Increasing Dialysate Flow Rate over 500 ml/min for Reused High-Flux Dialyzers do not Increase Delivered Dialysis Dose: A Prospective Randomized Cross Over Study

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ABSTRACT

Objective: The primary objectives were: 1) to study the impact of Qd (500 vs 800 ml/min) on the delivered dose by reused dialyzers, and 2) to determine dialysis efficiency of a dialyzer reused 15 times.

Materials and Methods: A prospective randomized-controlled crossover study was conducted in 42 thrice-weekly hemodialysis (HD) patients (630 HD sessions in each Qd). Delivered doses at both Qds were assessed by single-pool Kt/V (spKt/V), equilibrated Kt/V (eKt/V) and online clearance monitoring Kt/V (Kt/V_{OCM}), measured at mid-week HD session using a new dialyzer and then again at every mid-week HD session.

Results: Although the spKt/V in HD sessions using new dialyzers at Qd of 500 ml/min was slightly lower than spKt/V at Qd of 800 ml/min (2.19±0.08 vs. 2.34±0.08, respectively, P=0.04), when accounting for urea rebound as assessed by eKt/V and Kt/V_{OCM}, there was no significant difference. The average delivered doses in dialyzers reused 15 times, with the mean average of spKt/V, eKt/V and Kt/V_{OCM} at Qd 500 ml/min, were not significantly inferior to the delivered doses at Qd 800 ml/min. Reusing a dialyzer 15 times did not decrease dialysis efficiency and delivered doses in all HD sessions reached spKt/V >1.4.

Conclusion: Increasing Qd over 500 ml/min for modern dialyzers does not significantly increase delivered dose of dialysis. Dialyzer reuse does not affect dialysis efficiency and provides adequate dialysis therapy.

Keywords: Dialysate flow rate; hemodialysis adequacy; reused dialyzer; delivered Kt/V; online Kt/V; equilibrated Kt/V (Siriraj Med J 2022; 74: 152-160)

INTRODUCTION

An adequate hemodialysis dose delivery is an important and independent predictor of morbidity and all-cause mortality in maintenance hemodialysis (HD) patients.[1] Current clinical practice guidelines for hemodialysis adequacy recommend a delivered single-pool Kt/V (spKt/V) of at least 1.2 per HD session (for 3-time-weekly HD patients without significant residual renal function), and higher doses of up to 1.4 in females and patients with high comorbidities.[1,2] The delivered

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dose of HD depends on dialyzer mass transfer-area coefficient (KoA), HD treatment time, and operating parameters, especially blood flow rate (Qb) and dialysate flow rate (Qd).[3] High-efficiency dialysis requires dialyzer with high KoA, Qb > 300 ml/min and Qd ≥ 500 ml/min. Increasing Qd from 500 ml/min to 800 ml/min has been recommended to maximize dialysis efficiency in high-efficiency HD. Previous studies[4-6] in early generation dialyzers showed that increasing Qd from 500 ml/min to 800 ml/min alter the dialyzer KoA and results in a larger increase in urea clearance than the predicted assuming a constant KoA, which was explained by a better flow distribution through the dialysate compartment and a decrease in dialysate-side boundary layer resistance. Recent studies[7-10] of newer dialyzers with improved dialysate flow distribution designs (such as hollow fiber undulations, spacer yarns, and changes in fiber packing density) have been accompanied by an increase in urea clearance of the dialyzer, and revealed that dialysate flow rate beyond 500 - 600 ml/min does not significantly increase delivered Kt/V. However, these studies were performed in single-use dialyzers.

In chronic hemodialysis, reuse of dialyzers has been widely practiced in developing countries, including Thailand. In our hemodialysis unit, patients who were treated with high-efficiency high-flux dialysis usually increasing Qd to 800 ml/min in order to maximize the dialysis dose and the dialyzer was reused 15 times. There is limited data on the effect of Qd in high-flux high-efficiency dialysis with a reused dialyzer related to delivered dose and hemodialysis adequacy. Increasing the dialysate flow rates results in a higher dialysis cost, require more water treatment, and leads to a higher risk of exposure to dialysis water impurities. The objectives of this study were to: 1) evaluate the effect of Qd of 800 ml/min and 500 ml/min on delivered dialysis dose in high-efficiency high-flux dialysis patients who used a reused dialyzer; 2) to determine dialysis efficiency and HD adequacy of a reused dialyzer.

