Pediatr Neonatol 2009;50(6):275–279

ORIGINAL ARTICLE

Peritoneal Dialysis in Infants and Children After Open Heart Surgery

Jen-Chung Chien[1,3], Be-Tau Hwang[2,3,4], Zen-Chung Weng[5,6]
Laura Chun-Chang Meng[3], Pi-Chang Lee[3,4*]

[1]*Department of Pediatrics, Lo-Tung Pohai Hospital, Ilan, Taiwan*
[2]*Department of Pediatrics, Zhongxiao Branch, Taipei City Hospital, Taipei, Taiwan*
[3]*Department of Pediatrics, Taipei Veterans General Hospital, Taipei, Taiwan*
[4]*Department of Pediatrics, National Yang-Ming University School of Medicine, Taipei, Taiwan*
[5]*Department of Surgery, Taipei Veterans General Hospital, Taipei, Taiwan*
[6]*Department of Surgery, National Yang-Ming University School of Medicine, Taipei, Taiwan*

Received: Jan 9, 2009
Revised: Apr 9, 2009
Accepted: Apr 28, 2009

KEY WORDS:
acute renal failure;
congenital heart disease;
open heart surgery;
peritoneal dialysis

Background: Infants and children who undergo surgical repair of complex congenital heart diseases are prone to developing renal dysfunction. The purpose of this study was to investigate the risk factors associated with prolonged peritoneal dialysis (PD) and the mortality of pediatric patients with acute renal failure (ARF) after open heart surgery.
Methods: From June 1999 to May 2007, a total of 542 children underwent open heart surgery for congenital heart disease. Fifteen (2.8%) experienced ARF and seven (1.3%) required PD. The clinical and laboratory variables were compared between the survivor and non-survivor groups of ARF patients that needed PD.
Results: The non-survivors (n=3, 43%) had a longer cardiopulmonary bypass time (154±21 *vs.* 111±8 minutes, p=0.012) and longer aorta clamping time (92±40 *vs.* 66±15 minutes, p=0.010) than the survivors (n=4, 57%). Before the PD, the pH and base excess of the arterial blood gas analysis in the survivors was much higher than that non-survivors (7.30±0.04 *vs.* 7.16±0.10, p=0.039; −5.15±3.13 *vs.* −12.07±2.9 mmol/L, p=0.031). Furthermore, the survivors had a shorter interval between the onset of ARF and the day the PD was begun (1.2±0.4 *vs.* 4.3±1.2 days, p=0.001), and shorter duration of PD (6.6±2.7 *vs.* 13.0±3.5 days, p=0.036) than non-survivors.
Conclusion: Early intervention with PD is a safe and effective method for managing patients with ARF after open heart surgery. The cardiopulmonary bypass and aortic clamping duration, time of initiating PD, duration of the PD, sepsis, and relative complications may predict the prognosis of these patients.

1. Introduction

The development of acute renal failure (ARF) is a frequently reported complication after cardiopulmonary bypass surgery in infants and children. Studies have reported a high mortality rate—ranging from 30–79%.[1–3] Fluid restrictions, diuretics, and inotropic agents have been the initial therapeutic strategies for mild renal dysfunction and low cardiac output syndrome. The more severe cases require a slow and continuous removal of the fluid by hemofiltration or peritoneal dialysis (PD). Compared with

*Corresponding author. Division of Pediatric Cardiology, Department of Pediatrics, Taipei Veterans General Hospital, 201 Shih-Pai Road, Section 2, Taipei, Taiwan.
E-mail: pichang_lee@yahoo.com

hemofiltration, PD in pediatric patients is associated with advantages in the establishment of vascular access, avoidance of systemic anticoagulation, and decreased associated risks of ischemic and embolic complications.[4,5]

The feasibility and efficacy of PD, optimal timing of application, complications, prognosis, and predictive risk factors of the mortality in children undergoing PD after open heart surgery are currently under discussion.[1,2,6–9] We reviewed our experience with PD in treating children with ARF after surgical repair of congenital heart disease. The aims of this study were: (1) to determine the differences in clinical and laboratory variables between survivors and non-survivors receiving PD; (2) to identify risk factors predisposing to a prolonged PD and mortality; (3) to improve the future application and success of PD in pediatric patients with renal dysfunction after open heart surgery.

