Pediatr Nephrol (1999) 13:641–645

DIALYSIS / ORIGINAL ARTICLE

Jonathan M. Sorof · Daniel Stromberg
Eileen D. Brewer · Timothy F. Feltes
Charles D. Fraser, Jr.

Early initiation of peritoneal dialysis after surgical repair of congenital heart disease

Received: 26 August 1998 / Revised: 21 December 1998 / Accepted: 5 January 1999

Abstract The mortality rate of infants who require renal replacement therapy after surgical repair of congenital heart disease has been reported to be 30%–79%. We report our experience with early initiation of continuous manual peritoneal dialysis (CPD) to treat fluid overload in 20 consecutive critically ill children who underwent CPD post cardiotomy. CPD catheters were inserted at the discretion of the cardiothoracic surgeon. CPD was started for evidence of total body fluid overload with inadequate urine output, and stopped when negative fluid balance was achieved and urine output improved. Median age was 10 days (range 3–186 days), mean time to start CPD post-operatively was 22 h (range 5–40 h), and mean duration of CPD was 50 h (range 13–92 h). CPD resulted in mean ultrafiltration of 93 ml/kg per day (range 43–233 ml/kg per day). Net negative fluid balance was 106 ml/kg per day (range 49–273 ml/kg per day). During CPD, the mean number of inotropes decreased from 2.2 to 1.6 ($P<0.05$) and urine output increased from 2.2 to 3.9 ml/kg per hour ($P<0.01$). No patient died during CPD or had CPD discontinued due to adverse hemodynamic effects. The overall mortality rate was 20%. We conclude that early initiation of CPD can safely and effectively promote fluid removal in infants after repair of congenital heart disease, with a lower mortality rate than has previously been reported.

Key words Peritoneal dialysis · Kidney failure · Heart defects · Congenital

J.M. Sorof (✉) · D. Stromberg · E.D. Brewer · T.F. Feltes
C.D. Fraser, Jr.
Department of Pediatrics, Texas Children's Hospital,
Baylor College of Medicine, Houston, Texas, USA

Mailing address: J.M. Sorof
6621 Fannin Street MC3–2482, Houston,
TX 77030-2399, USA
e-mail: jsorof@texaschildrenshospital.org
Tel.: +1-713-770-3754, Fax: +1-713-770-3889

Introduction

Infants who undergo surgical repair of complex congenital heart disease are prone to develop renal dysfunction characterized by oliguria and fluid overload [1–6]. Coincident with this fluid overload, many of these patients also suffer from hemodynamic instability due to poor myocardial function and require inotropic support to maintain adequate systemic blood pressure. Infants with fluid overload and hemodynamic instability are generally considered poor candidates for fluid removal by renal replacement therapy. Despite the potential difficulties in establishing negative balance, renal replacement therapy has become an accepted treatment in the management of these patients. Previous studies have reported varying degrees of success in achieving negative fluid balance using the modalities of continuous peritoneal dialysis, continuous veno-venous hemofiltration (CVVH), and continuous arterio-venous hemofiltration (CAVH), with reported mortality rates in the range of 30%–79% [1, 4, 5, 7–12]. We reviewed our experience using continuous manual peritoneal dialysis (CPD) to treat renal dysfunction and fluid overload in small children receiving inotropic support after surgical repair of congenital heart disease. The aims of the study were to determine: (1) whether CPD is effective in removing fluid and establishing negative fluid balance in hemodynamically unstable children receiving inotropic support, (2) whether CPD is limited by infectious or mechanical complications associated with the newly placed, uncuffed peritoneal dialysis catheters, and (3) the overall mortality rate in these children who receive CPD.

