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Haemofiltration: Experience in a Local Paediatric Intensive Care Unit

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Abstract We report 17 children who were admitted to our paediatric intensive care unit (PICU) and required haemofiltration for renal replacement therapy between 1996 and 1999. Ten patients were male and 7 were female. The median age was 26 months (range 8 months to 19.7 years). The main indication for acute renal replacement was acute renal failure (n=13). Other indications included tumour lysis syndrome (n=2), removal of toxin (n=1) and end-stage renal failure with peritonitis (n=1). Continuous venovenous haemofiltration (CVVH) was performed in 12 patients, continuous venovenous haemodiafiltration (CVVHD) in 6 patients, continuous arteriovenous haemofiltration (CAVH) in 2 patients, continuous arteriovenous haemodiafiltration (CAVHD) in one patient and one patient underwent intermittent haemofiltration (IHF). The most common vascular access used was femoral vessels (n=15), followed by the subclavian veins (n=2). The median duration of haemofiltration was 22 hours (range 3 hours to 20 days). Analysis of the results showed that the drop in central venous pressure (p=0.002) and the reduction in serum urea level (p=0.0425) after haemofiltration were statistically significant. Blockage of filters and vascular accesses were the commonest complications observed. Otherwise, no other major complications were noticed in our patients. Ten patients (59%) survived and were discharged from PICU and seven patients (41%) died from the underlying diseases. We concluded that haemofiltration is an effective and safe means for acute renal replacement therapy.

Key words Haemofiltration – intensive care unit

Introduction

The role of continuous renal replacement therapy (CRRT) has become increasingly important as a therapy for critically ill children in intensive care units. Continuous arterio-venous haemofiltration, which was first described by Kramer[1] in 1977, started to be applied in adult patients as an alternative form of renal replacement therapy to peritoneal dialysis and haemodialysis. Subsequently, this technique was adopted and used in paediatric patients. With the advance of technology in clinical medicine, different modalities of CRRT are now available and the choice depends on the condition of the patient, the availability of equipment and the preference and experience of the clinician. We report our experience with continuous arterio-venous haemofiltration (CAVH), continuous arterio-venous haemodiafiltration (CAVHD), continuous venovenous haemofiltration (CVVH) and continuous venovenous haemodiafiltration (CVVHD). The effectiveness of haemofiltration, complications and outcome in our group of patients were also described.

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Methods

The records of all paediatric patients admitted to Queen Elizabeth Hospital Paediatric Intensive Care Unit from January 1996 to December 1999 were retrieved from the hospital record office computer system. The hospital records of those who had haemofiltration done were reviewed retrospectively. The data retrieved from the hospital records included demographic data of the patients, the diagnosis of the underlying disease, the PRISM score and the duration of ICU stay, the number of organ failure, and the outcome. The indication for haemofiltration and the particulars about the haemofiltration procedure were also recorded. The haemodynamic changes, serum urea and creatinine level before and after haemofiltration were compared. Data are presented as means±SEM and median. Statistical analysis was performed with the Wilcoxon match paired test and statistical significance set at $p<0.05$.

Results

From January 1996 to December 1999, 17 critically ill infants and children were admitted to the Paediatric Intensive Care Unit (PICU) of Queen Elizabeth Hospital in Hong Kong and required renal replacement therapy. Ten were male and seven were female. Their age ranged from 8 months to 19.7 years, with a median age of 26 months. Their median weight was 11.4 kg, with a range of 7.6 kg to 40 kg. The average stay in PICU was 43.3 days. Five patients stayed in PICU for less than 1 week. The longest duration of PICU stay was 1 year. The characteristics of the 17 patients were listed in Table 1. Among 17 patients, only 4 were suffering from primary renal disease, namely Bardet-Biedl syndrome, haemolytic uremic syndrome, reflux nephropathy with acute pyelonephritis and mesangial proliferative glomerulonephritis. Ten patients had 3 or more organ dysfunction and they all required mechanical ventilatory support for different duration during the process of haemofiltration. Nine patients required inotropic support during renal replacement therapy (RRT) and 6 of the 9 patients suffered from multiorgan failures. The main indication for RRT was acute renal failure in 13 patients. Other indications for RRT included fluid retention secondary to hyperhydration in chemotherapy, tumour lysis syndrome and removal of hepatic toxin in a patient with neonatal haemochromatosis. One patient who suffered from end-stage renal failure had to shift from peritoneal dialysis to intermittent haemofiltration temporarily because of peritonitis.