2. Materials and Methods

2.1. Study population

From June 1999 to May 2007, the medical records of 542 children that underwent open heart surgery at Taipei Veterans General Hospital were reviewed retrospectively. Among them, 15 (2.7%) experienced ARF after open heart surgery; six received conservative medical treatment only, two received continuous veno-venous hemofiltration, and seven received PD. We divided the seven patients who underwent PD into two groups depending on the outcome: group I, three children (42%) died after PD; group II, four children (58%) survived after PD.

2.2. Acute renal failure (ARF) and peritoneal dialysis (PD)

ARF was defined as a creatinine level of more than 1.2 mg/dL or oliguria (<0.5 mL/kg/hour) for more than 4 hours despite aggressive diuretic therapy and optimization of the inotropic support, or a combination of both.[6] The indications for PD included: (1) hypervolemia with severe edema; (2) anuria or oliguria for more than 4 hours despite aggressive diuretic and inotropic support; (3) hyperkalemia (>5.5 mmol/L); (4) metabolic acidosis (serum pH<7.3, HCO3<18 mmol/L)—persistent after failing to be corrected by at least two boluses of an intravenous sodium bicarbonate infusion and adjustment of the fluid status with an inotropic support; (5) low cardiac output with renal insufficiency.

The PD catheter was connected to a closed system for peritoneal drainage. The dialysate solutions used were standard commercial preparations (Dianeal PD-2; Baxter International Inc., Deerfield, IL, USA); heparin (500 U/L of dialysate) and potassium chloride were added. The dextrose concentration varied from 1.5–4.5%, and the choice of dextrose concentration depended on the presence of serum hyperglycemia. PD was started with a dwell volume from 10 mL to 20 mL/kg with a dwell time of 1–2 hours. The recovery of the urine output was defined as a urine output >1 mL/kg/hour, and the recovery of serum creatinine was defined as a decline in serum creatinine to preoperative levels. Indications for stopping PD included a return to a sufficient urine output, maintaining a negative fluid balance, and normalization of the serum electrolytes and acid-base status.

2.3. Data collection and analysis

The age and body weight, diagnosis of the congenital heart disease, surgical procedure performed, cardiopulmonary bypass time, and aorta clamping duration were recorded. For the patients who experienced acute renal failure, the following data were collected before PD: pH, bicarbonate levels, base excess levels, serum potassium levels, serum blood urea nitrogen levels, serum creatinine levels, and daily urinary output. The fluid balance and fluid supply per kilogram of bodyweight during the 4 hours before the initiation of the PD were calculated. For patients requiring PD, we recorded the following: time to onset of acute renal failure, indication for PD, duration of PD, time interval between PD and peak creatinine level, time interval between PD and urine output recovery, and time interval between PD and creatinine recovery. Additionally, the total duration of the mechanical ventilation, inotropic agent therapy, and PD complication were recorded. The prognosis and cause of death were noted.

Data are expressed as the mean±standard deviation or median (range) as appropriate. Univariate analysis was performed to compare the demographic data. The Mann-Whitney U test was used to compare preoperative, intraoperative, and postoperative variables between the survivors and non-survivors of PD. A p value of <0.05 was considered statistically significant. All statistical analyses were performed using SigmaStat® 3.1 (Jandel Scientific, San Rafael, CA, USA).

3. Results

Seven (47%) children were managed with PD for ARF; the patients' age, type of congenital heart defect, and operation are shown in Table 1. The cause of death in non-survivors included infection (sepsis, infective endocarditis, and disseminated intravascular coagulopathy) in two patients, and pump failure

Table 1 Demographic data of seven patients who underwent peritoneal dialysis after open heart surgery

No.	Age	Diagnosis	Open heart surgery	Mortality
1	4 yr	DORV, remove type VSD, pulmonary stenosis	Total correction	Yes
2	10 d	Congenital mitral stenosis, hypoplastic left heart, CoA, PDA, pulmonary hypertension	Mitral valve commissurotomy & ASD repair	Yes
3	4 yr	TOF, MAPCAs	Total correction, surgical ligation of an MAPCA	Yes
4	9 d	CoA, VSD, PDA	Two stages: (1) correction of a CoA, ligation of a PDA; (2) VSD repair	No
5	5 mo	TOF	Total correction	No
6	15 d	TOF, PA, MAPCAs	RVOT reconstruction	No
7	14 mo	TOF	Total correction	No

ASD = atrial septal defect; CoA = coarctation of the aorta; DORV = double outlet of the right ventricle; MAPCAs = major aortopulmonary collateral arteries; PA = pulmonary atresia; PDA = patent ductus arteriosus; RVOT = right ventricle outflow tract; TOF = tetralogy of Fallot; VSD = ventricular septal defect.

