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ORIGINAL ARTICLE

Efficacy and outcomes of continuous peritoneal dialysis versus daily intermittent hemodialysis in pediatric acute kidney injury

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Abstract
Background Acute kidney injury (AKI) requiring renal replacement therapy (RRT) is associated with high patient morbidity and mortality. There is no consensus on the best RRT modality for pediatric AKI.
Methods The efficacy and safety of continuous peritoneal dialysis (cPD) and daily intermittent hemodialysis (dHD) were compared in 136 children aged 1 month to 16 years requiring RRT for AKI. Mortality, risk factors and causes of death, 1-month and 3-month renal recovery rates, and technique-related complications were assessed.
Results Uremia control and the rate of catheter-related complications were comparable in the groups. Thirty-day survival was 60.7 % (51 out of 84) with cPD and 36.5 % (19 out of 52) with dHD ($p = 0.019$). Although age <1 year, extended time lag from disease onset to RRT initiation, mechanical ventilation, and extended vasopressor dependence independently predicted death, adjusted mortality was higher with dHD relative to cPD (hazard ratio [HR] 1.75, 95%CI 1.18–2.84, $p = 0.022$). Almost all fatalities in the dHD group (94 %) occurred during or within an hour of a HD session. Renal function normalized in 27 % of survivors after 4 weeks and in 51 % after 3 months. The risk of permanent end-stage renal disease was increased in patients with an intrinsic renal cause of AKI (HR 2.72; 95 % CI 1.37–3.83; $p = 0.029$) and in those with delayed RRT initiation (HR 2.17; 95 % CI 123–2.93; $p = 0.015$), but did not differ between patients treated with dHD and cPD.
Conclusions Favorable patient survival with cPD compared with dHD in children treated for AKI was evident in this study.

Keywords Pediatric acute kidney injury · Continuous peritoneal dialysis · Daily intermittent hemodialysis

Introduction

Acute kidney injury (AKI) requiring renal replacement therapy (RRT) is an important risk factor for morbidity and mortality in pediatric intensive care units. Dialysis management of these children is difficult because of multiple organ dysfunction, hemodynamic instability and access issues [1]. Peritoneal dialysis (PD) was the first RRT modality used for the management of AKI in children and it is still considered the preferred method in younger children [2]. However, practice of PD has gradually declined following the introduction of continuous renal replacement therapy (CRRT) [3]. The efficacies of the different RRT modalities available for children with AKI in developed and developing countries are not only variable and region-specific but also highly dependent on the country's socio-economic status [2]. Randomized clinical trials comparing different RRT modalities for the treatment of children with AKI are lacking [2]. There is also no consensus in literature on the best dialysis method or ideal dose in pediatric AKI. In this retrospective study, we analyze the efficacy of continuous peritoneal dialysis (cPD) versus daily intermittent hemodialysis (dHD) in managing pediatric AKI.

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Patients and methods

Study design & setting

We retrospectively reviewed the case records of 136 children (1 month to 16 years) requiring cPD or dHD for treatment of AKI at our pediatric nephrology service between October 2013 and October 2015. The study was approved by the Institutional Review Board of our institute and we adhered to the Declaration of Helsinki when conducting the study.

Inclusion and exclusion criteria

All patients aged 1 month to 16 years at study entry, with AKI requiring RRT, were included in this single-center retrospective analysis. The indication for RRT was defined by the presence of at least one of the following criteria:

1. Clinical symptoms of uremia (gastrointestinal symptoms such as nausea, vomiting not otherwise explained; or neurological symptoms such as mental confusion, severe weakness, seizures/coma not otherwise explained; or evidence of pericardial effusion or acidotic breathing
2. Persistent oliguria (urine output <0.5 ml/kg/min for >24 h) or anuria (for >12 h or <0.3 ml/kg/h for >12 h), despite adequate hydration
3. Fluid overload not responding to diuretic
4. Severe metabolic acidosis (pH <7.2) not responding to conventional treatment
5. Hyperkalemia not responding to conservative treatment
6. Persistent and symptomatic hyponatremia not responding to conservative treatment

