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Volumetric control of continuous haemodialysis in multiple organ failure

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Abstract

A system for precise volumetric control of continuous haemodialysis and its use in providing renal replacement treatment in the intensive care unit to 10 children with multiple organ failure are described. The system, termed slow efficient dialysis, provided effective clearance of urea, creatinine, potassium, and phosphate. It provided precise control of the volume of ultrafiltrate removed in a prospective manner ('dial up' fluid balance) to reduce haemodynamic instability and fluid management problems. The ease of use of this system for intensive care nurses meant that the system ran without the assistance of a second intensive care or renal nurse.

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Acute renal failure is a life threatening illness that may result from renal disease or from multiorgan failure. In children, the prognosis of acute renal failure associated with multiorgan failure is particularly poor.[1–4]

Peritoneal dialysis is generally the first line treatment in children with acute renal failure.[5] It is not always possible, however, to perform peritoneal dialysis after abdominal surgery, or when previous surgery has left the peritoneum scarred. Peritoneal dialysis may fail because of either technical problems with leakage of dialysate or complications such as peritonitis[6] and peritoneal pleural leaks. The mechanical restriction of peritoneal dialysis fluid in the abdomen may also cause problems with ventilation[7 8] and venous return to the heart leading to hypoxia and hypotension in an already critically ill child.

Intermittent haemodialysis presents greater technical difficulties than peritoneal dialysis and because of higher fluid and solute clearance, a greater potential for haemodynamic instability. Continuous arteriovenous and continuous venovenous haemofiltration and dialysis are more suitable renal replacement treatments than intermittent dialysis in critically ill children.[9–13] Continuous arteriovenous haemofiltration (CAVH) alone is less efficient than acute peritoneal dialysis in the removal of urea and creatinine. When it is combined with dialysis in continuous arteriovenous haemofiltration and dialysis (CAVHD), however, urea clearance is increased by 4–5 fold.[9 11] Both CAVH and CAVHD are capable of removing more fluid than either acute peritoneal dialysis or intermittent haemodialysis,[11] but the unpredictable and variable ultrafiltration rates typical of conventional non-volumetric systems tend to provoke or exacerbate cardiovascular instability.

We have employed a system termed slow efficient dialysis that allows the volumetric control of continuous venovenous haemodialysis for the management of fluid balance, acidaemia, and electrolyte control in critically ill patients. It has been used in our intensive care unit for over four years to treat adults,[14] we now describe its use in 10 children with multiorgan failure.

Methods

ACCESS

The size of the child determined the access type, size, and placement. In children weighing over 5 kg, a dual lumen venous catheter was used. Children weighing 5–10 kg had a 7 French gauge (FG) catheter, those of 11–35 kg had a 9 FG catheter, and children over 36 kg had an 11 FG catheter placed. The internal jugular or femoral vein were cannulated. In the child under 5 kg two separate venous catheters were used. These catheters allowed adequate blood flow rates for the slow efficient dialysis machine of 4–6 ml/kg/minute.

DIALYSIS

The venovenous extracorporeal circuit consisted of a blood pump module (AK10, Gambro AB), hollow fibre dialyser (details in table 1), and blood lines (Kimal Scientific Products). The blood lines used were neonatal (volume 25 ml), paediatric (volume 60 ml), and adult (volume 125 ml) depending upon the size of the child. Using neonatal lines with the Amicon 0·1 m^2 haemofilter (priming volume 6 ml) the extracorporeal circuit volume was 31 ml. The extracorporeal circuit was primed with 4·5% human albumin solution. Maintaining a small ratio of extracorporeal circuit volume to intravascular blood volume avoids the need for blood priming.

Table 1 Dialyser or haemofilter used

Weight of child (kg)	*Dialyser or haemofilter*	*Effective surface area of dialyser or haemofilter (m^2)*
0–5	Amicon	0·1
5–10	Gambro FH22	0·16
5–15	Nipro FB30U	0·3
15–25	Nipro FB50U	0·5
	Gambro FH66	
35–50	Nipro FB70U	0·7
50–70	Nipro UF203	1·7

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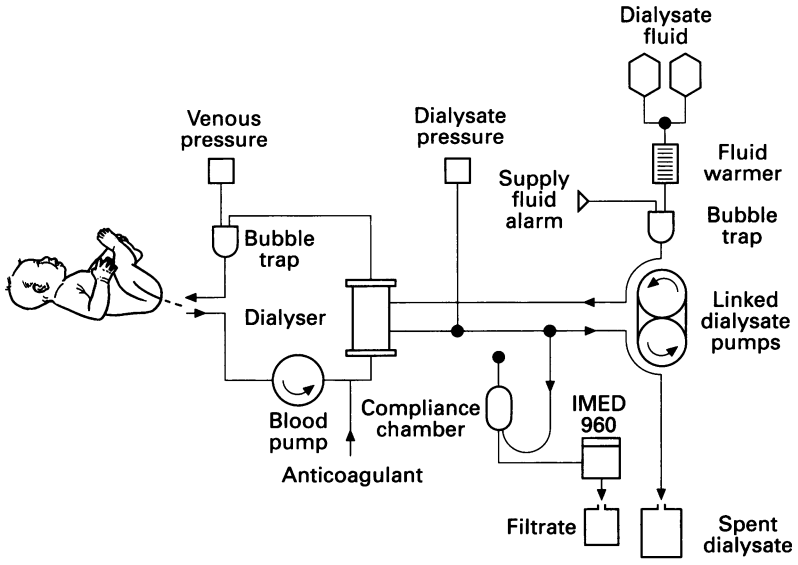

