ACUTE HEMOFILTRATION IN INTENSIVE CARE SETTING

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SYNOPSIS

Continuous arteriovenous hemofiltration (CAVH) and pump-assisted continous veno-venous hemofiltration using small hollow-fibre hemofilters were used as the first-line dialytic therapy in critically ill patients with acute renal failure. During an eight-month period, 15 patients had 18 treatments. The technique is especially applicable in patients with vascular instability and severe fluid overload. The total urea removal achieved by CAVH was comparable to that of hemodialysis. The mean arterial pressure improved (pre-treatment 77.3 ± 14.9 mmHg, post-treatment 88.1 ± 11.7 mmHg, $P < 0.01$) and the central venous pressure fell (pre-treatment 15.7 ± 5.0 cm, post-treatment 9.3 ± 3.1 cm, $P < 0.001$) with effective removal of fluid by ultrafiltration. Pump-assisted hemofiltration has advantages of shorter treatment period and higher filtration fraction. We conclude that CAVH should be used as the first-line dialytic therapy in intensive care setting and these patients should switch to conventional hemodialysis only when they are hemodynamically stable.

INTRODUCTION

Hemodialysis may not always be feasible in the critically ill patients complicated with acute renal failure. Not uncommonly, vascular instability and hypotension preclude effective hemodialysis, and peritoneal dialysis may be contraindicated by abdominal surgery, respiratory distress or infection. In 1977, continuous arteriovenous hemofiltration (CAVH) was first applied for emergency fluid removal (1). In 1980, Paganini and Nakamoto (2) used the technique to maintain fluid balance in anuric patients needing parenteral nutritional feeding. Shortly after, Kramer and coworkers demonstrated that CAVH could be used for dialytic therapy in the intensive care setting (3). In the present report, we studied CAVH as a first-line dialytic therapy in intensive care setting for patients in whom conventional dialysis would be difficult and compared the efficacy of CAVH with hemodialysis.

METHODS

Patients

All patients treated with acute hemofiltration between August 1984 and March 1985 were included in the study. Treatments were done in the Intensive Care Unit or Acute Renal Dialysis Center of the Prince of Wales Hospital, Hong Kong. Patients were chosen because they were considered to be poor candidates for conventional dialytic procedures.

Fifteen patients were studied. The clinical data and the indications for CAVH were summarized in Table 1. Ten patients underwent CAVH and the remaining five patients had pump-assisted veno-venous hemofiltration. Six of the fifteen patients became hemodynamically stable after the hemofiltration and were later switched to hemodialysis treatment. Seven patients needed vasopressor support to maintain the blood pressure and five patients needed ventilatory support. The patient's pulse rate, blood pressure, and central venous pressure were recorded every 30 minutes during the hemofiltration. The change in body weight was carefully monitored with electronic bed scale. The ultrafiltration volume was measured every 30 minutes. The filtrate composition and the sieving coefficient were evaluated by taking blood samples from pre-filter and post-filter tubings and by pairing these samples with filtrate collected over a one-minute period. The post-dilutional replacement fluid was discontinued for three minutes prior to blood sampling to avoid dilution of the sample. Levels of blood nitrogen urea, creatinine, electrolytes, and plasma proteins were measured by the Technicon sequential multiple analyser. Simultaneously, ultrafiltrate samples were analysed by the same method. The sieving coefficients of albumin, globulin, and electrolytes were calculated using the following equation:

$$\text{sieving coefficient} = \frac{2 \times \text{concentration in the filtrate}}{\text{concentration in inlet} + \text{concentration in outlet}}$$

The rates of removal of urea nitrogen, creatinine and electrolytes during acute hemofiltration were calculated from the concentration in the ultrafiltrate and the volume of ultrafiltrate. The quantity of urea nitrogen removed during hemodialysis was calculated from the urea kinetics, as described previously (4).