Patients were excluded when any of the following criteria were met:

1. Pre-existing chronic kidney disease
2. Patients receiving chronic RRT
3. Kidney transplant recipients
4. Any other mode of RRT

RRT modalities

Dialytic management and therapeutic decisions in our children were individualized by the pediatric intensivist and nephrologist team based on the patient's specific clinical and hemodynamic status and underlying condition. In general, we preferred cPD in children under 5 years of age and dHD for older children. In post-surgical cases mainly cPD was used because of the risk of anticoagulant-associated bleeding from the surgical wound. In cases of vasculitis or hemolytic uremic syndrome dHD was preferred as vascular access was also needed for plasmapheresis.

cPD

cPD was performed daily throughout 24 h using a HOMECHOICE PRO Cycler (Baxter) and Dianeal (Baxter) PD solution, with the exception of low-birthweight infants in whom PD was applied manually, as fill volumes were too small for cycler machines. Peritoneal access was established by placement of a double-cuff tunneled Tenckhoff catheter inserted by a pediatric surgeon in the emergency operating theater. The initial fill volume was limited to 10–20 ml/kg to minimize the risk of dialysate leakage and thereafter volume was gradually increased to approximately 30–40 ml/kg (800–1,100 ml/m^2) as tolerated by the patient. The initial cycle duration, including inflow, dwell, and drain times, was 60–90 min; dwell time was gradually extended as fluid and solute removal targets were achieved. In small infants, the cycle duration was reduced to achieve adequate ultrafiltration and solute removal. In patients with fluid overload, Dianeal PD solution containing 2.5 or 4.25 % glucose was used.

dHD

The treatment dose for dHD was 3 h of HD daily at a blood flow of 5 ml/kg/min. A double lumen catheter for central venous access (jugular or femoral vein depending on the ease of access) was inserted with ultrasound guidance at the bedside. HD with volumetric control (Fresenius 5008 Pediatric; Fresenius, Bad Homburg, Germany) was performed using polysulfone membranes. Dialysate flow was 10–15 ml/kg/min; volumetric ultrafiltration control, water purified by reverse osmosis, and bicarbonate dialysate were used. We used the blood volume monitoring (BVM) module of the Fresenius 5008 routinely in all patients. Bicarbonate, potassium, and sodium dialysate concentrations were adjusted according to individual requirements. Actual HD duration and total ultrafiltration volume were recorded at the end of each session.

Outcome measurement

The principal treatment target in both groups was the absence of any criteria for acute RRT and improvement of the general clinical condition. Dialysis was interrupted when there was partial renal function recovery defined as the restoration of diuresis associated with a progressive fall in serum values for creatinine and urea. Lack of renal functional recovery was diagnosed if the need for RRT

persisted after 30 days of RRT, and in the case of patient death. At the 3-month follow-up, we categorized all surviving patients as per the Kidney Disease: Improving Global Outcomes (KDIGO) Chronic Kidney Disease classification [4].

Clinical and laboratory follow-up of study patients

Baseline demographics and laboratory data, concomitant diagnoses, and reasons for AKI were recorded. For the assessment of clinical disease severity over time, the PRISM-III clinical scoring system was used [5]. Hypertension was defined as systolic/diastolic blood pressure exceeding the 95th percentile for sex, age, and height [6]. Estimated glomerular filtration rate was calculated according to modified Schwartz formula [7]. Data on respective RRT treatments, necessity for mechanical ventilation or vasopressor support, routine laboratory data (daily until study day 10 and thereafter every other day), and outcome-related data were recorded daily. Patients were followed up closely for 30 days after starting RRT and underwent a follow-up examination at 3 months.

Statistical analysis

Between groups, data for continuous variables were evaluated using a *t* test for independent variables. Comparisons of proportions were made using Chi-squared testing. Kaplan–Meier survival analysis was performed and the survival probability was compared between the study arms using log-rank test. The impact of the exploratory variables age, duration of oliguria or anuria, AKI etiology, RRT modality, baseline biochemistry, the need for mechanical ventilation or any vasopressor on survival probability was evaluated by multivariate Cox regression analysis. Throughout the text, data are expressed as means ± SDs, medians (lower and upper extremities) and percentages, as appropriate, and $p \leq 0.05$ was considered statistically significant. SPSS for Windows version 16 software (SPSS, Chicago, IL, USA) was used for all statistical analyses.