(congestive heart failure, extensive myocardial injury, and cardiogenic shock) in one patient. However, there were no deaths directly attributable to the PD complication. The four survivors experienced a period of a low cardiac output and systemic hypotension, which was suspected to be the cause of the ARF in the postoperative period.

The indications and complications of PD are shown in Table 2. The clinical and laboratory comparisons between the two groups are shown in Table 3. The non-survivors had a longer cardiopulmonary bypass time (154±21 *vs*. 111±8 minutes, $p=0.012$) and longer aorta clamping time (92±40 *vs*. 66±15 minutes, $p=0.010$) than survivors ($n=4$, 57%). Before PD, the pH and base excess of arterial blood gas in the survivors was much higher than in non-survivors (7.30±0.04 *vs*. 7.16±0.10, $p=0.039$; −5.15±3.13 *vs*. −12.07±2.9 mmol/L, $p=0.031$). Furthermore, the survivors had a shorter interval between the onset of the ARF and PD (1.2±0.4 *vs*. 4.3±1.2 days, $p=0.001$), a shorter duration of PD (6.6±2.7 *vs*. 13.0±3.5 days, $p=0.036$), less inotropic agent therapy (10.0±4.2 *vs*. 24.3±5.5 days, $p=0.011$), less mechanical ventilation therapy (7.4±2.2 *vs*. 26.3±6.4 days, $p=0.002$), and lower incidence of hyperglycemia (2.8±2.2 *vs*. 7.7±1.5 days, $p=0.022$).

Table 2 Indications and complications for peritoneal dialysis

	Non-survivors group I ($n=3$)	Survivors group II ($n=4$)
Hypervolemia	3	4
Oliguria	0	3
Anuria	3	1
Hyperkalemia	2	1
Metabolic acidosis	3	2
Complications		
Hyperglycemia	2	2
Electrolyte imbalance	3	1

4. Discussion

Early intervention with PD is a safe and effective method for managing patients with ARF after open heart surgery. The risk factors for a prolonged PD and mortality include: (1) prolonged cardiopulmonary bypass time; (2) prolonged aortic clamping time; (3) significant metabolic acidosis before PD; (4) delayed timing in beginning PD; (5) associated infections.

The incidence of ARF after cardiopulmonary bypass surgery in our infants and children was 2.7%, which was relatively low in comparison to previous published reports (1.6–17%).[8,10,11] ARF is often related to underlying defects in the patients and the complexity of the operation. The more complicated the cardiac lesions and cyanotic heart disease is, the longer the cardiopulmonary bypass time that is required and the higher the incidence of postoperative ARF.[12]

PD is currently chosen as the primary renal replacement therapy because it is relatively easy to employ, is efficacious, and has a low complication rate.[4,5,10,11,13,14] This is contrary to continuous veno-venous and arterio-venous hemofiltration, which requires anticoagulation and vascular access, and may lead to complication, especially in neonates and young infants.[4,6,7] The mortality rate in our patients after PD was 42%, a finding comparable with

Table 3 Comparison of clinical and laboratory variables between the two groups of patients with acute renal failure requiring penitoneal dialysis

Variables	Non-survivors group I (n=3)	Survivors group II (n=4)	p
Age (mo)	32.4±27.5	4.9±6.4	0.090
Sex (male:female)	1:2	3:1	
Body weight at surgery (kg)	13.3±9.9	5.1±3.2	0.172
CPB time (min)	154.0±21.1	111.3±7.5	0.012*
Cross-clamp time (min)	92.0±40.1	65.5±14.8	0.010*
Onset of ARF after surgery (d)	3.7±2.9	5.2±3.2	0.552
Beginning of PD (d)	7.6±5.0	6.4±3.6	0.688
Before PD			
pH	7.16±0.10	7.30±0.04	0.039*
Bicarbonate (mmol/L)	13.2±1.06	19.5±3.4	0.029*
Base excess (mmol/L)	−12.07±2.9	−5.15±3.13	0.031*
Potassium (mmol/L)	4.4±1.2	5.6±1.5	0.229
BUN (mg/dL)	47.7±19.3	35.0±36.5	0.250
Creatinine (mg/dL)	2.7±2.8	1.5±1.1	0.397
Interval between ARF & the beginning of PD (d)	4.3±1.2	1.2±0.4	0.001*
Duration of PD (d)	13±3.5	6.6±2.7	0.036*
Interval between PD & peak Cr (d)	6.3±0.6	2.5±1.3	0.005*
Interval between PD & UO recovery (d)	–	4.8±2.7	–
Interval between PD & Cr recovery (d)	–	9.8±5.9	–
Duration of inotropic agents (d)	24.3±5.5	10±4.2	0.011*
Time of mechanical ventilation (d)	26.3±6.4	7.4±2.2	0.002*
Duration of hyperglycemia (d)	7.7±1.5	2.8±2.2	0.022*