Table 2 described the particulars of renal replacement therapy (RRT) in these 17 patients. The femoral vessels were chosen for vascular access in 15 patients. Depending on whether arteriovenous or venovenous haemofiltration was carried out, the femoral veins or arteries were catheterised. The remaining 2 patients used subclavian veins for CVVH. The haemofiltration machine we used was Gambro, Sweden™ AK10 machine. "Hotline™" warmer (Sims medical system, Smith Industry, Rockland, USA) was used for warming the circuit. There were 4 types of dual lumen catheters used in this group of patients. The size of the catheters chosen depended on the size of the patient. The type of haemofilters used depended on the body surface area of the patient. For those haemofilters that required a large priming volume, blood was used for priming the circuit. CVVH was performed in 12 patients and 6 underwent CVVHD. CAVH was carried out in 2 patients and CAVHD in 1 patient. Intermittent haemofiltration was carried out in Patient *4* initially, but was changed to CVVH 2 days later because of blockage of the filter. Patient *6* and *16* were shifted from CVVH to CVVHD for better urea clearance. In cases of haemodiafiltration, 1.5% PD fluid was used as dialysate.

Heparin was used for anticoagulation and the dosage was adjusted according to coagulation tests performed at regular intervals. Activated partial prothrombin time (APTT) was kept at 1.5 to 2 times of normal level. In cases with prolonged APTT at the start of haemofiltration, predilution method was used instead of heparinisation. Haemofiltration replacement fluid, HF4 was used in all our cases and it was given either at the pre-filter or the post-filter end of the circuit.

The duration of RRT ranged from 3 hours to 20 days, with a mean duration of 81.3 hours and the median was 22 hours. The lowest blood flow rate was 30 ml/min and the highest was 150 ml/min. The mean blood flow rate was 4.35±0.52 ml/kg/min. The median ultrafiltrate rate was 24 ml/kg/hr with the lowest at 15 ml/kg/hr and highest at 50 ml/kg/hr. For patients using CVVHD, 1.5% PD fluid was used as the dialysate solution and the median flow rate was 10 ml/min, ranged from 5 ml/min to 13 ml/min. No hyperglycemic episodes that required intervention were noticed in those patients, who used dextrose-based PD fluid as dialysate.

The average number of filters used per patient was 1.8 and 10 patients required only 1 filter to complete the

Table 1 Characteristics of the 17 patients who had undergone haemofiltration in the period 1996-1999