Results

Baseline demographics

The baseline patient characteristics of the two treatment cohorts are summarized in Table 1. Apart from the fact that children selected for cPD were significantly younger than those started on dHD, the characteristics of the two cohorts did not differ. AKI was caused by pre-renal causes in approximately two thirds of patients in both treatment groups. Oliguria was the main indication for dialysis in both groups. At the start of RRT, 30–40 % of study patients required mechanical ventilation and more than 80 % required vasopressor support in the two groups (Table 1).

Course of RRT

The median duration of cPD was 4 (range 2–30) days. The mean dwell volume was 810 ± 354 ml/m^2. PD solution containing 1.5, 2.5, and 4.25 % glucose was used in 64 %, 29 % and 7 % of children respectively. The median number of dHD sessions was 7 (range 4–30); the mean session duration was 158 ± 52 min. The mean blood flow rate was 5.1 ± 1.4 ml/kg/min, and the mean dialysate flow rate 19.4 ± 4.2 ml/kg/min. Unfractionated heparin was used for anticoagulation in 65 % of dHD sessions.

The mean biochemical indices of kidney function and the fraction of patients in need of vasopressors or mechanical ventilation on days 3, 5, 10, 15, and 30 were lower in the survivors receiving cPD than in those undergoing dHD (Table 2). The total duration of mechanical ventilation ($p = 0.005$) and of vasopressor use ($p = 0.008$) were significantly lower in the cPD than in the dHD group. Disease severity over time was assessed by PRISM-III scoring, which likewise demonstrated a more favorable disease course in the cPD group from day 5 onward (Tables 2, 3).

Patient survival

Sixty-six patients died within 30 days of the initiation of RRT. The underlying cause of AKI was the strongest predictor of mortality. All deaths occurred in patients with AKI of "pre-renal" or "unknown" etiologies, whereas all patients with AKI with renal or post-renal causes survived. The actuarial patient survival by RRT modality is given in Fig. 1. The 30-day survival rate was 60.7 % (51 out of 84) in the cPD compared with the 36.5 % (19 out of 52) in the dHD group ($p = 0.019$) (Fig. 1). In the patients treated with cPD, fatalities were mostly related to the underlying etiology of AKI (post-cardiac surgery with refractory heart failure (8 out of 33), cerebral ischemia (10 out of 33), and overwhelming sepsis (15 out of 33). Five of the 33 deaths occurred after partial renal recovery and discontinuation of PD therapy. In the dHD group, the leading causes of death were cardiac failure and/or cardiac arrhythmia (10 out of 33), sepsis (10 out of 33), hypotensive episodes (5 out of 33), dialysis disequilibrium syndrome (4 out of 33), hyponatremia (2 out of 33), and sudden death of unknown etiology (2 out of 33). We defined the most immediate clinical condition as a cause of death, realizing that, for example, cardiac arrhythmia or failure may cause hypotension and vice versa. Some patients died of multiple

Table 1 Baseline characteristics of patients at start of renal replacement therapy (*RRT*)