MATERIALS AND METHODS

Study design

We performed a single-center prospective randomized-controlled crossover study in maintenance HD patients conducted at Siriraj Hospital, Mahidol University, Thailand between June 2018 - April 2020. Inclusion criteria for the study were age above 18, 4-hour three time weekly high-flux dialysis with a stable spKt/V (±5%) for at least two months, and the reuse of a dialyzer. The exclusion criteria were pregnancy, hepatitis B virus infection and being seropositive for HIV.

Before the intervention in each patient, bolus dose and maintenance dose of heparin were adjusted according to activated partial thromboplastin time (aPTT) level (at baseline, 3, 60, 180 and 240 minutes) to maintain a ratio of 1.8-2.5 for the duration of HD and at least 1.4 at the end of dialysis to prevent dialyzer clots and achieve reuse. Automatic dialyzer reprocessing machine (Meditop KIDNY- KLEEN®) was used to reprocess dialyzers and disinfected with peracetic acid, and measure blood compartment volume or total cell volume (TCV) of reused dialyzers. Percentage of TCV (%TCV) of a reused dialyzer was defined as the percentage of blood compartment volume measured by automatic dialyzer reprocessing machine divided by the priming volume value of the new dialyzer that provided by the manufacturer (Supplement Table 1). Reused dialyzers were discarded if its TCV less than 80% of baseline value or if it failed a leak test.

Patients were randomly assigned (using online software www.randomization.com) to be dialyzed according to an AB or BA schedule, where A represents 15 consecutive dialysis treatments with a Qd of 800 ml/min, and B represents 15 consecutive dialysis treatments with a Qd of 500 ml/min. The blood flow rate and dialyzer were kept constant for a given patient. The intervention of A and B began during a mid-week dialysis session with a new dialyzer followed by sessions with a reused dialyzer for a total of 15 times. The delivered dialysis dose was measured (during both A and B) at mid-week HD sessions with a new dialyzer and again at every mid-week HD session corresponding to the reused dialyzer no. 4, 7, 10, 13, and 15 (total of six measurements in each dialyzer). The delivered doses of dialysis were assessed by spKt/V (the Daugirdas second generation equation), equilibrated Kt/V (eKt/V) estimated by the rate equation[11], and online clearance monitoring Kt/V (Kt/V_{OCM}).[12] Kt/V_{OCM} was calculated by serial measurements of ionic dialysance of sodium (as a surrogate for effective urea clearance) made throughout HD treatment by using HD machines equipped with an online conductivity monitor and software dose-calculation tool DCTool (Fresenius Medical Care, Germany). Volume distribution of urea (V) will be calculated by the system from the weight, height, age and sex using the formula developed by Watson.

Data collection

Baseline data included patient's age, sex, height, body weight, dialysis vintage, comorbidities, medical history, vascular access, and HD treatment parameters, which consist of dialysis dose, Qb, Qd, post-HD body weight (W), ultrafiltration (UF), total processed blood

Supplement TABLE 1. Summary of dialyzer specifications#

	Hdf 100s	Hf 80s	EL210HR	EL190HR	FB190U
Surface area (m^2)	2.3	1.8	2.1	1.9	1.9
Priming volume (ml)	138	110	130	115	115
Ultrafiltration coefficient (Kuf) (ml/h/mmHg)	60	55	82	76	37.70
Dialyzer KoA_{urea} (ml/min)	1,167	805	1,976	1,171	1,367
Inulin clearance (ml/min)*	145	120	145	132	N/A
Myoglobin clearance (ml/min)*	N/A	N/A	104	101	47
Membrane component	Polysulfone	Polysulfone	Polynephron	Polynephron	Cellulose triacetate
Number of patients n, (%)	15 (35.70%)	3 (7.10%)	22 (52.40%)	1 (2.40%)	1 (2.40%)

* Blood flow rate 300 ml/min, Dialysate flow rate 500 ml/min
\# Data from the manufacturer's dialyzer specification sheets

Calculations

Single-pool delivered Kt/V (spKt/V) was calculated using the Daugirdas second generation equation** as follows: spKt/V = -Ln(R-0.008×t) + (4-3.5×R) × UF/W, where Ln is the natural logarithm, R is the post-dialysis/pre-dialysis blood urea nitrogen ratio, t is dialysis time (in hours), UF is ultrafiltration volume (in liters), and W is the patient's post-dialysis body weight (Kg).