Case	Sex	Age (yr)	Diagnosis	Indication	No. of organ failure	Outcome
1	M	2.2	Status epilepticus	ARF, uraemia	5	Died
2	M	1.3	T-cell lymphoma	Fluid overload, uraemia	3	Survived & discharged from PICU
3	F	19	Mitochondrial cytopathy	ARF	3	Survived & discharged from PICU shifted to PD
4	F	12	Bardet-Biedl syndrome	ESRF, peritonitis	1	Survived & discharged from PICU continue with HD
5	M	8	ALL, tumour lysis syndrome	Tumour lysis syndrome, uraemia	2	Survived & discharged from PICU
6	F	1	Haemolytic uraemic syndrome	ARF, uraemia	1	Survived & discharged from PICU
7	M	12	ALL, tumour lysis syndrome, septicaemia	Tumour lysis syndrome, uraemia	2	Survived & discharged from PICU
8	F	1.3	Hepatoblastoma, haemoperitoneum	ARF	5	Died
9	M	8.7	ATN, mesangial proliferative glomerulonephritis	ATN, fluid retention, pulmonary oedema	3	Survived & discharged from PICU shifted to PD
10	F	10	CNS germinoma, ARDS, ATN	ATN, fluid retention, pulmonary oedema, uraemia	4	Died
11	F	0.7	Neonatal haemochromatosis	Removal of hepatic toxin	2	Died
12	M	1.4	Hypernatremic dehydration, septicaemia	ARF, uraemia	2	Survived & discharged from PICU
13	M	1.3	ARF, reflux nephropathy, acute pyelonephritis	Uraemia, hyperphosphatemia and persistent metabolic acidosis	2	Survived & discharged from PICU
14	M	3.7	Influenza (H5N1), septicaemia, ARDS, MOF	ARF, uraemia	5	Died
15	M	1	Down's syndrome, imperforated anus, chronic lung disease haemochromatosis, MOF	ARF	4	Died
16	M	1.2	Congenital tracheal stenosis	ARF	3	Died
17	F	2.5	Chronic lung disease, short gut syndrome septicaemic shock	ARF	3	Survived & discharged from PICU

ALL: acute lymphoblastic leukaemia, ARDS: acute respiratory distress syndrome, ARF: acute renal failure, ATN: acute tubular necrosis, MOF: multi-organ failure, HD: haemodialysis, PD: peritoneal dialysis.

Table 2 Summary of haemofiltration procedures

Patient	RRT	Vascular access	Catheter	Haemofilter	Anticoagulation	Duration of RRT (hr)
1	CVVH	Femoral vein	Medcomp™	Amicron™ D20	Heparinisation	111
2	CVVH	Femoral vein	Medcomp™	Amicron™ D20	Predilution	48
3	CVVHD	Femoral vein	Medcomp™	Gambro™ FH66	Predilution	20
4	Intermittent HF, CVVH	Femoral vein	Vascath™	Gambro™ FH66	Heparinisation & Predilution	20
5	CAVHD & CVVHD	Femoral vein	Gamcath™	Gambro™ FH66	Heparinisation	24
6	CVVH & CVVHD	Subclavian vein	Medcomp™	Gambro™ FH22	Heparinisation & Predilution	4
7	CVVHD	Femoral vein	Medcomp™	Gambro™ FH66	Heparinisation	22
8	CAVH	Femoral vein & artery	Vascath™	NA	Heparinisation & Predilution	290
9	CAVH & CVVH	Femoral vein & artery	Vascath™	Gambro™ FH22	Heparinisation	188
10	CVVH & CVVHD	Femoral vein	Quinton™	NA	Heparinisation	11
11	CAVH	Femoral vein & artery	Vascath™	NA	Heparinisation	74
12	CVVH	Femoral vein	Medcomp™/ Gamcath™	NA	Heparinisation & Predilution	52
13	CVVH	Femoral vein	Gamcath™	Amicron™ D20	Heparinisation & Predilution	4
14	CVVH	Subclavian vein	Medcomp™	Amicron™ D20	Nil	3
15	CVVH	Femoral vein	Medcomp™	Gambro™ FH22	Predilution	21
16	CVVH & CVVHD	Femoral vein	Gamcath™	NA	Predilution	10
17	CVVH	Femoral vein	Vascath™	Gambro™ FH22	Predilution	480

CAVH: continuous arterio-venous haemofiltration, CAVHD: continuous arterio-venous haemodiafiltration, CVVH: continuous venovenous haemofiltration, CVVHD: continuous venovenous haemodiafiltration, HF: haemofiltration, NA: data not available.

process. The mean duration for a filter used was 56.79± 27.9 hours (mean±SD). Six filters were consumed in Patient *12* with a mean duration of 8.67 hr/filter. Patient *17* used only 1 filter for the whole process, which lasted for 20 days. The main reason for filter change was blockage in the circuit and increased resistance of venous return. Renal replacement therapy was changed from haemofiltration to peritoneal dialysis in two patients, whose kidney functions had not recovered from acute tubular necrosis and prolonged therapy was anticipated. One patient was put on a chronic haemodialysis program after her medical condition was stabilised by haemofiltration in our intensive care unit.