	cPD ($n=84$)	dHD ($n=52$)
Age (years), median (range)	3.2 (0.1–7.6)	8.4 (3.2–15.6)
Height/length SDS[a]	0.34 ± 0.23	0.37 ± 0.17
BMI SDS[a]	0.85 ± 0.56	0.96 ± 0.34
Male gender, *n* (%)	43 (51)	35 (67)
Mechanical ventilation, *n* (%)	33 (39)	17 (32)
Vasopressor treatment, *n* (%)	72 (86)	43 (82)
Oliguria, *n* (%)	78 (93)	47 (90)
Temperature (°C), mean ± SD	37.9 ± 1.6	37.4 ± 1.3
Time from disease onset to start of RRT (days), median, (range)	3 (1–9)	2 (1–7)
Time from hospital admission to start of RRT (days), median, (range)	2 (1–5)	2 (1–4)
ICU care, *n* (%)	78 (93)	47 (90)
PRISM-3 (12 h) score, median, (range)	32 (12–64)	27 (14–58)
AKI etiology, *n* (%)		
Pre-renal	57 (68)	33 (63)
Sepsis/Infection	22 (26)	15 (28)
Hypoxia-Ischemia	11 (13)	1 (1)
Volume depletion	8 (9)	8 (16)
Cardiogenic shock	7 (8)	6 (11)
Post-surgical	9 (11)	3 (5)
Intrinsic renal disease	14 (17)	11 (21)
Post infectious glomerulonephritis	3 (21)	2 (18)
Hemolytic uraemic syndrome	3 (21)	4 (36)
Vasculitis	3 (21)	2 (18)
Systemic lupus erythematosus	2 (14)	1 (9)
Others	3 (21)	2 (18)
Post-renal	3 (3)	3 (5)
Unknown	10 (13)	5 (13)
Hemoglobin (g/dl), mean ± SD	10.7 ± 2.5	11.2 ± 2.1
Serum urea (mg/dl), mean ± SD	142 ± 64	158 ± 83
Serum creatinine (mg/dl), mean ± SD	2.7 ± 1.5	2.9 ± 1.3
eGFR (ml/min/1.73 m^2), mean ± SD	12.6 ± 8.2	15.3 ± 7.4
Serum sodium (mM), mean ± SD	132 ± 13	137 ± 13
Serum potassium (mM), mean ± SD	5.15 ± 1.81	4.09 ± 1.54
Baseline blood pH, mean ± SD	7.21 ± 0.4	7.23 ± 0.2
Baseline HCO3-, mean ± SD	18.9 ± 5.8	19.3 ± 4.7

BMI body mass index, *ICU* Intensive Care Unit, *AKI* acute kidney injury, *eGFR* estimated glomerular filtration rate, *n* number

[a] Height/length and BMI standard deviation calculated according to WHO standards

"causes." All but two fatalities in the dHD group (94 %) occurred during or within an hour of a dHD session.

Renal outcome

One month after the initiation of RRT, 59 out of 70 surviving patients (84 %) had come off dialysis (Table 3). Renal recovery continued during further follow-up. Even though only one additional patient was able to discontinue dialysis, the fraction of patients with complete renal recovery (eGFR > 90 ml/min/1.73 m^2) increased from 27 % to 51 % by month 3. Renal outcome in the survivors strongly depended on the underlying etiology. Although eGFR had improved to >60 ml/min/1.73 m^2 at 30 days in 41 out of 45children (91 %) with prerenal, postrenal or unknown etiology, eGFR was <60 in 20 out of 25 subjects (80 %) with AKI due to primary renal diseases. Whereas the fraction of survivors achieving full renal recovery did not differ significantly between the RRT groups, patients who had received dHD tended to be more likely to remain with end-stage renal disease than those treated with cPD ($p=0.14$).

Table 2 Disease course of patients according to renal replacement therapy (RRT) modalities

