Daily Dialysis and Flexible Schedules: How to Assess Kt/V and EKR$_c$?

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*D*espite the growing interest in daily hemodialysis (DHD), logistic and economic factors limit its dissemination. Not the least of these factors is the lack of uniform criteria for measuring efficiency.

From November 1998 to November 2000, 19 patients were on DHD in our unit. The dialysis prescription was bicarbonate buffer; 6 sessions per week; 2 – 3 hours; blood flow 250 – 350 mL/min; individual K, HCO$_3$, and Na levels; membrane 1.6 – 2 m^2 (polysulfone, polycarbonate). The prescription represented the minimum dialysis requirement; patients were free to add up to 30 minutes per session, further increase or any decreases needed confirmation by the caregivers.

The aim of the study was to assess Kt/V$_{urea}$ variability in this clinical setting, and to identify the minimum number of dialysis sessions required to obtain a reliable estimate of weekly Kt/V$_{urea}$ [relative error (RE) < 10%].

We studied 169 dialysis sessions in 13 clinically stable patients on DHD for ≥ 3 months, with ≥ 3 Kt/V$_{urea}$ measurements within 2 weeks (median: 10; range: 3 – 32 sessions), tested in the same laboratory. To assess variability, we employed the simplest formula (the Lowrie Kt/V$_{urea}$), the widely used Daugirdas II formula, and the derived single-pool equivalent renal clearance (EKR$_c$), according to Casino.

The variability of Kt/V$_{urea}$ per session was high (Lowrie: RE = 2.5% – 22.1%; Daugirdas II and EKR$_c$: RE = 3.6% – 24%). Averaging several dialysis sessions leads to a more reliable estimate of weekly efficiency (6 sessions: RE = 0; 3 sessions, Lowrie formula: Kt/V$_{urea}$ RE = 1.1% – 9.7%; Daugirdas II and EKR$_c$: RE = 1.6% – 10.6%). In patients with wide time variations, variability may be lower if weekly efficiency is determined on the basis of "average hourly Kt/V$_{urea}$," which is calculated by dividing Kt/V$_{urea}$ by the number of hours in the studied sessions, and then multiplying by the hours of dialysis performed in the whole week (Lowrie formula, Kt/V$_{urea}$: RE = 4.8% – 16.6% for 1 session, 2.1% – 7.3% for 3 sessions). Once again, the RE decreases sharply when data from 3 sessions are considered. Therefore, for flexible DHD, we suggest averaging the data from ≥ 3 sessions for weekly Kt/V$_{urea}$ assessment.

Introduction

Daily hemodialysis (DHD) is currently one of the most interesting dialysis options, because of the favorable clinical results confirmed in a growing number of patients. Furthermore, more frequent sessions enable the achievement of very high efficiency, which is almost impossible with conventional treatment [1–4]. However, the DHD schedule has not been standardized, and an optimal efficiency target has not been defined. Several different treatment schedules fall under the umbrella term of "daily hemodialysis," ranging from 8 hours, 6 – 7 nights per week ("long, nightly hemodialysis") to 1.75 hours – 2.5 hours, 6 – 7 days per week ("short daily hemodialysis") [1–8].

The definition of the "ideal" daily hemodialysis schedule is not univocal, and almost every center has developed a personal approach to this treatment. The differences render comparisons between the results obtained in various settings very difficult, reducing the strength of concordant results obtained in small cohorts of patients [7,9,10].

Furthermore, Kt/V$_{urea}$, the "gold standard" of hemodialysis efficiency, has been validated only in conventional hemodialysis. Its validity may be questionable under a completely different schedule such as in daily hemodialysis. In the search for other efficiency markers, the time-averaged deviation (TAD) and the relationship between the TAD and the time-averaged concentration (TAC) have been proposed as indices of the physiology/unphysiology concept [11,12]. Several problems remain unsolved, such as membrane biocompatibility, reuse of dialyzers, and the role of the removal of middle molecules [13–15].

An interesting solution that permits efficiency comparisons among schedules characterized by varying numbers of sessions per week comes from the model of Casino, who proposes equivalent renal urea clearance corrected for urea volume (EKR$_c$) as a practical means to calculate efficiency, comparing it to the continuous renal urea clearance [4,16]. Using this model, the kinetic advantage of daily hemodialy-

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sis becomes more evident, because the same weekly Kt/V$_{urea}$ (calculated as a sum of Kt/V$_{urea}$ of all sessions) corresponds to a higher EKR$_c$ in relation to the number of sessions [4,16].