*p<0.05. ARF=acute renal failure; CPB=cardiopulmonary bypass; BUN=blood urea nitrogen; Cr=creatinine; PD=peritoneal dialysis; UO=urine output.

other reports (24–79%).[6,8,11,13,14] However, the variation in patient demographics, operational complexity, dialysis modality, and indication for initiation of renal support makes the comparison of the outcome difficult.

In the present study, we found that the cardiopulmonary bypass time, aorta clamp time, acidosis before PD, and the timing of the initiation of PD affected the prognosis in ARF patients. A prolonged cardiopulmonary bypass triggers important inflammatory reactions, including the release of kinin, coagulation factor XII, complement factors by endothelial cells, and leucocytes—the reactions are associated with capillary leak syndrome, resulting in hypovolemia and renal hypoperfusion.[10,15] Furthermore, a prolonged aorta clamp time may decrease tissue perfusion, possibly causing ischemic injury. Acidosis, including the lowering of pH, HCO3 and base excess, has been used as an indicator of the severity of the shock, to discriminate survivors from non-survivors, and has been strongly correlated with lactate, another serious indicator of potential mortality.[16,17]

The optimal timing for intervention with PD is still controversial.[1,2,6] Many authors have suggested that early intervention with PD is needed—as soon as ARF occurs. Dittrich et al used a prophylactic and early start of PD when the risk factors for ARF were present; they reported a better control of fluid balance and a more favorable patient outcome, with a mortality rate of 27%.[6] In the present study, the time of the application of the PD in the survivors was significantly earlier than non-survivors. This change in treatment time was caused by a change in hospital policy for treating ARF patients after open heart surgery—for the last 3 years, renal replacement therapy has been a requirement. We do not wait to start PD until a low cardiac output, hypervolemia, edema, anuria, progressive renal function impairment or severe acidosis occur; instead, we introduce PD if the patient has risk factors for ARF and when a low cardiac output, oliguria, and hypervolemia are present. In our limited experience, the fluid balance status improves remarkably after initiation of PD. No major complications related to the PD were noted—including catheter

leak, peritonitis, bowel perforation, or hemorrhage. However, hyperglycemia was found in two survivors and two non-survivors, and an electrolyte imbalance was found in one survivor and three non-survivors. The complication rate in the present study was quite low, and the safety was comparable with other series (20–75%).[1,18] The renal function normalized in all four surviving children, and this rate was in agreement with the other studies.[10,19]

We further determined other risk factors associated with a longer duration of PD. The risk factors included the postoperative occurrence of low cardiac output syndrome, prolonged inotropic agent therapy and postoperative ventilator settings, associated sepsis, bacteremia, infective endocarditis, disseminated intravascular coagulopathy, and multiple organ failure. All of these conditions affect the duration of hospitalization, and the survival rate of children requiring PD. By comparing the differences in variables between survivors and non-survivors, we can predict the prognosis of patients receiving PD after cardiac surgery.

Because only small patient numbers were enrolled in both groups, grouping for statistical analysis was not satisfactory, and the study had a low statistical power. More studies are needed to investigate the risk factors of prolonged PD and mortality in pediatric patients with ARF.

In conclusion, PD is effective in achieving a negative fluid balance and producing fewer hemodynamic changes in infants and young children with acute renal failure after open heart surgery. For such high-risk infants or children with ARF, we suggest prophylactic or early intra-operative placement of PD catheters. Early intervention with PD for a more rapid institution of renal replacement therapy can effectively avoid the need for severe fluid restrictions and the potential of a progressive cardiorespiratory compromise. The cardiopulmonary bypass duration, low cardiac output syndrome, time of PD initiation, duration of PD, sepsis, and relative complications could help to predict the prognosis of PD in patients with ARF after open heart surgery.