	Baseline	Day 1	Day 3	Day 5	Day 10	Day 15	Day 30
Cumulative mortality (*n*)							
cPD		6	12	16	21	25	33
dHD		5	8	11	14	19	33
Need for any vasopressor, number/number of current survivors (%)							
cPD	72/84 (86)	62/78 (79)	32/72 (44)	12/68 (18)	06/63 (10)	00/59 (0)	00/51 (0)
dHD	43/52 (82)	38/47 (81)	35/44 (80)	17/41 (41)	09/38 (24)	01/33 (3)	00/19 (0)
Need for mechanical ventilation, number/number of current survivors (%)							
cPD	33/84 (39)	25/78 (32)	21/72 (29)	11/68 (16)	03/63 (5)	00/59 (0)	00/51 (0)
dHD	17/52 (32)	12/47 (26)	09/44 (20)	08/41 (19)	03/38 (8)	02/33 (6)	00/19 (0)
Oliguria, number/number of current survivors (%)							
cPD	78 /84 (93)	72/78 (92)	57/72 (79)	37/68 (54)	21/63 (33)	11/59 (19)	6/51 (12)
dHD	47/52 (90)	42/47 (89)	35/44 (80)	23/41 (56)	17/38 (45)	12/33 (36)	5/19 (26)
Serum urea(mg/dl), mean ± SD							
cPD	142 ± 64	122 ± 56	113 ± 58	118 ± 74	102 ± 31	97 ± 24	106 ± 54
dHD	158 ± 83	108 ± 63	112 ± 23	128 ± 43	118 ± 23	102 ± 53	108 ± 73
eGFR (ml/min/1.73 m^2), mean ± SD							
cPD	12.6 ± 8.2	24.3 ± 18.3	35.1 ± 23.6	51.4 ± 31.7	46.9 ± 23.4	74.6 ± 38.2	72.5 ± 41.4
dHD	15.3 ± 7.4	29.5 ± 21.4	36.3 ± 27.3	46.7 ± 35.4	51.4 ± 34.7	42.3 ± 24.8	49.8 ± 35.5
PRISM III score, median (range)							
cPD	32 (12–64)	27 (9–52)	22 (7–39)	18 (3–46)	15 (0–42)	11 (0–46)	8 (0–36)
cHD	27 (14–58)	25 (12–60)	22 (11–48)	23 (4–38)	21 (5–39)	18 (0–59)	14 (0–48)

CPD continuous peritoneal dialysis, *DHD* daily intermittent hemodialysis

Prognostic indicators

Multivariate Cox regression analysis revealed that age <1 year, extended time lag (≥72 h) from disease onset to start of critical care treatment, the need for mechanical ventilation, and the duration of vasopressor dependence (≥72 h) were major independent predictors of death (Table 4). AKI caused by volume depletion had the most favorable (hazard ratio [HR] 0.58, $p = 0.023$), and AKI following post-surgery had the poorest survival prognosis (HR 2.45, $p = 0.011$). Independently of all these factors, the choice of cPD was associated with a significantly lower risk of mortality than selection for dHD (HR 1.75; $p = 0.022$). An intrinsic renal cause of AKI (HR 2.72; 95 % CI 1.37–3.83), $p = 0.029$) and ≥72-h time lag from disease onset to start of RRT (HR 2.17; 95 % CI 123–2.93; $p = 0.015$) were independent risk factors for remaining on dialysis at 3 months. The choice of RRT modality (dHD vs cPD) did not significantly affect the 3-month end stage renal disease (ESRD) risk (HR 1.15, $p = 0.18$).

Complications of RRT

In the dHD group a total of 37 transient hypotensive episodes and 11 transient hypertensive episodes occurred during or within 1 h of dHD sessions, despite blood volume monitoring. Hence, we assume that these episodes were linked to the dialysis procedure. However, hypotension or hypertension may also occur because of the disease process itself. On the contrary, there were no transient hypertensive or hypotensive episodes with cPD. Hypertension or hypotension in the cPD group was probably related to the disease process itself, as it was not transient and in most cases had presented since admission. Peritonitis occurred in 5 cPD patients (6 %); cPD was continued with antibiotic treatment and the PD effluent turned sterile in all cases. In the dHD group, catheter-related infection occurred in 5 patients (9 %); the catheter was removed and re-implanted at a different site in all cases. One child in the dHD group was switched to cPD after 22 days on dialysis because of an access problem. Mechanical complications occurred at similar frequency with both treatment modalities (cPD, 10 % vs dHD, 13 %). In cPD, catheter leakage and migration were the main mechanical complications, but there was no need to interrupt therapy. In these cases, the catheter was reinserted and the volume of dialysate per cycle reduced. Surgical insertion of the PD catheter instead of using a percutaneous approach may be the reason for the low rate of PD complications in this cohort. In dHD, partial or total catheter obstruction was the most common complication; it was resolved by catheter replacement.