The pre-RRT, systolic and diastolic blood pressure, central venous pressure, serum urea, creatinine and urine output were compared with post-RRT readings. We found that the drop in central venous pressure and the reduction in serum urea level were significant. The mean central venous pressure (CVP) before and after RRT was 13.5± 1.7 cmH_2O and 8.42±1.6 cmH_2O respectively. The median CVP were 12 cmH_2O and 8 cmH_2O before and after haemofiltration respectively, with p= 0.023. The mean serum urea before and after RRT was 23.8±5.1 mmol/L and 15.1±3.4 mmol/L respectively. The median serum urea before haemofiltration was 17.9 mmol/L and 9.2 mmol/L after haemofiltration, with p=0.045. The urine output

improved or remained normal in 8 patients. There was no significant change in blood pressures before and after haemofiltration.

The mortality rate in this study was 41.2%. Ten patients survived and were discharged from PICU. In the survived group, one patient (Patient *4*) continued renal replacement therapy by haemodialysis and 2 patients required peritoneal dialysis after discharged from PICU. Seven patients died in PICU and one of them (Patient *12*) recovered his renal function before death. The mean number of organ failure in the survived group was 2.2±0.25 and the median was 2. The mean in those who died was 4±0.43 and the median was 4. When comparing the median of the number of organ failure in the survived and deceased groups by Mann Whitney test, the difference was statistically significant with p=0.0094.

The major complication observed during the haemofiltration process was blockage of vascular access or the filter leading to transient suspension of the procedure. Two patients also suffered from disseminated intravascular coagulopathy and the procedure was complicated by bleeding from the wounds of vascular access. Electrolytes disturbances were mild in all cases and were readily corrected by adjustment of the quantity of electrolytes supplement given.

Discussion

Peritoneal dialysis and intermittent haemodialysis are technically feasible procedures for renal support in infants and children. Since intermittent haemodialysis may have rapid osmolar shifts and haemodynamic instability and peritoneal dialysis may worsen respiratory function in critically ill children and is contraindicated in patients with abdominal trauma and surgery,[2] these drawbacks made intensivists and nephrologists explored the use of haemofiltration in recent decade. Continuous haemofiltration, either arteriovenous or venovenous, is a useful tool for renal replacement therapy to control uraemia, fluid, electrolytes and acid-base balance. It is a simple method by which fluid and solutes can be removed from the body by convection transport.[3] The main advantage of CAVH is its simplicity and safety in terms of handling and haemodynamic stability. A disadvantage is its rather low urea clearance, which can be overcome by adding dialysate into the circuit, CAVHD. CVVH has a better urea clearance than CAVH because a pump is used in the circuit to increase the blood flow rate. Although a previous paediatric study found that the choice between CAVH and CVVH had no effect on mortality and outcome,[4] CVVH is now often the preferred method of CRRT for children, because circuit blood flow is regulated mechanically and does not depend on a patient's cardiac output. CAVH was chosen as the mode of haemofiltration for 2 patients in our study because of their small size and technically CVVH was more difficult in small infants. Some of the patients shifted from haemofiltration to haemodiafiltration to improve their urea clearance.