Technique

A hollow fiber hemofilter with a polysulfone asymmetric membrane (0.25 m^2) was used (Amicon Diafilter-20). In the five patients with pump-assisted hemofiltration, Amicon-30 hemofilter was used. The inlet and outlet ports of the filter were connected to the patient with hemodialysis blood lines. The ultrafiltrate was collected in a graduated collection bag linked to the ultrafiltrate port by a line 50 cm long. The arterial and venous lines were attached to the patient by different types of angioaccess. In ten patients, femoral dialysis catheters [16 gauge] (Argon, Athens, Texas) were used to cannulate femoral artery and vein using the Seldinger technique. Dual lumen subclavian catheters (Quinton-Mahurkar, Seattle, Washington) were used in the remaining five patients undergoing pump-assisted veno-venous hemofiltration. The blood flow rate (Q_B) in these five patients was maintained at 125 ml/min by the use of a blood pump (Gambro AK-10 system blood monitor).

An initial bolus of 1500 units of heparin was administered at the onset of hemofiltration via the sleeve on the arterial line. Thereafter, a constant infusion of heparin was given with a Harvard pump (Harvard Apparatus, South Natick, Massachusetts), and the dose rate of heparin infusion was adjusted such that the activated partial thromboplastin time was maintained twice the baseline value. Replacement fluid was infused into the venous (postdilution) lines. Constant infusion pump (IVAC 630, San Diego, California) was used to maintain the desirable rate of infusion which was to be determined every 15-30 minutes. Replacement fluid composition was varied for individual patient as dictated by clinical considerations. Equal volume of normal saline and Hartman's solution or Ringer's lactate was suitable for most patients.

The measurement of blood flow rate (Q_B), plasma flow rate (Q_P), and filtration fraction (FF) were performed by taking blood samples from a sampling sleeve along the arterial (inlet) and venous (outlet) lines. Simultaneously, ultrafiltration samples were collected and ultrafiltration rate (U_F) was determined. Hematocrit (Hct) was measured by the spun capillary tube method, and the blood flow rate at the filter inlet was calculated with the following equation:

$$Q_B = (U_F \times \text{Hct outlet})/(\text{Hct outlet} - \text{Hct inlet})$$

The plasma flow rate at the filter inlet was determined as:

$$Q_P = Q_B \times (1 - \text{Hct inlet}/100)$$

The filtration fraction was calculated from the following equation:

$$FF = U_F/Q_P$$

Statistics

The results are expressed as mean ± standard deviation and the hemodynamic and biochemical changes before and after the hemofiltration treatment are analysed by Student's paired t-test. The rates of urea removal by CAVH and conventional hemodialysis are analysed with Student's t-test.

RESULTS

Patient outcome and complication

In the eight-month period, 15 patients underwent 18 treatments. The mean age was 52 years (range 33-70). Thirteen patients had acute renal failure and two had acute on chronic renal failure without previous dialysis therapy (Table 1). The mean duration of treatment was 22.1 hours (range 5.5-46). Six patients were switched to hemodialysis treatment when they became hemodynamically stable after hemofiltration treatment. Twelve patients had complete recovery of renal function. One patient (case 5) had hepato-renal syndrome and his renal function and urinary output improved with CAVH. Nevertheless, he died one week later with hepatic encephalopathy. One patient (case 1) died of intracerebral thrombosis. One patient (case 6) had cerebral anoxia despite active cardiorespiratory resuscitation and maintenance dialytic therapy was subsequently discontinued because of confirmed brain death. Post-mortem examination revealed end-stage renal failure due to chronic glomerulonephritis.

Complications experienced with acute hemofiltration (CAVH or pump-assisted hemofiltration) were mainly related to hemorrhage. Bleeding from the femoral puncture site occurred in three patients while bleeding from the subclavian puncture site occurred in two patients. One patient (case 1) died of intracerebral

