

Simultaneous Cardiopulmonary Bypass and Dialysis

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Abstract

An increasing number of patients are presenting for cardiac surgery with renal impairment. A simplified technique for dialysis during cardiopulmonary bypass (CPB) was designed and evaluated in the laboratory. The system has successfully been applied to patient care.

A dialysis circuit consisting of a hollow fiber dializer, a roller pump for propelling dialyzing fluid, and blood lines was incorporated into a simulated CPB circuit primed with blood having values comparable to those found in the uremic patient: hematocrit, 14 percent; potassium, 8.8 mEq/L; colloid osmotic pressure, 8.7 mm Hg; creatinine, 19.6 mg/dl; BUN, 109 mg/dl. Blood flow through the dializer was controlled to produce inlet pressure of 200 mm Hg, similar to the pressure found in the arterial line filter. Lactated Ringers contained in one liter bags was used as dialysate. Dialysate was aspirated through the dializer using a roller pump. Four dialyses were carried out varying the ultrafiltration pressure and the frequency with which fresh dialysate was used.

Creatinine, BUN, and potassium levels returned to normal while the colloid osmotic pressure and hematocrit were elevated. More frequent changes in dialyzing bath resulted in more rapid dialysance and increasing ultrafiltration pressure resulted in more rapid hematocrit and colloid osmotic pressure elevation.

This technique has been applied to patients in renal failure undergoing heart surgery and has been effective in reducing fluid load and normalizing blood chemistries.

Introduction

Cardiac surgery, including coronary artery bypass and aortic valve replacement, has been successfully per-

formed on chronic uremic patients.^{1,2,3} Traditional hemodialysis has been utilized in several instances both pre-operatively and in the post-operative period. Concurrent hemodialysis and cardiopulmonary bypass (CPB)⁴ may be more advantageous than the traditional method of dialysis in the pre-operative period in that it is applicable to patients in whom the rigors of dialysis might compromise their pre-operative status and in the uremic patient presenting for emergency cardiac surgery.

Placement of an artificial kidney in the CPB circuit has proven to be a reliable method of hemoconcentrating through ultrafiltration.⁵ The addition of dialysis should allow control of both fluid volume and solute concentration. This study was performed to determine whether dialysis can be performed simply and efficaciously concurrent with CPB.

Methods and Materials

Four CPB procedures were simulated incorporating the TriEx Hollow Fiber dializer^a into the CPB circuit. This artificial kidney (AK) consists of three bundles of hollow cellulosic fibers sealed inside a three-chambered plastic case. The fibers have a total surface area of approximately 1.6 m² and the dializer has an ultrafiltration rate of approximately 5ml per hour per mm Hg transmembrane pressure.

The "patient" in the simulated circuit consisted of a 1000ml polyvinyl chloride (PVC) reservoir bag^b, a roller pump^c, and a heat exchanger^d to maintain blood temperature at 37 degrees. PCV tubing completed the patient circuit.

a Extracorporeal Medical Specialties, King of Prussia, PA 19406

b Model R500, SciMed Life Systems, Minneapolis, MN 55441

c Olson Medical, Ashland, MA 09154

d OmniTherm, SciMed Life Systems, Minneapolis, MN 55441

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The blood path for the dialysis circuit consisted of 1/4" PVC tubing, the AK and a roller pump used to provide a constant inlet pressure of 200 mm Hg into the AK. The dialyzing fluid, Lactated Ringers^e, was circulated through the AK under negative pressure by a roller pump and a partial occlusion clamp on the tubing on the negative pressure side of the pump. One liter containers of Lactated Ringers were used.

The patient circuit was primed with constituents selected to simulate 1500 ml of blood from a severely uremic patient. Expired packed red cells were used to achieve a mean hematocrit of 14 percent.

This blood was added to a mixture of Lactated Ringers to which had been added 300 mg of creatinine, 3600 mg of urea and 1600 mg of glucose. The colloid osmotic pressure was adjusted by the addition of 25 percent albumin. This procedure produced blood with a mean potassium concentration of 8.8 mEq/L, a mean creatinine level of 19.6 mg/dl, a mean BUN of 109 mg/dl, a mean glucose concentration of 94 mg/dl and a mean colloid osmotic pressure (COP) of 8.7 mm Hg.