References

1. Lin MC, Fu YC, Fu LS, Jan SL, Chi CS. Peritoneal dialysis in children with acute renal failure after open heart surgery. *Acta Paediatr Taiwan* 2003;44:89–92.
2. Sorof JM, Stromberg D, Brewer ED, Feltes TF, Fraser CD Jr. Early initiation of peritoneal dialysis after surgical repair of congenital heart disease. *Pediatr Nephrol* 1999;13:641–5.
3. Picca S, Principato F, Mazzera E, et al. Risks of acute renal failure after cardiopulmonary bypass surgery in children: a retrospective 10-year case-control study. *Nephrol Dial Transplant* 1995;10:630–6.
4. Fleming F, Bohn D, Edwards H, et al. Renal replacement therapy after repair of congenital heart disease in children: a comparison of hemofiltration and peritoneal dialysis. *J Thorac Cardiovasc Surg* 1995;109:322–31.
5. Giuffre RM, Tam KH, Williams WW, Freedom RM. Acute renal failure complicating pediatric cardiac surgery: a comparison of survivors and nonsurvivors following acute peritoneal dialysis. *Pediatr Cardiol* 1992;13:208–13.
6. Dittrich S, Dahnert I, Vogel M, et al. Peritoneal dialysis after infant open heart surgery: observation in 27 patients. *Ann Thorac Surg* 1999;68:160–3.
7. Dittrich S, Vogel M, Dahnert I, et al. Acute hemodynamic effects of post cardiotomy peritoneal dialysis in neonates and infants. *Intensive Care Med* 2000;26:101–4.
8. Pedersen KR, Hjortdal VE, Christensen S, et al. Clinical outcome in children with acute renal failure treated with peritoneal dialysis after surgery for congenital heart disease. *Kidney Int Suppl* 2008;108:81–6.
9. Ricci Z, Morrelli S, Ronco C, et al. Inotropic support and peritoneal dialysis adequacy in neonates after cardiac surgery. *Interact Cardiovasc Thorac Surg* 2008;7:116–20.
10. Kist-van Holthe tot Echten JE, Goedvolk CA, Doornaar M.B, et al. Acute renal insufficiency and renal replacement therapy after pediatric cardiopulmonary bypass surgery. *Pediatr Cardiol* 2001;22:321–6.
11. Chan KL, Ip P, Chiu CS, Cheung YF. Peritoneal dialysis after surgery for congenital heart disease in infants and young children. *Ann Thorac Surg* 2003;76:1443–9.
12. Dittrich S, Kurschat K, Dahnert I, et al. Renal function after cardiopulmonary bypass surgery in cyanotic congenital heart disease. *Int J Cardiol* 2000;73:173–9.
13. Werner HA, Wensley DF, Lirenman DS, LeBlanc JG. Peritoneal dialysis in children after cardiopulmonary bypass. *J Thorac Cardiovasc Surg* 1997;113:64–8.
14. Weng KP, Hsieh KS, Huang SH, Lin CC, Pan JY. Peritoneal dialysis in treatment of postoperative heart failure after cardiac surgery in infants. *Acta Paediatr Taiwan* 2004;45: 81–4.
15. Journois D. Hemofiltration during cardiopulmonary bypass. *Kidney Int* 1998;53:174–7.
16. Davis JW, Shackford SR, Holbrook TL. Base deficit as a sensitive indicator of compensated shock and tissue oxygen utilization. *Surg Gynecol Obstet* 1991;173:473–6.
17. Boigner H, Brannath W, Hermon M, et al. Predictors of mortality at initiation of peritoneal dialysis in children after cardiac surgery. *Ann Thorac Surg* 2004;77:61–5.
18. Swan P, Darwish A, Elbarbary M, Al Halees Z. The safety of peritoneal drainage and dialysis after cardiopulmonary bypass in children. *J Thorac Cardiovasc Surg* 1997;114:688–9.
19. Shaw NJ, Brocklebank JT, Dickinson DF, Wilson N, Walker DR. Long-term outcome for children with acute renal failure following cardiac surgery. *Int J Cardiol* 1991;31:641–5.