Equilibrated Kt/V (eKt/V) was calculated by adjusting the spKt/V for postdialysis urea rebound using the rate equation described by Daugirdas and Schneditz as follows: eKt/V = spKt/V – [0.6 x(spKt/V)/t] + 0.03 (for arteriovenous access) and eKt/V = spKt/V – [0.47×(spKt/V)/t] + 0.02 (for venous catheters), where t represents the duration of dialysis in hours.

** Daugirda JT. Second generation logarithmic estimates of single-pool variable volume Kt/V: An analysis of error. J Am Soc Nephrol 1993; 4:1205-13.

volume (TBV), effective dialysis time, heparin dosage, type of dialyzer and number of dialyzer reuse with %TCV. Patients gave written informed consent to participate in this study as approved by the Human Research Protection Unit, Faculty of Medicine Siriraj Hospital, Mahidol University, Thailand.

Exposures and outcomes

The primary outcome was differences between delivered spKt/V, eKt/V and Kt/V_{OCM} at two different dialysate flow rates. Secondary outcomes were differences between eKt/V and Kt/V_{OCM}, and how the number of times a dialyzer was related to dialyzer urea clearance efficacy and HD adequacy. In this study, the hemodialysis adequacy threshold was set to delivered spKt/V > 1.4, considering high proportion of comorbidities and females (43%) in the patient population.

Statistics

The data are reported as mean ± standard deviation (SD) or median (minimum-maximum), depending on the distribution analysis. A two-sided p value of <0.05 was considered as significant. The primary outcome was non-inferiority of delivered dialysis dose at two Qds in first use and reused dialyzer, which were assessed by ANOVA using NCSS program with significance, α = 0.05 and non-inferiority margin of spKt/V = 0.25.

RESULTS

Forty-two HD patients were studied and a total of 1,260 HD sessions (630 HD sessions in each Qd) were performed. The dialyzers used in this study were HdF100s 35.7%, HF80s 7.1%, EL210HR 52.4%, EL190HR 2.4%, FB210U 2.4% and FB190U 2.4%. The characteristics of the dialyzers were summarized in the Supplement Table 1. Eighty-one percent of patients needed heparin dose adjustments to achieve an appropriate aPTT level throughout the HD sessions for prevent dialyzer clots before the intervention. All dialyzers used in this study were reused 15 times. The average %TCV in reused dialyzers at both Qds were not significantly different (Qd 800 ml/min, %TCV 97.80±1.20% vs Qd 500 ml/min, %TCV, 97.99±0.96%).

Baseline patient characteristics

The patient's baseline characteristics are summarized in Table 1. The mean age of 42 patients was 66.3±15.3 years (range 29.2 - 84.4 years) and 57.1% were men.

The effect of dialysate flow rate on delivered spKt/V in reused dialyzers

The mean spKt/V in the HD sessions using new dialyzers at Qd of 500 ml/min was slightly less than the mean spKt/V at Qd of 800 ml/min (2.19± 0.08 vs. 2.34± 0.08, respectively, p=0.04) (Table 2). In the HD sessions of reused dialyzers no. 4, 7, 10 and 13, the mean spKt/V at Qd 500 ml/min were significantly inferior to spKt/V at Qd 800 ml/min, whereas, the mean spKt/V in reused dialyzers no. 15 at both Qds was not different. However, the magnitude of differences in spKt/V was not clinically meaningful. The mean average spKt/V of dialyzers reused 15 times was calculated from the average of spKt/V of the new dialyzers and reused dialyzers (total of six measurements of spKt/V in each dialyzer). The mean average spKt/V of the reused dialyzers after 15 times at Qd 500 ml/min was not significantly inferior to spKt/V at Qd 800 ml/min (2.21±0.07 vs 2.31±0.07, respectively, p<0.01). All measurements of the delivered dose achieved hemodialysis adequacy thresholds of spKt/V > 1.4 at both dialysate flow rates.