Table 3 Clinical outcome of patients according to renal replacement therapy (RRT) modalities

	cPD	dHD	*p*
Days on RRT, median (range)	4 (2–30)	7 (4–30)	
Days on vasopressor therapy, median (range)	3 (1–12)	5 (3–16)	
Days on mechanical ventilation, median (range)	4 (1–15)	7 (4–18)	
Treatment complications, number/number of survivors (%)			
Peritonitis/catheter related infection	5/84 (6)	5/52 (9)	0.65
Exit site bleeding	Nil	1/52 (2)	0.80
Mechanical	8/84 (10)	7/52 (13)	0.67
Patient survival, number/number of survivors (%)			
Day 15	59/84 (70)	33/52 (63)	0.52
Day 30	51/84 (60)	19/52 (36)	0.019
Renal recovery (non-dialysis dependent), number/number of survivors (%)			
Day 15	48/59 (81)	21/33 (63)	0.10
Day 30	45/51 (88)	14/19 (74)	0.26
3 months	46/51 (90)	13/18 (72)	0.14
Renal status at day 30 (eGFR in ml/min/1.73 m^2), number/number of survivors (%)			
eGFR > 90	14/51 (27)	5/19 (26)	0.92
eGFR > 60-90	22/51 (43)	5/19 (26)	0.31
eGFR > 30-60	7/51 (14)	3/19 (16)	0.83
eGFR 15-30	2/51 (4)	1/19 (5)	0.81
eGFR < 15	6/51 (12)	5/19 (26)	0.26
Renal status at 3 months, number/number of survivors (%)			
CKD stage 1	27/51 (53)	8/18 (44)	0.73
CKD stage 2	14/51 (27)	4/18 (22)	0.90
CKD stage 3	4/51 (8)	1/18 (6)	0.74
CKD stage 4	1/51 (2)	0/18 (0)	0.55
CKD stage 5	5/51 (10)	5/18 (28)	0.14

One patient in the HD group died at 2 months following a road traffic accident

eGFR estimated glomerular filtration rate, *CKD* chronic kidney disease, *HD* hemodialysis

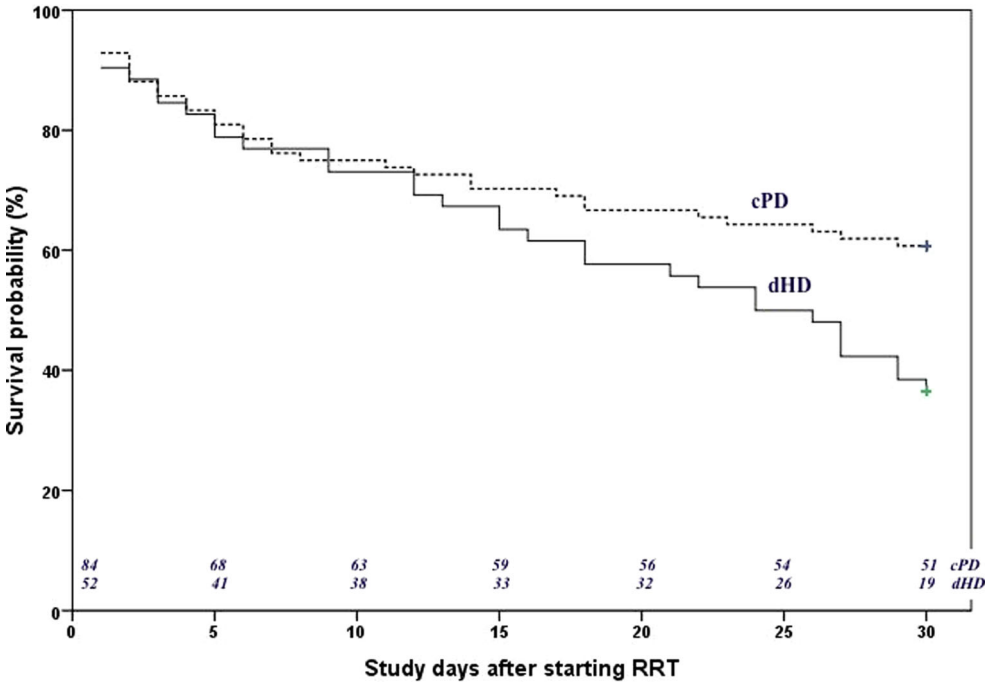

Fig 1 Kaplan–Meier analysis of patient survival within 30 days of the start of continuous peritoneal dialysis (*cPD*) or daily hemodialysis (*dHD*) in children with acute kidney injury (AKI). (Log-rank $p = 0.019$). *RRT* renal replacement therapy