TABLE 1: SUMMARY OF CLINICAL DATA AND INDICATION OF 15 PATIENTS ON CAVH*

Patient	Sex/Age	Indication	Access	Outcome
1	F/68	CRF, Aminoglycoside toxicity	Femoral vessels	died of intracerebral thrombosis
2	F/35	ARF — septicemia, aminoglycoside toxicity	Femoral vessels	complete recovery
3	M/39	ARF — septicemia	Femoral vessels	complete recovery
4	F/70	ARF — cholangitis and septicemia	Femoral vessels	complete recovery
5	M/60	ARF — Hepato-renal syndrome	Femoral vessels	stable renal function died of hepatic failure
6	F/33	post-cardiac arrrest Bronchopneumonia, CRF	Femoral vessels	septicemia, brain death
7	M/48	Ischemic cardiomyopathy myocardial infarction, ARF	Femoral vessels	complete recovery
8	M/45	ARF — aminoglycoside toxicity	Femoral vessels	complete recovery
9	F/66	ARF — cholangitis	Femoral vessels	complete recovery
10	M/52	ARF — retroperitoneal lymphoma	Femoral vessels	complete recovery of renal function, died 8 months later because of septicemia
11*	F/40	ARF — septicemic, multiple — injections	subclavian vein	complete recovery
12*	M/50	ARF — myocardial infarction cardiogenic shock	subclavian vein	complete recovery
13*	M/70	ARF — ruptured aortic aneurysm	subclavian vein	complete recovery
14*	M/60	ARF — post cholecystectomy, septicaemia	subclavian vein	complete recovery
15*	F/45	ARF — post bowel surgery	subclavian vein	complete recovery

* Blood pump used
Abbreviations: ARF — acute renal failure
CRF — chronic renal failure

thrombosis and the atherosclerotic plague was believed to arise from the femoral artery. Infection by Staphlococcus epidermidis at the subclavian puncture site occurred in one patient and the infection was controlled with appropriate antibiotic and the removal of the catheter. All the catheter tips were cultured and no organism was grown. Blood leakage due to rupture of the hollow fibre was not detected in our 18 treatment even when pump was used. Difficulties in maintaining a satisfactory rate of reinfusion of replacement fluid occurred in our first patient on the pump as the hourly filtrate volume exceeded two litres. This was overcome by replacing the fluid through an additional peripheral intravenous drip.

Operational data

The operational values are summarized in Table 2. Because of the insertion of dual lumen subclavian catheter, a blood pump was needed in five patients (cases 11, 12, 13, 14, 15). The blood and plasma flow rates ranged from 60.5—85.1 ml/min and 46.9—68.4 ml/min respectively in patients without a pump. With a blood flow rate of 125 ml/min regulated by a pump, the plasma flow rate increased (ranged 72.4—95.8 ml/min). The filtration rate ranged from 6.1—11.6 ml/min without a pump and from 16.2—31.2 ml/min with a blood pump. The filtration fraction increased with the use of the blood pump (mean 26.7%) as compared with that obtained without a pump (mean 15.4%). The higher filtration fraction indicates a higher efficency achieved by using a blood pump. The filtration volume ranged from 5.7 litres to 20.6 litres. The volume of replacement fluid was adjusted according to the state of hydration and the hemodynamic stability of the patient. An average of 1.49 litres of fluid was removed during the procedure. Seven of our fifteen patients had severe hypotension with the systollic blood pressure less than 90 mmHg and the diastolic blood pressure less than 60 mmHg and this precluded effective hemodialysis (Table 3). The cardiovascular stability improved with gradual removal of fluid by hemofiltration and the mean arterial pressure increased from 77.3 ± 14.8 mmHg to 88.1 ± 11.7 mmHg ($P < 0.01$) towards the end of hemofiltration. The central venous pressure fell significantly from 15.7 ± 5.0 cm to 9.3 ± 3.1 cm ($P < 0.001$) with effective removal of fluid. Clinically, these patients experienced an improved peripheral circulation with the procedure.