The effect of dialysate flow rate on eKt/V

The mean eKt/V in the HD sessions of new dialyzers, and reused dialyzers no. 4, 7, and 13 at Qd of 500 ml/min

TABLE 1. Baseline characteristics of study population (n = 42 patients).

Parameters	
Age, years	66.3±15.3
Male sex, n (%)	24 (57.10)
Mean post-HD body weight, Kg	58.85±11.82
Comorbid diseases, n (%)	
Hypertension	39 (92.9)
Diabetes	16 (38.1)
Atherosclerotic heart disease	16 (38.1)
Polycystic kidney disease	2 (4.8)
Miscellaneous (hyperlipidemia (3)/chronic glomerulonephritis (1)/gout (1) /benign prostate hypertrophy (1)/ malignancy (1)	7 (16.7)
Dialysis vintage, months	106.2±68.4
Vascular access, n (%)	
Arteriovenous fistula	17 (40.48)
Arteriovenous graft	6 (14.29)
Permanent dual lumen catheter	19 (45.23)
Blood flow rate, n (%)	
300/350/400 ml/min	1 (2.4) / 11 (26.2) / 30 (71.4)
Heparin dose, units/session	
Total	4,431±3,712
Loading dose	1,681±1,761
Maintenance dose	2,750±1,944

TABLE 2. Mean delivered spKt/V at dialysate flow rate of 800 and 500 ml/min.

Dialyzer	Mean spKt/V		Mean	95%CI		P value
Reuse No.	Qd 800 ml/min	Qd 500 ml/min	difference	Lower	Upper	Non-Inferiority
New	2.34±0.08	2.19±0.08	0.15	-0.07	0.37	0.04
4	2.35±0.07	2.22±0.07	0.13	-0.07	0.33	0.22
7	2.35±0.07	2.21±0.07	0.14	-0.07	0.35	0.29
10	2.30±0.08	2.24±0.08	0.07	-0.17	0.30	0.13
13	2.29±0.07	2.19±0.07	0.10	-0.10	0.30	0.14
15	2.23±0.07	2.23±0.07	0.00	-0.21	0.21	0.02
Average	2.31±0.07	2.21±0.07	0.10	0.05	0.14	<0.01

were not significantly inferior to the mean eKt/V at Qd of 800 ml/min (Table 3). In reused dialyzers no.10 and 15, the mean eKt/V at Qd 500 ml/min were significantly inferior to eKt/V at Qd 800 ml/min. However, the magnitude of difference of eKt/V may not be clinically significant. The mean average eKt/V of dialyzers reused 15 times at Qd 500 ml/min was not significantly inferior to eKt/V at Qd 800 ml/min (1.93±0.27 vs 2.03±0.29, respectively, $p<0.01$).

The effect of dialysate flow rate on Kt/V_{OCM}

The mean Kt/V_{OCM} at Qd of 500 ml/min in HD sessions using new dialyzers and reused dialyzers were not significantly inferior to Kt/V_{OCM} at Qd of 800 ml/min (Table 4). The mean average Kt/V_{OCM} of dialyzers reused 15 times at Qd 500 ml/min was also not significantly inferior to Kt/V_{OCM} at Qd 800 ml/min (1.85±0.04 vs 1.98±0.05, respectively, $p<0.01$).

Comparison between eKt/V and Kt/V_{OCM}

The mean average of Kt/V_{OCM} at both Qds were significantly lower than the mean average eKt/V (Table 5). However, the magnitude of difference between Kt/V_{OCM} and eKt/V may not be clinically significant. The Kt/V_{OCM} was highly correlated with eKt/V at the both Qds, with $r = 0.91$ at Qd 800 ml/min ($p<0.01$), and $r = 0.87$ at Qd 500 ml/min ($p<0.01$).

The total processed blood volume and effective time in HD sessions of new dialyzers and reused dialyzers were not significantly different (Table 6). The average effective

TABLE 3. Mean eKt/V at dialysate flow rate of 800 and 500 ml/min.