The choice of vascular catheters depends on the size of the patient.[5] Table 3 described the types of catheters that were used in our group of patients. They are all dual lumen catheters. Usually, Fr. 6.5 or 7 catheter was used in our patients and larger catheter with Fr 10 could be used in bigger size patients. The choice of haemofilters was also guided by the patient's size and body surface area, BSA.[5] We chose haemofilter with surface area close to that of the patient's BSA so that the urea clearance could be kept at 3 ml/kg/min at a same blood flow rate. The type of haemofilters we used, together with their corresponding surface area and other particulars were listed in Table 4. The blood flow rate, BFR was calculated as 3-8 ml/kg/min and the ultrafiltration rate was usually kept <25% of the blood flow to the filter because increase ultrafiltration rate would lead to increase viscosity at the distal end of the filter and this will shorten the lifespan of the haemofilter.[6]

The replacement fluid, HF4™ (Bichsel Laboratory, Switzerland) was used in this group of patients. The composition of HF4™ was shown in Table 5 and was compared with other formula like Ringer's Lactate solution. In recent years, our replacement solution was changed to HF2™ (Bichsel Laboratory, Switzerland), which had a similar composition as HF4™, except its potassium content was even much lower. To avoid clotting of the extracorporeal circuit, heparin was used as anticoagulant of the circuit. The loading dose was 10-20 units of heparin per kg followed by a maintenance infusion at 5-15 units/kg per hr.[5] We aimed at keeping the activated partial prothrombin time 1.5-2 times of normal. In case where

Table 3 Sizes and lengths of different vascular catheters for haemofiltration

Catheter	Size	Length
Gamcath™ (Germany)	Fr. 6.5	12.5 cm
Medcomp™ (USA)	Fr. 7	10 cm
Mahurkar-Quinton™ (USA)	Fr. 10	12 cm
Vascath™ (Canada)	Fr. 6.5/7	12.5 cm

Table 4 Paediatric haemofilters

Company (ml/min)	Type	Area (m^2)	Haemofilter vol. (ml)	Total circuit vol. (ml) for AV H	Ultrafiltration range
Amicron™	Minifiter plus	0.08	6	15	1 to 8
	D20	0.4	20	38	5 to 13
Gambro™	FH22	0.16	11	13 **	2 to 5
	FH66*	0.6	43	82 **	-

*FH66 is now not available in the market and was replaced by FH6S.

**Gambro™ neonatal VVH line volume is 25 ml and Paediatric line volume is 56 ml.

Table 5 Composition of different haemofiltration replacement fluids

Haemofiltration replacement fluid	Ringer's Lactate solution	HF2	HF4
Sodium (mmol/L)	130	135	135
Potassium (mmol/L)	3	2	3
Calcium (mmol/L)	3	1.88	1.89
Magnesium (mmol/L)	-	0.75	0.75
Chloride (mmol/L)	109	108	109
Lactate (mmol/L)	28	33.75	33.75
Glucose (g/L)	-	1.5	1.5

heparinisation was contraindicated, predilution method was used. Predilution has the disadvantage of decreasing the efficiency of the circuit and increases cost for the procedure because a proportion of the generated filtrate is actually the predilution fluid. However, it does prolong the life span of the filter. Usually 5-15% of the blood flow volume is given as predilution.[6] The median ultrafiltration in our group of patients was 28 ml/kg/hr, which was in the suggested range of 20-40 ml/kg/hr for continuous haemofiltration. The rate of ultrafiltration was controlled by volumetric pump (IVAC™, USA) which had a better and exact control on the rate of ultrafiltrate. In case of arterio-venous haemofiltration, the rate of ultrafiltrate was determined by the difference in arterial-venous pressure and varied accordingly.

The drop in the central venous pressure before and after haemofiltration was significant. This reflected that retained fluid was removed by the procedure. However, it should be aware that not all the cases in the study were fluid overloaded at the time when haemofiltration was started. Correction of electrolyte disturbances and uremia were alternate indications. The removal of urea, which was one of the indications for haemofiltration, was satisfactory and the drop of serum urea level was statistically significant. The commonest complication that occurred during haemofiltration process was blockage of the filter and the circuit. Bleeding from the vascular access site in Patient *17* was secondary to her coagulopathy and predilution was used instead of heparinisation during the procedure. Electrolytes disturbances were trivial and easily corrected with adjustment of supplement content in replacement fluid.