Patients and methods

The records of all patients who underwent CPD after surgical repair of complex congenital heart disease after July 1995 were reviewed. Conventional hemofiltration at the end of cardiopulmonary bypass was employed in the majority of patients to increase hematocrit and reduce extravascular fluid retention. Soft silicone rubber uncuffed peritoneal catheters were placed midline in the

lower abdomen intraoperatively in selected patients at the discretion of the cardiothoracic surgeon. Newborns undergoing complete repair, patients thought to be at risk for right heart failure, patients with increased pulmonary vascular resistance, and patients undergoing cavopulmonary diversion were considered for CPD catheter placement. In addition, the determination of whether to place a catheter was based on the age of the patient and the duration of cardiopulmonary bypass time. The decisions to place PD catheters and when to begin and end CPD were made by the cardiothoracic surgeon and the pediatric cardiologist. The indications for starting CPD included: (1) physical evidence of total body fluid overload/anasarca, (2) urine output ≤2 ml/kg per hour unresponsive to intravenous furosemide given intermittently (1–2 mg/kg per dose) or continuously (0.1–0.3 mg/kg per hour) for >4 h, (3) acid-base or electrolyte disturbances (serum pH<7.3 and serum bicarbonate concentration<18 mmol/l or serum potassium concentration >6.0 mmol/l), and (4) low cardiac output with renal insufficiency. The indications for stopping CPD included: (1) resolution of clinical edema with urine output sufficient to maintain even or negative fluid balance and (2) correction of electrolyte imbalance.

CPD was managed in all cases by a pediatric nephrologist using an identical dialysis protocol. Manual exchanges were performed using the Dialy-Nate Set (peritoneal dialysis set for neonates, Bard Access Systems, Salt Lake City, Utah, USA). This system is specifically designed for low-volume exchanges in small children by providing a completely enclosed system that includes a buretrol to measure small quantities of inflow and outflow. The dialysate bags were changed once every 24 h only by a trained pediatric dialysis nurse, and the entire system including tubing was changed every 72 h. Each exchange was initially prescribed to allow 5 min for fill, 45 min of dwell, and 10 min for drain. CPD was started with dwell volumes of 10 ml/kg and dextrose concentration of 1.5%. The dextrose concentration was adjusted from 1.5% to 4.25%, and dwell time was adjusted from 1 to 2 h as needed to achieve the maximum daily negative fluid balance tolerated by the patient's hemodynamic status. Ultrafiltered fluid was replaced with crystalloid or colloid as needed to further titrate the rate of net fluid removal and to maintain blood pressure in the desired range. Serum albumin was measured daily, and albumin was administered as a 5% or 25% solution, depending on whether clinical edema was appreciated, to maintain serum albumin in the range of 3.0–4.0 mg/dl. Hemodynamic variables and filling pressure were aggressively monitored using indwelling left atrial catheters. Potassium was added to the dialysis fluid as needed at concentrations of 1–4 mEq/l of dialysis fluid to maintain serum potassium concentrations in the range of 3.5–4.5 mEq/l. Antibiotics were added to the dialysis fluid as required to treat systemic infections at doses sufficient to maintain adequate antibiotic tissue levels.

All fluid balance calculations were based on the period during which CPD was actively being performed and normalized to patient weight based on the estimated ideal body weight at the time of admission. Patients were not weighed during the post-operative recovery period. Daily fluid balance was calculated as the difference between the total fluid intake and total fluid output per day. Total fluid output was calculated as the sum of urine output, CPD ultrafiltration, and chest tube output. Fluid intake and output were normalized to a 24-h period in order to calculate a net negative fluid balance per day. Fluid values are expressed as either median and range or mean plus or minus standard deviation. A paired two-tailed *t*-test was used to compare serum blood urea and creatinine concentrations, urine output, and numbers of inotropes required at the start and end of CPD. The level of significance was chosen as $P<0.05$.

Results

Temporary peritoneal dialysis catheters were placed in 24% (209/882) of patients who underwent surgical repair of congenital cardiac anomalies during the time period reviewed. Among these 209 patients, the complication rate was 4.8% (n=10). Six patients had omental hernias upon catheter removal requiring brief operative reductions, 2 had minor wound dehiscences at catheter insertion sites requiring local wound care, 1 patient had small bowel obstruction necessitating laparotomy and adhesion takedown, and 1 patient developed culture-negative peritonitis treated with intraperitoneal antibiotics. No patient had a documented episode of bacterial peritonitis. CPD was performed in 44 total patients. This number comprised 5% of all patients and 21% of those who had catheters placed. Several patients had slight leakage of dialysate fluid from the exit site; however no patient had CPD discontinued due to exit site leakage. No peritoneal catheters were removed prematurely due to primary non-function or exit site infections. No patients died during CPD or required discontinuation of CPD due to adverse cardiorespiratory effects. The overall mortality rate among all 44 patients was 18% (8/44).