Dialyzer	Mean eKt/V		Mean of	95%CI		P value
reuse No.	Qd 800 ml/min	Qd 500 ml/min	difference	Lower	Upper	Non-Inferiority
New	2.03±0.35	1.92±0.30	0.10	0.04	0.17	<0.01
4	2.04±0.30	1.95±0.29	0.09	0.03	0.16	<0.01
7	2.00±0.34	1.97±0.31	0.03	-0.06	0.11	<0.01
10	2.08±0.54	1.94±0.31	0.14	0.01	0.27	0.11
13	1.98±0.29	1.93±0.30	0.06	-0.01	0.12	<0.01
15	2.04±0.36	1.90±0.43	0.15	0.02	0.26	0.09
Average	2.03±0.29	1.93±0.27	0.10	-0.12	-0.03	<0.01

TABLE 4. Online clearance Kt/V at dialysate flow rate of 800 and 500 ml/min.

Dialyzer Reuse No.	Mean Kt/V_{OCM} Qd 800 ml/min	Qd 500 ml/min	Mean of difference	95%CI Lower	Upper	P value Non-Inferiority
New	1.99±0.32	1.87±0.29	0.11	0.06	0.17	<0.01
4	1.99±0.32	1.85±0.28	0.14	0.08	0.19	<0.01
7	1.99±0.34	1.87±0.29	0.12	0.05	0.18	<0.01
10	1.93±0.34	1.87±0.29	0.06	0.00	0.12	0.05
13	1.96±0.32	1.82±0.30	0.14	0.07	0.20	<0.01
15	2.00±0.40	1.83±0.29	0.17	0.07	0.27	<0.01
Average	1.98±0.05	1.85±0.04	0.13	0.06	0.17	<0.01

TABLE 5. Comparison of Kt/V_{OCM} and eKt/V at dialysate flow rate of 800 and 500 ml/min.

Dialyzer reuse No.	Kt/V_{OCM}	eKt/V	Mean difference	95% CI Lower	Upper	P value Inferiority
Qd 800 ml/min						
New	1.99±0.32	2.03±0.35	-0.04	-0.11	0.03	<0.01
4	1.99±0.32	2.04±0.30	-0.05	-0.12	0.03	<0.01
7	1.99±0.34	2.00±0.34	-0.02	-0.08	0.04	0.61
10	1.93±0.34	2.08±0.54	-0.15	-0.28	-0.02	0.03
13	1.96±0.32	1.98±0.29	-0.03	-0.10	0.05	0.48
15	2.00±0.40	2.04±0.36	-0.04	-0.16	0.08	0.49
Average	1.98±0.30	2.03±0.05	-0.05	-0.00	0.11	<0.01
Qd 500 ml/min						
New	1.87±0.29	1.92±0.30	-0.05	-0.12	-0.02	<0.01
4	1.85±0.28	1.95±0.29	-0.09	-0.17	-0.02	<0.01
7	1.87±0.29	1.97±0.31	-0.10	-0.18	-0.02	<0.01
10	1.87±0.29	1.94±0.31	-0.07	-0.13	-0.00	0.04
13	1.82±0.30	1.93±0.30	-0.11	-0.19	-0.03	<0.01
15	1.83±0.29	1.90±0.43	-0.07	0.18	0.05	<0.01
Average	1.85±0.30	1.93±0.04	-0.08	0.02	0.14	<0.01

TABLE 6. Total processed blood volume (TBV), effective dialysis time, % total cell volume (TCV) related to Kt/V_{OCM} and eKt/V at Qd 800 and 500 ml/min.