Four simulated CPB procedures with concurrent dialysis were performed. Each procedure lasted two hours. During the first procedure, the one liter dialyzing fluid bag was changed at the midpoint. During the next two, the dialyzing fluid was changed every half hour and during the final procedure, the fluid was changed every ten minutes. Prior to "bypass" and at ten minute intervals thereafter, levels of creatinine, BUN, potassium and glucose were determined.^f Hematocrits were measured^g and total protein (TP) concentrations determined,^h and COP was estimated using the following formula:

$$\text{COP} = (\text{TP} \times 3.32) - 2.0^6$$

Blood pressures on the inlet and outlet sides, (PBi) and (PBo), of the AK were measured by pressure transducersⁱ proximal and distal to the AK. Dialysate pressure (PD) was measured by a negative pressure gauge.^j Transmembrane pressure (TMP) was calculated using the formula:

$$\text{TMP} = (\text{PBi} + \text{PBo})/2 - \text{PD}$$

Five patients presenting for cardiac surgery between June 1983 and May 1984 with renal failure were dialyzed while undergoing CPB. The TriEx Hollow Fiber dialyzer was inserted into the routine CPB circuit in place of the arterial filter purge line. One fourth inch ID PVC tubing attached to the blood inlet of the dialyzer was attached to the purge port of the arterial line filter^k by means of a three way stopcock^l, a male to male connector^m and a catheter adapterⁿ. Blood was returned to the cardiomy reservoir^o from the AK via 1/4 inch PVC tubing connecting to the priming port of the reservoir. Arterial line pressure served to move blood through the AK. A separate roller pump^p was used to recirculate dialysate. One half inch ID tubing fit the dialysate ports. This tubing was stepped down to tubing with 3/8 inch ID by 3/32 inch wall thickness. On the dialysate outlet side of the AK, the 3/8 inch tubing was inserted in the pump head^p before being further reduced by inserting a 3/8 by 1/4 inch reducer and attaching a rapid prime line. The AK was thus placed on the negative pressure side of the dialysate pump and negative pressure was controlled by a partial occlusion clamp on the inlet side where the 3/8 inch line was stepped down to a rapid prime line. Both rapid prime line spikes were inserted into a one liter bag of Lactated Ringers from which 500 ml of solution had been removed.

CPB was initiated in the normal fashion and once the bypass was stable, dialysis was begun by opening the arterial line filter purge port stopcock to the full open position. Dialysate flow was begun at two liters per minute and the partial occluding clamp on the negative pressure line closed until gas was observed to be coming out of solution. The dialysate was changed every half hour. Potassium rich, ice cold, crystalloid cardioplegic solution (Table 1) was administered to all patients. A primary dose of 750 ml. was delivered either to the aortic root or directly into the coronary arteries followed by subsequent 400 to 500 ml. doses approximately every 20 minutes. Pre-bypass levels of creatinine, BUN, hematocrit, COP, potassium, sodium, chloride and glucose

e Travenol Laboratories, Deerfield, IL 60015
 f Automated Clinical Analyzer, Dupont Clinical Systems Division Wilmington, DE 19898
 g Microcentrifuge, Lab-Line Instruments, Melrose Park, IL 60161
 h A/O Refractometer, American Optical, Buffalo, NY 14240
 i Model Db 23, Gould-Statham Instrument, Inc. Hato Rey, Puerto Rico 00919
 j Series A Suction Regulator, Puritan-Bennett, Norcross, GA 30071

k Model EC 3840, Pall Biomedical Products Corporation, Glen Cove, NY 1542
 l # 41-210-002 Stopcock with male L-L, Cobe Laboratories, Lakewood, CO 80215
 m # 040-180-000 Double Male Luer Lock Adapter, Cobe Laboratories Lakewood, CO 80215
 n Catheter Adapter, Becton-Dickinson, Rutherford, NJ 07070
 o Model Q220F, Bentley Laboratories, Irvine, CA 92714
 p Compuflow Model, Travenol Laboratories, Deerfield, IL 60015

Table 1
Constituents of Cardioplegic Solution

Lactated Ringers		1000ml
Na ⁺	130 mEq/L	
k ⁺	4 mEq/L	
Ca ⁺⁺	3 mEq/L	
Cl ⁻	109 mEq/L	
Lactate ⁻	28 mEq/L	
KCl	2 mEq/L	10ml
NaHCO ₃	1 mEq/ml	5ml

were obtained and compared to post by-pass values. Fluid intake and output were carefully monitored during CPB.