The records of 20 consecutive patients who received post-operative CPD from July 1995 to April 1996 were further reviewed in detail to determine the fluid balance achieved during CPD. Clinical characteristics of these patients are shown in Table 1. The most-common cardiac lesion was hypoplastic left heart syndrome (n=6). The mean pre-operative weight was 3.8±1.2 kg. Fifteen patients weighed less than 4.0 kg. The median age at the start of CPD was 10 days. Thirteen patients were less than 2 weeks of age. The mean time from surgery to start of CPD was 22±9 h. Fifteen patients started CPD within 24 h of surgery. The mean duration of CPD was 50±24 h. The mean urine output at the start of CPD was 2.2±1.6 ml/kg per hour. Five patients had urine output ≤1.0 ml/kg per hour and 14 patients had urine output ≤2.0 ml/kg per hour. No patients were anuric.

Table 1 Clinical characteristics of patients receiving continuous manual peritoneal dialysis (CPD) (*VSD* ventricular septal defect, *ASD* atrial septal defect)

Primary cardiac lesions	
Hypoplastic left heart syndrome	6
Transposition of great arteries	4
Tetralogy of Fallot	3
Total anomalous pulmonary venous return	2
Interrupted aortic arch	2
Anomalous left coronary artery	1
VSD/ADS	1
Tricuspid atresia	1
Total	20
Age at start of CPD (days) (median, range)	10 (3–186)
Pre-operative weight (kg) (mean, range)	3.8 (2.7–6.8)
Time to start of CPD (h) (mean, range)	22 (5–40)
Duration of CPD (h) (mean, range)	50 (13–92)

Clinical parameters during CPD are shown in Table 2. Total fluid intake during the period of CPD was 93± 25 ml/kg per day. Urine output was 3.6±1.4 ml/kg per hour during the period of CPD, which accounted for 87±33 ml/kg per day of total output. Net ultrafiltration was 3.9±1.8 ml/kg per hour, which accounted for 93±44 ml/kg per day of the total daily output. Total fluid output was 199±66 ml/kg per day, which included urine output, ultrafiltrate, and chest tube drainage. The net negative fluid balance normalized to a 24-h period was 106±49 ml/kg. The total net fluid balance achieved during the entire period that CPD was performed was 205±95 ml/kg. The serum blood urea nitrogen and creatinine concentrations did not differ before and after CPD. Blood urea nitrogen increased slightly from 16.5 mg/dl. to 20 mg/dl, and serum creatinine increased from 0.75 mg/dl to 0.79 mg/dl (P=NS). Urine output during the period of CPD increased from 2.2 ml/kg per hour to 3.9 ml/kg per hour (P<0.01). The mean number of inotropes per patient required for hemodynamic support decreased from 2.2±0.6 to 1.7±0.9 (P<0.05). The overall mortality rate among these 20 infants was 20% (4/20).

Table 2 Clinical parameters during CPD

Total negative fluid balance	205 ml/kg
Fluid balance normalized to 24 h	
Total fluid out	199 ml/kg
Urine output	87 ml/kg
Ultrafiltrate	93 ml/kg
Chest tube	19 ml/kg
Total fluid in	93 ml/kg
Net negative fluid balance	106 ml/kg
Pre CPD	
Blood urea nitrogen	16.5 mg/dl
Serum creatinine	0.7 mg/dl
Urine output	2.2 mg/kg per hour
Number of inotropic drugs	2.2
Post CPD	
Blood urea nitrogen	20.0 mg/dl
Serum creatinine	0.8 mg/dl
Urine output	3.9 ml/kg per hour**
Number of inotropic drugs	1.7*