Qd 800 ml/min	New Dialyzer	Reused Dialyzer no. 4	no. 7	no. 10	no. 13	no. 15	P value
TBV (L)	90.21±6.57	89.95±6.21	89.98±6.91	89.63±6.23	89.53±6.65	89.90±5.96	0.89
Time*	3.52±0.08	3.52±0.03	3.51±0.04	3.53±0.08	3.51±0.03	3.52±0.09	0.76
%TCV	100±0	98.63±2.59	98.46±2.54	97.42±3.61	96.62±4.36	96.49±5.04	0.00
Kt/V_{OCM}	1.99±0.32	1.99±0.32	1.99±0.34	1.93±0.34	1.96±0.32	2.00±0.40	0.53
eKt/V	2.03±0.35	2.04±0.30	2.00±0.34	2.08±0.54	1.98±0.29	2.04±0.36	0.23
Qd 500 ml/min	**New Dialyzer**	**Reused Dialyzer no. 4**	**no. 7**	**no. 10**	**no. 13**	**no. 15**	**P value**
TBV (L)	90.66±6.44	89.67±6.50	89.97±7.24	90.59±6.60	90.08±6.00	89.51±7.12	0.33
Time*	3.54±0.11	3.51±0.05	3.53±0.08	3.51±0.08	3.54±0.11	3.51±0.04	0.07
%TCV	100±0	99.39±1.56	98.29±3.25	98.15±2.87	97.62±4.09	96.42±5.23	0.00
Kt/V_{OCM}	1.87±0.29	1.85±0.28	1.87±0.29	1.87±0.29	1.82±0.30	1.83±0.29	0.19
eKt/V	1.92±0.30	1.95±0.29	1.98±0.31	1.94±0.31	1.93±0.30	1.90±0.43	0.72

% TCV defined as % of blood compartment volume of a reused dialyzer divided by the priming volume value of new dialyzer provided by the manufacturer.
*Effective time (hr.min)

treatment time was 3 hours 52 minutes. The TCV remained above 80% of the baseline value for dialyzers reused up to 15 times, and the average decrease in %TCV was only 1.4-3.5%. The reused dialyzers did not alter efficacy of hemodialysis. The eKt/V and Kt/V_{OCM} measured in HD sessions using new dialyzers and reused dialyzers were not significantly different at both Qds (Table 6).

DISCUSSION

We found little improvement in delivered dialysis dose as assessed by spKt/V, eKt/V and Kt/V_{OCM} while increasing Qd from 500 ml/min to 800 ml/min. Although the mean spKt/V in HD sessions using new dialyzers at Qd of 500 ml/min was slightly lower than spKt/V at Qd of 800 ml/min (2.19±0.08 vs. 2.34±0.08, P =0.04), when accounting for urea rebound by assessing eKt/V and Kt/V_{OCM}, there was no significant difference at both Qds (eKt/V 1.93±0.27 vs. 2.03±0.29; Kt/V_{OCM}1.85±0.04 vs.1.98±0.05 at Qd 500 and Qd 800 ml/min, respectively). When comparing the average delivered dialysis dose of dialyzers reused 15 times between Qd of 500 ml/min and 800 ml/min, the mean average spKt/V was not significantly different (2.21±0.07 vs 2.31±0.07), as well as the mean average eKt/V and Kt/V_{OCM}. A study by Bhiman JP, et al[10] showed that the urea KoA was independent of Qd in the range 500 ml/min to 800 ml/min for dialyzers with enhanced dialysate flow distribution features, suggesting that increasing the dialysate flow rate in this range would not significantly increase delivered Kt/V in modern dialyzers. Consistent with our results, a study by Ward RA, et al[8] in 42 patients comparing delivered Kt/V at Qd of 600 and 800 ml/min with a median Qb of 450 ml/min showed that an increase in Qd beyond 600 ml/min for dialyzer with enhanced Qd distribution does not offer extra benefit in delivered spKt/V and Kt/V_{OCM}. A recent randomized crossover study[13] reported that reducing the Qd from 500 ml/min to 400 ml/min in small patients (body weight < 65 kg) had no impact on Kt/V, interdialytic weight gain, blood pressure or electrolyte disturbance.

The equilibrated Kt/V, which accounts for the postdialysis urea rebound, can be determined by eKt/V estimated from rate equation or Kt/V_{OCM} by ionic dialysance method.[14] Although Kt/V_{OCM} was slightly lower than eKt/V, but the magnitude of difference did not appear to be clinically meaningful, and it is highly correlated with eKt/V. Our results showed that Kt/V_{OCM} is a practical instrument and the easiest method to use to monitor delivered dialysis doses in each HD treatment, and help maintain recommended HD adequacy, especially in patients using reused dialyzers.