Regardless of the kinetic formula used, no study so far has taken into account a crucial problem: the variability of Kt/V$_{urea}$ on short daily treatments. Variability may have a variety of sources, the most important probably being analytic error (the variability of urea testing is usually in the 2% – 10% range, depending upon urea levels) [17] and day-to-day variations in clinical parameters such as weight loss, blood flow, or recirculation. These problems are common with all hemodialysis schedules, but may be expected to be higher in short, daily hemodialysis because the slope of the concentration curve is steeper during the first hours of treatment. Variability is of course enhanced by the choice of flexible scheduling.

In our center, a flexible short daily hemodialysis schedule was progressively developed to give patients maximum freedom in scheduling, and to increase self-care and compliance. The prescribed time is intended as a minimum requirement, ensuring at least the same weekly Kt/V$_{urea}$ as the previous hemodialysis schedule yielded. Patients are allowed to increase treatment time within a constant range (usually 30 minutes). A further increase, or any decrease, needs confirmation by caregivers. This approach progressively led several patients to increase weekly hemodialysis time; however, it posed a challenge for the calculation of hemodialysis efficiency.

The aims of the present study were therefore to assess the variability of Kt/V$_{urea}$ in patients on a flexible short daily hemodialysis schedule, and to identify the minimum number of hemodialysis sessions required to obtain a reliable assessment of weekly efficiency (relative error [RE] < 10%). We tested the variability of three simple and widely used formulas for the assessment of weekly hemodialysis efficiency: Kt/V$_{urea}$ according to Lowrie [18] and to Daugirdas II [19], and the derived EKR$_c$ according to Casino [4]. This study represents a further step of a previous analysis, focused on variability in Kt/V$_{urea}$ under constant daily hemodialysis [20].

Material and methods

Patients on daily hemodialysis

The study was performed during the period March – November 2000 in the Sovrano Militare Ordine di Malta (SMOM) Unit, a freestanding hemodialysis unit, satellite of a large university center (Cattedra di Nefrologia of the University of Torino, Italy). The entire center follows 200 – 215 hemodialysis patients. In the period November 1998 to November 2000, 19 patients experienced at least a trial of 2 weeks of daily hemodialysis. The present study enrolled 13 clinically stable patients with follow-up ≥ 3 months (11 men, 2 women; median age 46 years, range 22 – 61 years). Of these, 7 patients performed treatment at home, 5 in the limited self-care unit, and 1 in alternating settings (3 sessions at home, 3 in-center).

Hemodialysis schedule

The short daily hemodialysis schedule was tailored for individual patients. The dialysis prescription was blood flow (Qb), 250 – 350 mL/min; dialysate flow (Qd), 500 mL/min; access, arteriovenous fistula in all patients (with prosthetic bridge in 2); needles, 16-gauge; maximum weight loss, 0.8 – 1.2 kg per hour; sessions, 6 per week; dialysis time, 2 – 3 hours; membranes, polysulfone and polyamide; surface area, 1.6 – 1.8 m^2. Patients were allowed to add up to 30 minutes to the hemodialysis session; any decrease in dialysis time or an increase above 30 minutes per session required confirmation by the caregivers. Most of the flexibility in dialysis time was related to the need for fluid removal.

Patients were free to perform hemodialysis at home each day of the week, including Sunday. They were permitted to change the day off dialysis and to switch occasionally to 3 or 4 sessions per week.

Data selection and blood sampling

Kinetic data were obtained from 169 hemodialysis sessions. Data were included if at least 3 measurements were available within 2 subsequent weeks in clinically stable patients without known vascular access problems. Sessions during hospitalizations for complications and within two weeks after discharge were excluded.

Data about time on dialysis, weight and weight loss, Qb and Qd were collected. Blood samples were obtained from the arterial line at the start of dialysis and at the end of the session after reducing ultrafiltration to a minimum and reducing Qb to 100 mL/min for 10 – 20 seconds. Home hemodialysis patients followed the same protocol.

Urea samples were analyzed at the same laboratory (nephrology laboratory of the Cattedra di Nefrologia, University of Torino), by the enzymatic (urease) method. The coefficient of variation changes with the urea level; it is lower at higher urea values. For a urea level of 114 mg/dL, it is 1.9%; for 58 mg/dL, 2.7%; for 14 mg/dL, 9% [17].

Calculation of Kt/V$_{urea}$, EKR$_c$, and coefficient of variation

Two Kt/V$_{urea}$ formulas were used. The Lowrie formula

$$Kt/V_{urea} = -\ln (C_t / C_0)$$

where K is urea clearance, t is duration of dialysis, V is urea distribution volume, Ln is the natural logarithm, C$_t$ is urea concentration at time t (post dialysis), and C$_0$ is urea concentration at time 0, was chosen for its mathematical simplicity [18]. The Daugirdas II formula

$$Kt/V_{urea} = \ln (C_t / C_0 - 0.008 \times t) + [4 - 3.5 \times (C_t / C_0)] \times UF / Wt$$

where, in addition, UF is ultrafiltration and Wt is weight at time t, was chosen for its wide use [19].