As reported by others, irrespective of the use of different modalities of renal replacement therapy for acute renal failure, the mortality was almost exclusively related to the overall medical condition rather than due to the presence of renal failure itself. This was reflected by the result that the mortality rate significantly increased with the number of organ failure. Our mortality of 41.2% was relatively low, when compared with other paediatric studies, which quoted a mortality rate of 40-80%.[7-11] Furthermore, the mortality was much higher among patients with acute renal failure complicating medical illness than those having renal failure secondary to primary renal disease.[12,13] Similar finding was noted in our study, as all the cases with primary renal disease survived.

In conclusion, haemofiltration is a safe and effective means for renal support. With the increase in experience and advance in technology in recent decades, the role of haemofiltration is not limited to renal replacement therapy. Haemofiltration has been used for removal of toxin metabolites in those patients suffering from inborn metabolic disease.[14] There is also increasing use of haemofiltration to remove endogenous inflammatory mediators in patients

suffering from septic shock syndrome.[15] Further large-scale prospective randomised studies are required to compare the effectiveness of different modes of haemofiltration under different clinical conditions.

References

1. Kramer P, Wigger W, Rieger J, Matthaei D, Scheler F. Arteriovenous haemofiltration: a new and simple method for treatment of over-hydrated patients resistant to diuretics. Klin Wochenschr 1977;55:1121-2.
2. Zobel G, Ring E, Kuttnig M, Grubbauer HM. Five years experience with continuous extracorporeal renal support in paediatric intensive care. Intensive Care Med 1991;17:315-9.
3. Schetz M, Lauwers PM, Ferdinande P. Extracorporeal treatment of acute renal failure in the intensive care unit: a critical view. Intensive Care Med 1989;15:349-7.
4. Smoyer WE, McAdams C, Kaplan BS, Sherbotie JR. Determinants of survival in pediatric continuous hemofiltration. J Am Soc Nephrol 1995;6:1401-9.
5. Bunchman TE, Donckerwolcke RA. Continuous arterial-venous diahemofiltration and continuous veno-venous diahemofilatration in infants and children. Paediatr Nephrol 1994;8:96-102.
6. Forni LG, Hilton PJ. Continuous hemofiltration in the treatment of acute renal failure. N Engl J Med 1997;336:1303-9.
7. Leone MR, Jenkins RD, Golper TA, Alexander SR. Early experience with continuous arteriovenous hemofiltration in critically ill pediatric infants. Crit Care Med 1986;14:1058-63.
8. Zobel G, Stein JI, Kuttnig M, Beitzke A, Metzler H, Rigler B. Continuous extracorporeal fluid removal in children with low cardiac output after cardiac operations. J Thorac Cardiovasc Surg 1991;101:593-7.
9. Zobel G, Ring E, Kuttnig M, Grubbauer HM. Continuous arteriovenous hemofiltration versus continuous venovenous hemofiltration in critically ill pediatric patients. In: Sieberth H-G, Mann H, Stummvoll HK (eds). Continuous hemofiltration. 1991 Karger, Basel, pp 257-260.
10. Bishof NA, Welch TR, Strife CF, Ryckman FC. Continuous hemodiafiltration in children. Pediatrics 1990;85:819-23.
11. Cameron JS. Acute renal failure – the continuing challenge. QJ Med 1986;234:337-43.
12. Zobel G, Trop M, Ring E, Grubbauer HM. Continuous arteriovenous hemofiltration in critically ill children with acute renal failure. Crit Care Med 1987;15:699-700.
13. Bunchman TE, McBryde KD, Mottes TE, Gardner JJ, Maxvold NJ, Brophy PD. Pediatric acute renal failure: outcome by modality and disease. Pediatr Nephrol 2001;16:1067-71.
14. Falk MC, Knight JF, Roy LP, et al. Continuous venovenous haemofiltration in the acute treatment of inborn errors of metabolism. Paediatric Nephrol 1994;8:330-3.
15. Butt W. Septic Shock. Pediatr Clin North Am 2001;48: 601-24.