltration rates were gradually increased up to 150 mL/hr, and the patient continued to tolerate fluid removal (Fig. 1). Following initiation of

Fig. 1. Graph demonstrating fluid balance prior to and after commencement of ultrafiltration following re-operation.

Table 1
Clinical parameters in relation to the initiation of ultrafiltration

Parameters	Day prior to surgery	POD 0	POD 1	POD 2 (UF start)	POD 3	POD 4	POD 5	POD 6	POD 7	POD 8	POD 9	POD 10
Ventilator settings												
PIP(cmH ₂ O) /IMV	30/16	34/16	30/12	30/22	36/22	40/30	40/30	40/30	36/30	36/30	36/30	34/30
PEEP (cm H ₂ O)	8	8	8	8	8	8	8	8	8	8	8	8
FiO ₂ /iNO (ppm)	40/0	40/0	40/0	80/40	85/30	1.0/20	0.8/20	0.6/20	0.5/20	0.5/20	0.5/20	0.5/20
pH (units)	7.43	7.45	7.47	7.33	7.35	7.29	7.27	7.36	7.38	7.34	7.24	7.29
pCO ₂ (mmHg)	42	43	35	41	35	44	48	42	30	36.7	46.8	42
paO ₂ (mmHg)	78	75	87	76	110	61.6	78.6	60.2	69.5	57.3	58.7	63.2
Right atrial pressure (mmHg)	N/A	10	14	20	20	18	16	14	11	RA lines out	N/A	N/A
Systemic blood pressure (mmHg)	90/50	98/50	90/48	70/40	70/26	70/28	74/30	78/36	80/48	78/44	76/40	84/44

POD = Postoperative day; UF = Ultrafiltration; PIP = Peak inspiratory pressure; IMV = Intermittent mandatory ventilation; PEEP = Positive end expiratory pressure; FiO₂ = Fraction of inspired oxygen; iNO = Inhaled nitric oxide; N/A = Not applicable; RA = Right atrial.

ultrafiltration therapy, the patient's clinical condition gradually improved with stabilization in hemodynamics and decreasing pulmonary edema and pulmonary hypertension, which allowed for discontinuation of neuromuscular blockade and weaning of ventilatory and inotropic support (Table 1). The patient was maintained on vasopressin and epinephrine infusions to maintain a systolic blood pressure greater than 70 mmHg.

Prior studies have demonstrated that solute clearance is not always successful using the Aquadex™ system [6]. In our experience, this type of ultrafiltration therapy allowed us to achieve some electrolyte control in the face of the patient's oliguric renal failure. The patient's potassium level at the start of therapy was 5.1 mmol/L, and peaked at 5.8 mmol/L on day 3 of therapy, and then steadily trended downward, reaching a low of 3.1 mmol/L by day 9 of therapy. Similarly, the patient's initial sodium was 148 mmol/L, reaching a low of 126 mmol/L on day 4 of therapy, at which time the patient began to receive 3% sodium chloride supplementation to maintain a sodium level above 130 mmol/L. The patient's hematocrit was consistently monitored using the continuous mechanism on the Aquadex™ system and remained stable ($\geq 24\%$) throughout the course.

Although ultrafiltration therapy allowed for significant clinical improvement, the patient was transitioned to continuous renal replacement therapy after day 9 of treatment secondary to persistent oliguria, worsening uremia, and anion gap acidosis (Fig. 2). His clinical status continued to improve with recovery of all organ systems, other than the kidneys. He was ultimately

Fig. 2. Graph demonstrating acid-base balance and renal function prior to and after commencement of ultrafiltration following re-operation.

transitioned to peritoneal dialysis prior to hospital discharge.

3. Discussion

Our patient developed AKI as a part of multiorgan dysfunction syndrome following surgery for complex congenital heart disease. CVVH was considered for treatment of his severe fluid overload, however, given his concurrent hemodynamic instability, ultrafiltration was thought to be a better choice in terms of preventing further clinical decompensation. The Aquadex™

Table 2
Characteristics of Aquadex™ versus continuous venovenous hemofiltration

	Aquadex™ UF 500 circuit for aquapheresis	Continuous venovenous hemofiltration circuit
Minimal blood flow rate	10 mL/min	75 mL/min
Total blood volume in circuit	33 mL	152 mL
Type of access required for therapy	Peripherally inserted central catheter or 2 large bore peripheral intravenous lines	>9 Fr double lumen hemodialysis catheter

Fig. 3. Illustration of Aquadex™ ultrafiltration circuit, previously published in Aquadex flexflow fluid removal system: User’s guide. Courtesy of Gambro AB.

circuit’s total blood capacity is only 33 mL [10]. This feature made the method a more feasible option for fluid removal for our patient, who would likely not tolerate large fluid shifts. In addition, should we have chosen another method of ultrafiltration, such as CVVH, higher blood flow rates would be required to prevent circuit thrombosis, and this would likely not have been well tolerated at that time. The low flow capability of this type of ultrafiltration makes it an attractive option for fluid removal in patients who may not otherwise be hemodynamically stable enough to tolerate other means of fluid removal (Table 2).

Initiation of CVVH in a patient this size requires the placement of a 9 Fr hemodialysis catheter into a central vein. In contrast, ultrafiltration can be performed

using two large bore peripheral 16 gauge reinforced intravenous catheters or a PICC. This helps to reduce the risks associated with catheter insertion, including infection, hemorrhage, and pneumothorax [9]. In the case of our patient, who was immunocompromised secondary to asplenia, who was coagulopathic secondary to thrombocytopenia, and in whom internal jugular and subclavian access was precluded due to his superior cavopulmonary anastomosis, the placement of a 6 Fr PICC in the lower extremity was deemed to be the safer option. Notably, the Aquadex™ system is capable of running at lower blood flow rates while maintaining acceptable ultrafiltration rates, without risk of clotting the circuit or access line, although therapeutic anticoagulation with heparin is still required [10].

The mechanism of ultrafiltration is by convection, eliminating iso-osmolar extracellular fluid, and hence avoiding the potential electrolyte abnormalities, such as hypomagnesemia, which is associated with other types of fluid removal modalities (Fig. 3) [1, 9]. This was a potential benefit in our patient, who had refractory arrhythmias. In addition, the benefits of ultrafiltration may extend beyond solute and water removal alone. Studies have shown that modified ultrafiltration during the rewarming phase of cardiopulmonary bypass decreases tumor necrosis factor- α and interleukin-6 levels after cardiopulmonary bypass. Similarly, ultrafiltration membranes, such as the one that is used in the Aquadex™ system, allow passage of small molecules, including pro-inflammatory cytokines that may cause myocardial depression and are implicated in the systemic inflammatory response that is observed in infants and children after congenital heart surgery [6, 11]. We speculate that removal of these substances by ultrafiltration in the post-operative period may have contributed to the overall improvement in our patient's clinical status and multiorgan dysfunction [1, 6–9, 11].

To our knowledge, this is the first report of the use of ultrafiltration therapy with the Aquadex™ system in the pediatric cardiac intensive care setting. We were successful in achieving a significant net negative fluid balance in a very complex patient without compromising hemodynamic stability or causing significant electrolyte imbalance in the setting of arrhythmia, with subsequent improvement in overall clinical status. Further studies are required to assess the utility of this therapy for treatment of fluid overload and systemic inflammatory response in other pediatric patients following complex congenital heart surgery.

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