Using the Daugirdas II formula, Kt/V_{urea} was calculated. Then, using the model developed by Casino, EKR_c was estimated by plotting Kt/V_{urea} on the diagram [4,19].

Variability was assessed both as Kt/V_{urea} variability and as variability of average hourly Kt/V_{urea}, the latter obtained by dividing Kt/V_{urea} by the hours of dialysis performed in the tested sessions. Weekly efficiency was obtained by multiplying average hourly Kt/V_{urea} by the number of hours of dialysis performed during the week.

The number of sessions required for an acceptable approximation of weekly efficiency (weekly Kt/V_{urea} and EKR_c) was then calculated.

Statistical analysis

Data were analyzed using SPSS 9.0 (SPSS Inc., Chicago, IL, U.S.A.) and Excel software (Microsoft Corporation, Redmond, WA, U.S.A.). Descriptive statistics (mean, standard deviation, median, range) were employed where appropriate. Calculation of error, incurred when estimating the overall weekly Kt/V_{urea} or EKR_c using a single observation, was based on the standard equation for finite samples:

$$sd\,(\,Kt/V_{urea}\,) = \delta^2\,/\,m^{1/2} \times [\,(\,M - m\,)\,/\,(\,M - 1\,)\,]^{1/2}$$

where $sd\,(\,Kt/V_{urea}\,)$ [or $sd\,(\,EKR\,)$] is the standard error when the mean Kt/V_{urea} or mean EKR_c is estimated on m samples (number of tests during the week) out of the population M (6 days per week) and δ^2 is the standard deviation. Relative error (RE) was calculated as

$$RE = sd\,(\,Kt/V_{urea}\ or\ EKR_c\,)\,/\ average.$$

Results

Hemodialysis schedule and its variations

In our center, daily hemodialysis is often suggested by the nephrologist and chosen by the patients in the presence of comorbid conditions, mainly cardiovascular ones (Table I). Therefore, our policy was to define a maximum rate of weight loss for each patient, which ranged from 0.8 kg to 1.2 kg per hour. No dietary limitations were prescribed. Patient demographics, comorbidity, and hemodialysis prescription, including the time ranges, are reported in Tables I and II.

Variability of Kt/V_{urea} per session

The ranges of dialysis time and of Kt/V_{urea}—expressed both as Kt/V_{urea} per session and as average hourly Kt/V_{urea}—were wide (Table III). Variability of Kt/V_{urea} was lower in patients with relatively constant schedules and with lower ranges of weight loss and dialysis time (Table III). Variability in average hourly Kt/V_{urea} was lower than in Kt/V_{urea} per session in most instances with wide time variations (Table III).

Variability of Kt/V, expressed as standard deviation, was not statistically different between the two formulas used (Lowrie and Daugirdas II) [18,19].

Identification of minimum number of sessions for weekly Kt/V_{urea} and EKR_c calculation

To identify the minimum number of sessions required to calculate weekly Kt/V_{urea} or EKR_c, with the goal of a relative error in the 5% – 10% range, we tested the hypothesis of using the data from 1 up to 6 hemodialysis sessions per week. We calculated Kt/V_{urea} both as Kt/V_{urea} per session and as aver-

TABLE I   Clinical data in 13 clinically stable patients on short daily dialysis for 3 months or longer.

Patient	Sex	Comorbidity	Age (years)	Duration of RRT (years)	Start of daily dialysis (Month/Day/Year)
1	M	Hypertension	36	4	12/11/1998
2	M	Hypertension	22	1	05/02/2000
		Systemic lupus erythematosus			
3	M	Diabetes type 2	42	1	05/10/1999
		Nephroangiosclerosis–			
		Ischemic nephropathy			
4	M	None	33	2	04/26/1999
5	M	Melanoma	51	2	06/26/1999
6	F	Peripheral vascular disease	52	2	08/22/2000
		Systemic lupus erythematosus			
7	M	Cardiovascular	46	19	06/05/2000
		(recurrent atrial fibrillation)			
8	F	Diabetes type 1	51	1	01/04/1999
		Neuropathy			
9	M	Cardiovascular (ischemic)	49	18	06/05/2000
10	M	Cardiovascular (angioplasty)	54	18	08/16/1999
11	M	Hypertension	51	23	12/07/1998
12	M	Cardiovascular (ischemic)	61	20	04/28/1999
13	M	Peripheral vascular disease	41	21	11/25/1998

RRT = renal replacement therapy.

TABLE II Dialysis schedules in 13 clinically stable patients on short daily dialysis for 3 months or longer.