Results

Table 2 summarizes the pertinent results obtained from the simulations. Dialysance rate was markedly increased by changing the dialysate bath more frequently. However, if the results from trials 2&3 and trial 4 are compared, it will be noted that increasing the frequency of change from 30 minutes to 10 minutes had little effect on the final results. Most of the dialysance occurred in the first 10 minutes.

Although the total ultrafiltrate volume was approximately the same in all trials, the rate of ultrafiltration was varied during each trial by changing the negative pressure on the dialysate side of the AK by changing the amount of occlusion exerted on the dialysate inlet line. It was found that approximately 200 mm Hg negative

Table 2
Results of Simulated CPB with Concurrent Dialysis

Function	Trial-1	Trials-2&3	Trial-4
Creatinine(mg/dl)*	-9	-20.2 ± 2.7	-20.9
BUN(mg/dl)*	-46	-108 ± 18	-117
K ⁺ (mEq/L)*	-3.6	-4.5 ± .28	-2.9
Hct(%)*	+3.5	+17 ± 5.7	+11.5
COP(mmHg)*	+4	+11.6 ± 5.3	+4.7
Glucose(mg/dl)*	-47	-92.5 ± 2.1	-65
Ultrafiltrate(ml)	1120	1378 ± 314	1104

* Results shown are changes from predialysis values

pressure would just begin to collapse the dialysate tubing and just begin to draw bubbles out of solution. Using a constant blood inlet pressure of 200 mmHg, the TMP was varied between 175 mm Hg and 500 mm Hg which produced ultrafiltration rates of 875ml/hr to 2500ml/hr.

Table III summarizes the data from the clinical trials. All patients had substantial reductions in BUN and cratinine levels. The potassium levels remained within the normal range despite the administration of large amounts of potassium rich cardioplegic solution(CPS). The ultrafiltration rate approximated one liter per hour. Ultrafiltration is further demonstrated by increasing hematocrit and COP.

Discussion

The effectiveness of this technique is verified by the laboratory simulation data and supported by the clinical data. It should be pointed out that in the simulations, the "patient" blood volume contained only 1500 ml of

Table 3
Patient Results

PATIENT	1	2	3	4	5
Procedure	MVR	MVR	MVR,AVR	AVR,An	CABG
Pump Time(min)	152	192	161	151	86
CPD Given(ml)	2200	2900	2100	3750	1600
BUN(mg/dl)*	43(-15)	37(-6)	49(-9)	54(-17)	65(-14)
Creatinine(mg/dl)*	3(-2)	11(-4)	1(-.2)	13(-6)	5(-2)
Potassium(mEq/L)*	5(.9)	5(.9)	4(.4)	5(.3)	5(-.1)
Hct(5%)*	33(6)	21(2)	25(2)	28(-2)	25(3)
COP(mmHg)	17(3)	15(1)	17(2)	14(2)	16(3)
Ultrafiltrate(ml)	2200	2900	2100	2400	1500

* Values are end of bypass and (change from prebypass)

blood where as the blood volume of an adult endstage renal disease patient may be five to six times that. Furthermore, the patient's solute reservoir includes the interstitial and intracellular fluid in addition to the blood. The reduction of solute concentration from the large patient solute reservoir does not proceed at the rate shown in the simulation. This is desirable for too rapid removal could result in the disequilibrium syndrome,⁷ which might well go undetected in the anesthetized, paralyzed patient.

It also should be noted that all of the patients reported were hemodialyzed within 24 hours prior to surgery so that it was not felt necessary to vigorously dialyze. For this reason, the dialysate bags were changed only every 30 minutes. The main objective was to maintain normal potassium levels and to control fluid balance via ultrafiltration.

Concurrent CPB and dialysis proved to be effective, safe and simple. The technique described obviates the requirement for complex hemodialysis machines in the operating room.

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