Circuit diagram of the volumetric control of continuous dialysis.

Sterile lactate (Haemofiltrasol 22, Gambro AB) or bicarbonate based dialysate fluid was pumped through the dialyser in a counter current direction to blood flow using a purpose built system (figure). Dialysate flow was controlled by two mechanically linked, peristaltic, occlusive pumps with identical insert tubing, one supplying fluid to the dialyser and the other removing spent dialysate distal to the dialyser at the same rate.[14] This constituted a fixed volumetric system, with the dialysate flow rate adjustable from 0–300 ml/minute. In the two children with uncontrolled acidaemia a bicarbonate containing dialysis solution was used. The bicarbonate containing dialysis fluid is not commercially available, and was therefore manufactured by means of a Fresenius 2008E haemodialysis machine in the renal unit at St James's University Hospital. The fluid was passed through a sterile particle collection filter before being collected into sterile empty plastic bags. The fluid is used within 24 hours of manufacture to avoid possible calcium salt precipitation. Samples were regularly sent to the microbiology department for culture and always proved to be sterile. The standard lactate containing haemofiltration solution and the bicarbonate fluid are compared in table 2.

Ultrafiltration was achieved by removal of fluid from a point between the dialyser and the out flow pump by means of a T piece connection into a cartridge pump (960A, IMED), which can be set at a variable rate of 0–999 ml/hour before use. The extracorporeal circuit was well flushed with at least one litre of 0·9% saline containing 1000 units of heparin/litre. After a loading dose of 50 units of heparin/kg, anticoagulation was provided by infusion of prostacyclin into the afferent blood line at a rate of 5 ng/kg/minute and heparin at a variable rate to maintain the activated partial thromboplastin time between 50–90 seconds. The system was prepared by the renal unit technical and medical staff and operated by intensive care unit trained nurses, under medical supervision.

In early trials of the system in adults, continuous pressure monitoring demonstrated sudden marked decreases in dialysate compartment pressure corresponding to the filling phase of the IMED 960 pump cycle. An air filled compliance chamber was, therefore, placed proximal to the pump and has proved capable of nearly abolishing these pressure swings.

Table 2 Comparison of electrolyte content of Haemofiltrasol 22 and bicarbonate containing dialysis fluid

	Haemofiltrasol 22 (mmol/l)	*Bicarbonate containing fluid (mmol/l)*
Sodium	140	137
Chloride	100	110
Bicarbonate	0	35
Calcium	1·6	1·8
Lactate	45	0
Magnesium	0·75	0·75

Results

CHILDREN

Ten children aged 9 months to 16 years (median 2·2 years) were treated with slow efficient dialysis. Peritoneal dialysis was either contraindicated, technically not possible, or had failed. All the children were mechanically ventilated and had failure of at least one organ in addition to acute renal failure. The underlying diagnosis and details of the patients are shown in table 3. The indication for starting renal replacement treatment in eight children was uraemia, in five fluid overload, in two hyperkalaemia, and in three uncontrolled acidaemia. Acute physiology and chronic health evaluation (APACHE II) score was assessed by the intensive care unit staff on the basis of the first 24 hours after admission.[15] The APACHE II scores ranged from 25–44 (median 33). The paediatric renal unit at St James's University Hospital is a regional unit serving Yorkshire and Humberside with a total catchment population of 4 million.

Child 8 was treated on three separate occasions with the system, including intra-operatively during his second orthotopic liver transplant. Treatment lasted from one to 15 days (median 4·5 days) and individual dialysers were changed before clotting and lasted up to five days. A standard artificial kidney used in regular haemodialysis circuits has a low flux and low filtration capacity compared with haemofilters with a high flux and high filtration capacity. The choice of dialyser used depended upon the child's weight (table 1). Blood flow rates varied from 25–150 ml/minute according to the size of the child. The dialysate flow rate in all cases was kept at 30 ml/minute as at these flow rates dysequilibrium did not occur. Steady state plasma urea and creatinine concentrations of <20 mmol/l and <300 mmol/l respectively were obtained. Potassium and phosphate clearances were sufficient to maintain normal or subnormal plasma concentrations. Potassium supplementation was required after