Post CPD vs. pre CPD: *P<0.5, **P<0.01

Discussion

The reported incidence of acute renal dysfunction after surgical repair of congenital heart disease ranges from 2% to 9% [1–6], and when present is associated with a high mortality rate [1, 4, 5, 8–13]. Extravascular fluid retention, which may include pulmonary edema, is a frequent complication of this renal dysfunction. The potential etiologies for this oliguria and concomitant fluid retention may include capillary leak syndrome, acute tubular necrosis secondary to cardiopulmonary bypass, decreased renal perfusion from poor myocardial function, multiple infusions of intraoperative blood products and crystalloid or colloid, and pre-existing extravascular fluid due to congestive heart failure. The fluid management of these patients is further complicated by the accompanying hemodynamic instability in the first few postoperative days, as evidenced by poor myocardial function and the need for inotropic support and afterload reduction. The accumulation of extravascular fluid may further exacerbate hemodynamic instability by impairing pulmonary gas exchange, decreasing lung compliance, and inhibiting diaphragmatic excursion from accumulation of ascites.

In this clinical context, several considerations exist that could prevent successful fluid removal by peritoneal

Table 3 Published reports of peritoneal dialysis after surgery for congenital heart disease (*NA* data not shown in the report)

Study (ref)	Age	Weight	Time to peritoneal dialysis	Duration	Ultrafiltrate	Mortality
Sorof et al. (n=20)	10 days (3–186)	3.8 kg (2.7–6.8)	22 h (5–40)	50 h (13–92)	–93 ml/kg per 24 h (43–233)	20%
Vricella et al. [13] (n=10)	1–31 days	2.9 kg	59 h	108 h	NA	30%
Book et al. [10] (n=15)	1 month to 14 years	NA	NA	2–12 days	NA	33%
Rigden et al. [1] (n=24)	1 day to 5 years	2.4–49 kg	3–80 h	1 h to 21 days	NA	38%
Werner et al. [5] (n=32)	22 months	9.2 kg	2.6 days	7.1 days	–48 ml/kg per day	47%
Giuffre et al. [12] (n=40)	2 days to 15 years	1.7–56 kg	NA	12.2 days	NA	57%
Fleming et al. [11] (n=21)	7 days to 11 years	6.7 kg (1.6–27 kg)	2.5 days (1–6 days)	136 h (4–360 h)	–9.2 ml/h (3.5–26 ml/h)	62%
Reznik et al. [8] (n=19)	NA	NA	9 days	NA	NA	79%

dialysis. Since the accumulated fluid is predominantly extravascular, fluid removal may be limited by hemodynamic instability and inability to refill the vascular space. Poor myocardial function could limit the effectiveness of CPD due to decreased perfusion of the peritoneum, thereby reducing the ability of the peritoneal membrane to exchange water and solute. Fluid removal may be further impaired by low oncotic pressure secondary to hypoalbuminemia, which may result from protein losses from chest tube drainage and continuous ultrafiltration. Furthermore, technical difficulties and complications may result from the immediate use of uncuffed peritoneal catheters placed intra-operatively due to the age and size of patients who undergo repair of these complex congenital cardiac lesions.

Despite these theoretical limitations, the use of CPD has become a standard therapeutic intervention in the post-operative management of infants after cardiopulmonary bypass. Several studies have reported using CPD in these children, with a mortality rate that ranges from 30% to 79%. Frequent complications have been reported, including catheter leak, peritonitis, and bowel perforations [1, 5, 8–16]. The mean patient age in these studies ranged from several days to years and the mean patient weight ranged from 2.9 to 11.4 kg. Most catheters were placed post-operatively after significant renal impairment with severe oliguria was already established, and CPD was not started in most cases until several days post-operatively. The actual negative fluid balance that was achieved during CPD is difficult to determine, because the amount of ultrafiltrate is either not specifically reported [1, 8, 10, 12, 13] or reported in milliliters per hour without standardizing to patient weight [11]. One study reported a net negative fluid balance of 48 ml/kg per day but excluded 4 of 32 patients who were unable to undergo effective dialysis and died within 24 h of starting CPD [5]. A study comparing CAVH, CVVH, and CPD found that only 35% of children receiving peritoneal dialysis were able to achieve a net negative fluid balance [11]. The methodology used in performing CPD is not clearly defined in most of these studies. Initial dwell volumes varied from 10 ml/kg to 30 ml/kg, and dwell duration is not specified. The large variation in age, weight, time to dialysis, criteria for starting CPD, and techniques for performing CPD make direct comparisons between these studies difficult. Table 3 summarizes the available data from studies that specifically address the use of peritoneal dialysis after surgical repair of congenital heart disease.