TABLE 2: OPERATIONAL DATA FOR 15 PATIENTS ON CAVH*

Patient	Blood flow rate (ml/min)	Plasma flow rate (ml/min)	Ultrafiltrate rate (ml/min)	Filtration fraction (%)	Treatment duration (hr)	Filtrate volume (litre)	Replacement volume (litre)	Maintenance heparin (IU/hr)
1	75.0	60.9	8.5	13.2	23	10.8	9.5	685
2	80.2	65.1	10.5	16.0	29	16.3	14.1	648
3	68.2	51.2	8.2	16.0	25	12.1	10.4	795
4	60.5	47.1	6.1	12.9	34	12.2	11.0	670
5	85.1	64.5	10.7	16.6	22	14.1	13.3	168
6	72.5	58.1	9.5	16.3	46	20.6	17.8	480
7	82.1	68.4	10.2	14.9	35	19.4	17.1	540
8	67.5	46.9	8.4	17.9	28	12.4	11.0	790
9	81.1	67.2	11.6	17.3	34	20.4	18.1	675
10	71.3	59.1	842	12.5	27	11.3	9.9	712
11*	125.0	95.7	19.4	20.3	6	7.0	6.9	1300
12*	125.0	76.5	26.1	34.1	5.5	8.6	6.1	1068
13*	125.0	83.9	31.2	37.2	5.5	10.3	10.2	310
14*	125.0	72.4	15.7	21.7	6	5.7	10.2	310
15*	125.0	80.1	16.2	20.2	6	6.1	5.2	650

* Blood pump used

TABLE 3: HEMODYNAMIC AND LABORATORY DATA FOR 15 PATIENTS ON CAVH*

Patient	pre-Tx BP (mmHg)	post-Tx BP (mmHg)	pre-Tx MAP (mmHg)	post-Tx MAP (mmHg)	pre-Tx CVP (cm)	post-Tx CVP (cm)	pre-Tx serum creatinine (umol/L)	post-Tx serum creatinine (umol/L)	Total urea removal (mmol)
1	80/50	160/100	60.0	86.7	16	12	1147	837	214
2	120/80	110/70	93.3	83.3	19	11	1185	905	312
3	90/60	120/80	70.0	93.3	6	6	1050	781	462
4	160/80	170/90	106.7	116.7	14	5	950	677	344
5	90/70	100/60	76.7	73.3	15	12	1461	1021	621
6	80/40	150/100	53.3	88.3	20	12	585	382	186
7	90/70	100/70	76.7	80.0	22	3	941	691	194
8	110/60	120/80	76.7	93.3	10	7	1010	792	511
9	100/60	115/75	76.7	86.7	9	9	1340	1129	490
10	90/70	120/70	76.7	86.7	15	12	889	631	214
11*	130/70	120/70	90.0	86.7	19	9	1042	774	228
12*	90/60	120/80	70.0	93.3	25	14	910	650	464
13*	130/90	140/90	103.3	106.6	12	9	885	655	275
14*	90/60	100/60	70.0	73.3	14	6	1151	874	260
15*	80/50	95/60	60.0	71.7	19	12	1024	810	271
			77.3 ± 14.8	88.1 ± 11.7††	15.7 ± 5.0	9.3 ± 3.1†	1038.0 ± 200.3	773.6 ± 171.5†	336.4 ± 133.2

* Blood pump used
Results are expressed as mean ± standard deviation
† ($P < 0.001$)
†† ($P < 0.01$)
Abbreviation Tx — treatment
BP — blood pressure, MAP — arterial pressure, CVP — central venous pressure

Biochemical data

Electrolytes, blood urea nitrogen and creatinine showed small differences between the filtrate and the plasma samples. The sieving coefficients of sodium, potassium, chloride, bicarbonate, phosphate, urea, and creatinine ranged from 0.91 to 1.0. The sieving coefficient of albumin, globulin, and bilirubin ranged from 0.015 to 0.09 indicating that the albumin and globulin were selectively retained and the low sieving coefficient of bilirubin was due to the albumin binding. Similarly, the sieving coefficient of calcium ranged from 0.54 to 0.69 because of the albumin binding.