Table 3 Patient details

Patient No	Age (years)	Sex	Diagnosis	APACHE II score*	Indication for dialysis	Days on dialysis system	Days on intensive care unit	Outcome
1	0·7	M	Fulminant liver failure after liver transplant	40	Oliguria, fluid overload	5	5	Died
2	1·1	F	Haemolytic uraemic syndrome with severe encephalopathy	25	Uraemia	3	5	Recovered
3	1·3	F	Gram negative septicaemia after oesophageal reconstruction	30	Uraemia, fluid overload	5	17	Recovered
4	1·5	F	Liver and respiratory failure secondary to *Coxiella burnetii* infection	29	Uraemia, fluid overload	3	3	Died
5	2·1	F	Gram negative septicaemia, intestinal neuronal dysplasia	44	Hyperkalaemia, acidaemia	6	7	Died
6	2·2	F	Meningococcal septicaemia, hypotension	31	Uraemia, acidaemia	4	4	Died
7	3·2	M	Acute liver failure	29	Uraemia, fluid overload	3	3	Died
8	4·1	M	Acute liver failure, liver transplant	39	Uraemia, hyperkalaemia, fluid overload	15	48	Died
9	15·7	F	Gram negative septicaemia, relapsed acute lymphoblastic leukaemia, cardiomyopathy	39	Uraemia	1	1	Died
10	16·1	F	Diabetic ketoacidotic coma, adult respiratory distress syndrome	34	Uraemia, fluid overload, acidaemia	10	25	Recovered

*APACHE II score range=25–44 (median 33).

12 hours' treatment in all patients, and was added to the dialysis fluid according to a sliding scale (table 4). Alternating potassium chloride and potassium phosphate was used to avoid hypophosphataemia and hypochloraemia. The system was operated by the single intensive care unit trained nurse assigned to the patient.

Children 2, 3, and 10 survived and have normal renal function. Three children required a bicarbonate containing dialysis fluid to control acidaemia. The range of ultrafiltration volume was readily controlled by adjusting the IMED pump. The maximum ultrafiltration rate was 200 ml/hour in child 10. The ultrafiltration rate could be varied immediately depending on the circulatory condition of the child.

Discussion

Continuous venovenous haemodialysis and filtration avoids the complication of prolonged arterial catheterisation[13] and, by providing predictable blood flow to the dialyser, eliminates the consequences of variable systemic blood pressure. Conventional CAVHD and continuous venovenous haemodialysis and filtration (CVVHD) circuits are non-volumetric depending on a gate clip or its equivalent being placed on the dialysis outflow line to control the rate of ultrafiltration. They therefore require continual adjustment and time consuming retrospective fluid balance calculations for satisfactory operation. When large volumes of ultrafiltrate are produced, accurate fluid balance management becomes a problem even in the most skilled hands, and potentially dangerous fluid imbalances can occur. The precise prospective control of fluid balance that is allowed by this volumetric system minimises the risk of patient deterioration as a consequence of dialysis,[15–17] and it is possible to maintain cardiovascular and respiratory stability for longer periods of time. The ease of supervision also allows a considerable reduction in nursing workload, with significant implications for the use of resources.

Table 4 Potassium replacement

Plasma potassium (mmol/l)	Potassium/l added to dialysis fluid
2·5–3·0	10
3·1–3·5	8
3·6–4·0	6
4·1–4·5	4
4·6–5·1	2
>5·1	0

An alternative method of volumetric control previously suggested uses IMED cartridge pumps to control dialysate flow.[10 18] These pumps function with a short cartridge filling phase, followed by prolonged emptying phase. Continual monitoring in our system without the compliance chamber revealed that the short filling phase was associated with a marked reduction in the dialysate compartment pressure.

Theoretically, two such pumps controlling delivery and output of dialysate could subject the dialyser membranes to severe pressure gradients when the filling phases are not synchronised. Peristaltic occlusion pumps do not produce such pressure swings. The use of a compliance chamber shields the dialyser from the only cartridge pump, but this modified IMED 960 pump would have to be irremovably fixed to the slow efficient dialysis machine as it would be a potential hazard if inadvertently exchanged for a normal intravenous fluid infusion pump.

The fact that only three out of 10 children survived is a reflection of the severity of illness and the poor prognosis of acute renal failure associated with multiple organ failure.[1–4]

Volumetric control of continuous dialysis is highly desirable and this has been achieved in the slow efficient dialysis system that uses mechanically linked peristaltic occlusion pumps to control delivery and outflow of dialysate. Satisfactory control of plasma chemistry was achieved in all patients. Peritoneal dialysis remains the initial renal replacement treatment of choice in children with acute renal failure. When peritoneal dialysis is impossible or has failed, however, slow efficient dialysis offers

major advantages over existing methods of continuous renal support, particularly in its ability to provide prospective dial-up control of fluid balance.

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