Table 4 Cox regression analysis of risk factors for mortality. Hazard ratio (*HR*) indicates the relative risk of death

		Unadjusted HR (95%CI)	*p*	Adjusted[a] HR (95%CI)	*p*
Age (years)	≥5	1		1	
	≥1 to < 5	0.68 (0.51–1.13)	0 .16	0.82 (0.59–1.38)	0.13
	<1	1.32 (1.21–2.54)	0.037	1.46 (1.13–2.79)	0.021
Etiology	Sepsis/Infection	1		1	
	Cardiogenic	1.21 (0.93–1.54)	0.064	1.16 (0.82–1.32)	0.076
	Post–surgical	2.53 (1.18–3.83)	0.008	2.45 (1.23–3.68)	0.011
	Renal	0.67 (0.42–0.95)	0.051	0.82 (0.57–1.29)	0.059
	Hypoxia–ischemia	1.47 (1.08–2.62)	0.037	1.34 (1.03–2.59)	0.043
	Volume depletion	0.43 (0.17–0.71)	0.018	0.58 (0.23–0.74)	0.023
Duration from disease onset to start of RRT	<24 h	1		1	
	≥24 to < 72 h	1.15 (1.06–1.35)	0.042	1.09 (0.92–1.19)	0.057
	≥72 h	2.03 (1.12–2.44)	0.012	1.87 (1.23–2.39)	0.019
RRT modality	cPD	1		1	
	dHD	1.34 (1.12–2.47)	0.028	1.75 (1.18–2.84)	0.022
Duration of vasopressor requirement	<72 h	1		1	
	>72 h	1.28 (1.18–2.29)	0.030	1.66 (1.12–2.38)	0.025
Ventilator support	No	1	0.018	1	0.015
	Yes	2.18 (1.38–3.17)		2.36 (1.45–3.46)	

RRT renal replacement therapy

[a] Adjusted hazard ratio for each factor was calculated after adjustment for the other factors of the first column

Discussion

There are few studies in the literature comparing different methods of dialysis in AKI and most present conflicting results. In this retrospective cohort study, we investigated the potential impact of two RRT modalities (dHD and cPD) on patient survival and renal recovery in the management of pediatric AKI. In line with previously published larger clinical trials in patients with AKI, severe sepsis/septic shock was the major underlying pathology in our study population [8]. Most patients initially presented with established multi-organ failure. In addition to requiring renal support, most patients also required vasopressor therapy. This may explain the rather high overall mortality rates observed in our study. Dialytic management of these patients is difficult because of multiple organ dysfunction and associated hemodynamic instability. In addition, malnutriton, either preexisting or acquired during the critical illness, can have a major impact on patient survival. It was difficult to assess the nutritional status in this retrospective study; although the positive mean BMI SDS at the start of RRT argues against that prevalent malnutrition does not play a role, weight for height indices in children with AKI are prone to confounding by both edema and dehydration.

Dialytic management and therapeutic decisions in our children were individualized by the pediatric intensivist and nephrologist team based on the patient's specific clinical and hemodynamic status. In the absence of study evidence from observational studies and comparatory clinical trials, there is currently no consensus on the best dialysis method and optimal dialysis dosing in pediatric AKI. However, there is common agreement that RRTs should correct any biochemical abnormalities, while providing adequate fluid and electrolyte balance to preserve organ function and allow functional recovery [1]. Prevailing center expertise and patient age are critical factors influencing the choice of dialysis modality for children [1, 2, 9]. PD is frequently used for the management of pediatric AKI and remains the preferred method in infants and young children, where vascular access is a limiting factor. In addition to avoiding central vein puncture and anticoagulation, the technical simplicity, relatively low cost, and low risk of treatment-related fluid–electrolyte imbalances in hemodynamically unstable patients are considered significant advantages of PD [1–3, 9, 10]. Concerns have been raised about the dialytic adequacy of PD, especially in hypercatabolic states [11]. In this study we observed adequate purification with cPD, although it took more time than HD; small solute clearance was comparable with that achieved with dHD.