The current study differs from the previous studies in several important ways. The patients overall were younger (median age 10 days) and smaller (mean weight 3.8 kg) compared with previous reports. CPD was started within 24 h post-operatively in most patients and the mean duration of CPD was only 50 h. Blood urea nitrogen and serum creatinine concentrations at the start of CPD were 16.5 mg/dl and 0.75 mg/dl, respectively, suggesting a lesser degree of renal dysfunction. The mean urine output of 2.2 ml/kg per hour at the start of CPD was also higher than the stated criteria for starting CPD in other studies of these patients. The success of CPD was also better than has been previously reported. Negative fluid balance was achieved in all patients with a mean value of 106 ml/kg per 24 h. More than half of this negative fluid balance was achieved through CPD ultrafiltration. The complication rate in patients who underwent CPD was very low and did not include any episodes of confirmed bacterial peritonitis or significant catheter leak. The mortality rate of 20% is less than has previously been reported.

The reasons for the better results seen in this study may be due to several factors. All catheters were placed intra-operatively in anticipation of the need for adjunctive fluid removal in high-risk children. The decision to start CPD was therefore not influenced by the concern of subjecting critically ill children to an additional surgical procedure. As a result, CPD was started earlier in patients with evidence of volume overload but not necessarily with severe oliguric renal failure. Although the patients in this study were younger and smaller than in previous studies, renal function may not have been impaired to the same extent, as evidenced by the lower serum creatinine and slightly higher urine output. It was in fact the goal of the clinicians to initiate CPD prior to the development of severe oliguria. This earlier initiation of CPD may have created a selection bias in favor of less ill children in whom a favorable outcome could have been achieved without renal replacement therapy. Such bias would be expected to result in fewer complications and a lower overall mortality rate. However, other studies have used similar criteria for selecting patients in whom to perform CPD with higher reported mortality rates [5]. An alternative explanation is that the early initiation of CPD improves pulmonary mechanics and oxygenation by decreasing the frequency and severity of pulmonary edema, and allows for better delivery of nutrition by avoiding the need for severe fluid restriction. However, this hypothesis cannot be tested from this descriptive study.

The low complication rate and successful achievement of negative fluid balance is most likely due to the coordinated methodological approach used by the physician team that cares for these patients. Intra-operative placement of the dialysis catheters under direct visualization is likely to decrease the infectious and mechanical complications associated with the early use of these catheters. In addition, the catheters are readily available when more aggressive fluid removal is desired. The decisions to start and end CPD are appropriately made by the cardiothoracic surgeon and pediatric cardiologist who are best able to evaluate the overall fluid status of the patient during the complex hemodynamic changes that occur after surgical repair of complex congenital heart disease. In consultation with the pediatric nephrologist, specific goals for fluid management can be established. The CPD set for neonates allows precise measurements of dwell and effluent volumes. By limiting the dwell volumes to 10 ml/kg in these infants with newly

placed uncuffed catheters, fluid leak around the catheter can be minimized while still allowing for substantial fluid removal by titration of the dextrose concentration and dwell duration. These small volumes minimize the chance of fluid leak from the exit site and avoid respiratory compromise. We believe that intra-operative catheter placement, low dwell volumes, use of an enclosed CPD fluid circuit, minimal entry into the system only by trained dialysis nurses, and complete replacement of the entire system every 72 h all contributed to the low complication rate.