The serum creatinine fell from 1038.0 ± 200.3 umol/1 to 773.3 ± 171.5 umol/1 ($P < 0.001$) with acute hemofiltration treatment. Table 4 compares the efficacy of CAVH and conventional hemodialysis in 6 patients who were switched from CAVH to hemodialysis after they became hemodynamically stable. The pre-treatment and post-treatment serum creatinine levels were not different and the total urea removed by CAVH was similar to that achieved by conventional hemodialysis despite CAVH had a slower rate of urea removal.

the intravascular volume. Vascular instability that has been experienced in hemodialysis is not frequently encountered. Disequilibrium syndrome is less likely to occur with CAVH as compared with acute hemodialysis as the removal of uremic toxins is slow and gradual. During the course of acute renal failure, parenteral supplementation of essential amino acids, and adequate calories is often required and CAVH allows a better fluid balance in these critically ill patients. The electrolytes disturbance could readily be corrected by altering the composition of the replacement fluid. The remaining clinical parameter of assessing the effectiveness of CAVH rests upon the ability of this therapeutic technique to maintain an acceptable level of plasma urea nitrogen. The level of urea nitrogen in plasma depends on the rate of production and removal. In our patients who underwent both CAVH and hemodialysis treatment, no significant differences had been demonstrated in their pre-treatment and post-treatment serum creatinine levels. The total amount of urea removed by each CAVH treatment was not significantly different from that achieved by conventional hemodialysis. Hence, we could conclude that, in patients without severe

TABLE 4: CLINICAL COMPARISON OF CONTINUOUS ARTERIOVENOUS HEMOFILTRATION (CAVH) AND HEMODIALYSIS (HD) PERFORMED IN 6 PATIENTS

n =	CAVH 6	HD 6	P value*
Length of treatment (hr)	31.8 ± 8.6	5 ± 0	< 0.001
Serum creatinine:			
before treatment (umol/L)	1027.7 ± 290.0	1124.0 ± 190.5	NS
after treatment (umol/L)	742.8 ± 220.2	541.2 ± 184.4	NS
Urea removal (mmol)	353.2 ± 166.5	260.4 ± 92.4	NS
rate of urea removal (umol/min)	164.0 ± 162.0	965.1 ± 264.2	< 0.001

The results are expressed as mean ± standard deviation
* Student t-test
Abbreviation: NS = not significant

DISCUSSION

Oliguric acute renal failure remains a difficult management problem in critically ill patients in the intensive care setting. The fluid retention, electrolyte imbalance, acidosis, and other metabolic disturbances may not always respond to conservative medical therapy and, not uncommonly, supportive dialytic therapy is required. Vascular instability and hypotension may preclude effective hemodialysis and peritoneal dialysis can be contraindicated by abdominal surgery or infection.

Our preliminary experience supports those reported by Lauer et al (5) and Kaplan et al (6) that CAVH is a useful alternative to conventional dialysis. We have demonstrated the effectiveness of CAVH as a dialytic therapy for patients in whom conventional dialysis would be difficult. The mean arterial pressure and central venous pressure improved significantly after the procedure with clinical improvement. In critically ill patients, we would now advocate CAVH as the first-line dialytic therapy even though hemodialysis or peritoneal dialysis appears to be technically feasible. The greatest advantage of CAVH is the continuous removal of fluid and controlled amount of replacement fluid is infused thus avoiding the drastic changes in catabolism, CAVH treatment could maintain an acceptable level of plasma urea nitrogen despite a slower rate of urea removal and a lower creatinine clearance as compared with hemodialysis.

Blood pump was used in five patients because of the insertion of dual lumen subclavian catheter. Contrary to the previous report (5), we find that the use of blood pump results in a higher efficiency as indicated by the higher filtration fraction. The total urea removal and the fall in serum creatinine in these five patients were comparable to those of the remaining ten patients on CAVH yet the treatment period of these five patients was less than six hours. Hence, pump-assisted hemofiltration has the advantages of a higher efficiency with a shorter treatment period yet maintaining a satisfactory hemodynamic stability. The other advantage in elderly patients is the avoidance of femoral artery puncture and the risk of atherosclerotic embolism as experienced in our patient may be reduced. A dual lumen catheter in the subclavian or femoral vein would provide a good access. The apparent disadvantages of pump-assisted hemofiltration are the higher maintenance dosage of heparin, rerquirement of a blood pump, and the attendance of a renal nurse.

In conclusion, CAVH is convenient to be used in the

intensive care setting and we advocate this to be the first-line dialytic therapy in the critically ill patients with acute renal failure. These patients should only switch to conventional hemodialysis after they become hemodynamically stable with initial CAVH treatment.

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