We found that reused dialyzers did not alter efficacy of hemodialysis and the delivered dose in all HD sessions at both Qds reached the HD adequacy thresholds of spKt/V > 1.4. Our results are consistent with Cheung AK's study[15] which showed that urea clearance decreased only slightly in reused dialyzers (approximately 1 to 2% per 10 reuses). A study by Ousseph et al[16] showed that both high-flux cellulosic and high-flux polysulfone dialyzers maintained their Kt/V at the 12^{th} and 15^{th} use, respectively, when dialyzers were reprocessed with Renalin and %TCV above 80% of the original value. In our study, 81% of patients needed heparin dose adjustment to achieve adequate aPTT level throughout HD session, and this resulted in a high residual TCV (mean %TCV > 96%) in dialyzers reused up to 15 times. The delivered dialysis doses of dialyzers reused for 15 times were not significantly different from those of new dialyzers (Table 6). This may result from a high residual TCV as well as the optimized effective HD time and adequate total processed blood volume (Table 6).

In our study, 78% of high-efficiency high-flux dialysis patients were prescribed with large dialyzers (dialyzer KoA > 1,160 ml/min with dialyzer surface area ≥ 2.1 m^2 and Kuf ≥ 60 ml/h/mmHg), which resulted in high delivered Kt/V in the range of 2, especially in patients with small body size (mean body weight 58.8 kg). High Kuf of the dialyzer has the benefit of a higher convective clearance from back filtration, resulting in increased middle molecule clearance. However, in the subgroup of small body size patients with this high range of Kt/V, dialysis prescription (especially Qd and Qb) should be adjusted to a more appropriate Kt/V range to save resources and preserve vascular access.

Our findings have some practical applications. First, the effect of reducing the Qd from 800 ml/min to 500 ml/min on delivered dialysis doses of high-efficiency dialysis using modern dialyzers is minimal. The delivered dialysis dose at Qd of 500 ml/min is preferred and this would result in dialysate cost savings of around 72 liters per dialysis session, less raw water consumption, and less the wear and tear on water treatment systems.[17] Reducing in water consumption will also decrease waste water production and electrical consumption, and these have a positive effect on the environment and carbon emissions, which has been recently concerned in dialysis practice as green nephrology and eco-dialysis.[17,18] However, increasing the Qd beyond 500 ml/min should be considered in selected patients who have not achieved HD adequacy despite using an appropriate dialyzer KoA and optimized Qb, especially in patients with high body weight. Second, reusing a dialyzer up to 15 times does not affect dialysis efficiency and provides adequate dialysis therapy as long as adequate anticoagulation throughout HD session and high residual TCV are maintained. Dialyzer reuse has some advantages, including less environmental impact from limiting waste disposal from dialyzers and packaging, and cost saving favoring in some developing countries. However, reprocessing of dialyzers requires additional personnel, disinfectants, room maintenance for safety and sterilization, and oversight mechanism of the dialyzer reuse standard. In developed countries, single-use practice is now preferable to reuse of dialyzers because the price of a high-flux dialyzer has recently gone down, and the operational cost of dialyzer reprocessing is rising, along with safety regulatory burden.[19,20]

Our study had some limitations. It was a single-center study. The Qbs used in this study were Qb of 400 ml/min in 71.4% of patients, and Qb of 350 ml/min in 26% of patients. Therefore, our results cannot be extrapolated to different dialysis treatment conditions that maximize Qb to >400 -450 ml/min. We did not evaluate the effect of Qd on other solutes removal such as protein-bound solutes or middle molecules, and the effect of reused dialyzer on sieving coefficient of middle molecule. However, increasing Qd in the range from 500 ml/min to 800 ml/min would not have any significant effect on clearance of these solutes.

CONCLUSION

Our data suggest that increasing dialysate flow rate beyond 500 ml/min for modern high-flux dialyzers does not significantly increase delivered dialysis dose. The delivered dose at Qd of 500 ml/min is more cost-effectiveness. Reuse of a dialyzer up to15 times does not affect dialysis efficiency and provides adequate dialysis therapy.

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