While this study documents that CPD can be performed safely and effectively post cardiotomy, even in the smallest and most critically ill children, it does not address the questions of whether the early use of CPD improves the outcome of these patients or which patients in particular are most likely to benefit from post-operative CPD. To do so would require a prospective, randomized study that matches patients on several clinical factors, including some measure of illness severity. However, the results from this study do challenge the conventional wisdom that critically ill children requiring inotropic support will not tolerate aggressive fluid removal by CPD. In addition, our results suggest that the criteria used to determine when CPD should be initiated may need re-examination. The routine placement of CPD catheters intra-operatively in high-risk infants allows for more rapid institution of renal replacement therapy and thereby avoids the need for severe fluid restriction and the potential for progressive respiratory compromise due to fluid overload. Rather than being viewed as a heroic measure reserved only for the most critically ill infant with severe renal dysfunction, we suggest that CPD may be used as a routine adjunctive therapy for post-operative fluid management with an acceptably low complication rate.

References

1. Rigden SP, Barratt TM, Dillon MJ, De Leval M, Stark J (1982) Acute renal failure complicating cardiopulmonary bypass surgery. Arch Dis Child 57:425–430
2. Baxter P, Rigby ML, Jones OD, Lincoln C, Shinebourne EA (1985) Acute renal failure following cardiopulmonary bypass in children: results of treatment. Int J Cardiol 7:235–243
3. Gomez-Campdera FJ, Maroto-Alvaro E, Galinanes M, Garcia E, Duarte J, Rengel-Aranda M (1988) Acute renal failure associated with cardiac surgery. Child Nephrol Urol 9:138–143
4. Heney D, Brocklebank JT, Wilson N (1989) Continuous arteriovenous haemofiltration in the newlyborn with acute renal failure and congenital heart disease. Nephrol Dial Transplant 4:870–876
5. Werner HA, Wensley DF, Lirenman DS, LeBlanc JG (1997) Peritoneal dialysis in children after cardiopulmonary bypass. J Thorac Cardiovasc Surg 113:64–68; discussion 68–70
6. Chesney RW, Kaplan BS, Freedom RM, Haller JA, Drummond KN (1975) Acute renal failure: an important complication of cardiac surgery in infants. J Pediatr 87:381–388
7. Paret G, Cohen AJ, Bohn DJ, Edwards H, Taylor R, Geary D, Williams WG (1992) Continuous arteriovenous hemofiltration after cardiac operations in infants and children. J Thorac Cardiovasc Surg 104:1225–1230
8. Reznik VM, Griswold WR, Peterson BM, Rodarte A, Ferris ME, Mendoza SA (1991) Peritoneal dialysis for acute renal failure in children. Pediatr Nephrol 5:715–717
9. Wood EG, Lynch RE, Fleming SS, Bunchman TE (1991) Ultrafiltration using low volume peritoneal dialysis in critically ill infants and children. Adv Perit Dial 7:266–268
10. Book K, Ohqvist G, Bjork VO, Lundberg S, Settergren G (1982) Peritoneal dialysis in infants and children after open heart surgery. Scand J Thorac Cardiovasc Surg 16:229–233
11. Fleming F, Bohn D, Edwards H, Cox P, Geary D, McCrindle BW, Williams WG (1995) Renal replacement therapy after repair of congenital heart disease in children. A comparison of hemofiltration and peritoneal dialysis. J Thorac Cardiovasc Surg 109:322–331
12. Giuffre RM, Tam KH, Williams WW, Freedom RM (1992) Acute renal failure complicating pediatric cardiac surgery: a comparison of survivors and nonsurvivors following acute peritoneal dialysis. Pediatr Cardiol 13:208–213
13. Vricella LA, Begona JA de, Gundry SR, Vigesaa RE, Kawauchi M, Bailey LL (1992) Aggressive peritoneal dialysis for treatment of acute kidney failure after neonatal heart transplantation. J Heart Lung Transplant 11:320–329
14. Blowey DL, McFarland K, Alon U, McGraw-Houchens M, Hellerstein S, Warady BA (1993) Peritoneal dialysis in the neonatal period: outcome data. J Perinatol 13:59–64
15. Iguchi A, Haneda K, Itoh T, Sadahiro M, Itoh Y, Akino Y, Suzuki Y, Mohri H (1990) Peritoneal dialysis in neonates and infants after open heart surgery. Nippon Kyobu Geka Gakkai Zasshi 38:1448–1452
16. Hanson J, Loftness S, Clarke D, Campbell D (1989) Peritoneal dialysis following open heart surgery in children. Pediatr Cardiol 10:125–128