We found a significantly better 30-day survival in children treated with cPD in comparison with dHD. However, bias by indication is a notorious problem of outcome studies in AKI. To overcome this limitation, we performed systematic multivariate adjustment for potential confounders. Indeed, age, cause of AKI, RRT modality, time from disease onset to start of critical care treatment, the need for mechanical ventilation, and the duration of vasopressor dependence were identified as

significant factors affecting patient survival. As expected, mortality was higher in infants and in children with intrinsic causes of renal failure. Moreover, we found poorer survival with prolonged vasopressor and ventilator support requirement, in keeping with findings of adult AKI trials [8, 9]. Higher survival rates with early initiation of RRT were also evident among both groups in our study.

However, even when accounting for all confounding factors by multivariate adjustment, the risk of death was 75 % higher with dHD relative to cPD. Notably, most deaths in patients undergoing dHD occurred during or shortly after the dialysis session, pointing to procedure-related risks. Our analysis of causes of death suggests that difficulties in fluid and electrolyte management might be the predominant hazard linked to the intermittent dialysis procedure. This is also suggested by the higher need for vasopressor support observed during treatment with dHD compared with cPD. An important factor in the development of hypotension during HD is the ultrafiltration-related decrease in blood volume with insufficient refill of the intravascular compartment, which may be caused by a transcellular fluid shift from the extracellular to the intracellular compartment. Notably, intradialytic hypotension often could not be prevented by blood volume monitoring. Sepsis and other specific causes of AKI may render the cardiac tissue more vulnerable to arrhythmia and mechanical failure, particularly when sudden electrolyte, osmolar, and blood volume changes occur during an HD session. We presume that this is the main reason for the high dialysis procedure-associated mortality in the dHD group. On the contrary, most fatalities in the cPD group occurred either because of overwhelming sepsis or in relation to the intrinsic cause of AKI, whereas none of the patients expired because of PD-related complications. The more continuous volume and electrolyte fluxes in cPD may represent a major advantage, particularly in children with AKI.

Besides the higher mortality rate, renal functional recovery tended to be inferior in the survivors who had undergone dHD than in those treated with cPD, with a more than two-fold higher fraction of survivors developing persistent end-stage renal disease. This finding is consistent with the notion that frequent intradialytic ischemic events might cause further renal damage during the treatment of AKI. However, having intrinsic kidney disease as a cause of AKI and delayed treatment initiation were more relevant for the survivors' risk of remaining with end-stage renal disease than the choice of RRT modality.

To overcome the limitations of HD, especially in hemodynamically unstable patients, there has been a trend toward replacing intermittent HD with continuous extracorporeal renal replacement therapy (CRRT) in pediatric ICUs. Hence, it may be argued that better results may have been obtained if CRRT rather than dHD had been applied in our patients. However, comparative trials in adults have not substantiated a major technical or even patient survival benefit of CRRT compared with intermittent HD techniques. Several studies even implied higher complication rates and worse outcomes with CRRT [12–16]. Technology dependence and increased financial cost are other major drawbacks of CRRT. Pediatric CRRT is even more technology-dependent than in adults because of the need for specialized consumables of varying sizes to accommodate large and small children. This aspect is particularly relevant in developing countries such as India, with the resources needed to establish costly CRRT techniques in pediatric ICUs usually lacking.

We recognize several limitations to our study. These included its nonrandomized character and the relatively small group sizes, which precluded a powerful statistical analysis. Also, we did not compare cPD or dHD with CRRT, the cost of which exceeds available resources in most developing countries. Nonetheless, we conclude that cPD may be equally effective as and safer than dHD in terms of patient survival and renal recovery. A randomized controlled trial could be performed to confirm the findings of our study.

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Compliance with ethical standards

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