Patient	Sex	Age (years)	Dry weight (kg)[a]	Qb (mL/min)[a]	Qd (mL/min)[a]	Membrane surface (m²)/type	Time range per session (min)	Average time per week
1[b]	M	37	70	300	500	1.8/polyamide	120–150	12 h 50 min
2[c]	M	22	50.5	300	500	1.8/polyamide	120–160	12 h 30 min
3[b]	M	43	109	300	500	1.8/polysulfone	135–180	15 h 40 min
4[b]	M	34	65.5	300	500	1.8/polyamide	120–165	12 h 30 min
5[b]	M	52	75	280	500	1.8/polyamide	120	12 h
6	F	52	77.5	280	500	1.6/polysulfone	120–135	13 h
7	M	46	81	350	500	1.8/polysulfone	150–180	15 h 30 min
8	F	51	56.3	250	500	1.6/polysulfone	120–160	13 h 30 min
9	M	49	66	300	500	1.8/polysulfone	135–150	14 h 30 min
10	M	46	57	300	500	1.6/polysulfone	120–150	13 h
11[b]	M	52	76.5	270	500	1.8/polyamide	120	12 h
12[b]	M	61	61.5	280	500	1.6/polysulfone	120–160	14 h 40 min
13[b]	M	42	64	300	500	1.6/polysulfone	120	12 h

[a] Reported according to dialysis prescription.
[b] Home hemodialysis patient. (All other patients performed dialysis in a limited self-care center.)
[c] Patient performing dialysis in alternating settings: 3 times at home, 3 times in self-care center.
Qb = blood flow; Qd = dialysate flow.

TABLE III Kt/V (Lowrie), average hourly Kt/V (Lowrie), Kt/V (Daugirdas II), average hourly Kt/V (Daugirdas II), single-pool EKR$_c$, weight loss, and time range per session in 13 patients on daily dialysis.

Patient	Sessions studied	Sex	Dry weight (kg)	Weight loss per session (kg)	Time range (min)	Kt/V per session (Lowrie)	Average hourly Kt/V (Lowrie)	Kt/V per session (Daugirdas)	Average hourly Kt/V (Daugirdas)	EKR$_c$ (assessed using Kt/V per session)
1	9	M	70	1.87±0.07	120–150	0.64±0.07	0.31±0.03	0.73±0.09	0.34±0.03	16.80±2.10
2	3	M	50.5	1.66±0.92	140–160	0.77±0.05	0.33±0.02	0.89±0.05	0.38±0.04	19.70±0.87
3	5	M	109	3.02±1.21	120–195	0.56±0.12	0.22±0.02	0.65±0.16	0.26±0.02	14.90±3.60
4	4	M	65.5	1.60±0.47	120	0.64±0.03	0.32±0.02	0.72±0.04	0.36±0.02	16.10±0.79
5	12	M	75	1.21±0.20	120	0.67±0.07	0.34±0.03	0.74±0.07	0.37±0.04	16.60±1.48
6	8	F	77.5	1.70±0.38	120–150	0.72±0.05	0.35±0.03	0.81±0.06	0.39±0.03	18.24±1.35
7	30	M	81	2.70±0.87	150–180	0.68±0.07	0.26±0.03	0.79±0.09	0.30±0.04	17.72±1.78
8	32	F	56.3	1.70±0.47	105–150	0.85±0.07	0.40±0.01	0.97±0.14	0.46±0.07	20.74±2.20
9	24	M	66	2.24±0.47	135–165	0.74±0.10	0.30±0.05	0.86±0.11	0.36±0.05	19.06±2.24
10	14	M	57	1.90±0.56	120–150	0.80±0.08	0.38±0.04	0.94±0.09	0.43±0.04	20.63±1.73
11	12	M	76.5	0.65±0.26	120–122	0.58±0.03	0.29±0.01	0.63±0.02	0.31±0.01	14.50±0.50
12	10	M	61.5	1.62±0.45	135–180	0.76±0.07	0.31±0.03	0.87±0.11	0.36±0.03	19.10±1.56
13	6	M	64	1.63±0.31	120	0.74±0.07	0.37±0.03	0.83±0.07	0.42±0.04	18.60±1.48

EKR$_c$ = corrected equivalent renal clearance.

age hourly Kt/V$_{urea}$. Single-pool EKR$_c$ calculation was performed according to Casino (Tables III and IV). The relative error is, by definition, at the maximum with 1 hemodialysis session and null with 6 sessions per week.

A sharp decrease is observed when data from 3 dialysis sessions are available, even if a further reduction is observed with data from 4 or 5 sessions (Tables IV and V).

Discussion

Daily hemodialysis provides very good clinical results, related at least in part to its high efficiency [11,12,14]. However, patients pay a price in terms of limits on their freedom in everyday life. To minimize the risk of a rigid daily routine, we allowed our patients to have a free diet, to choose the time of day and the days of the week to perform treatments, and occasionally to switch to 3 or 4 sessions per week for personal reasons or for working needs [21].

Because the policy of our center also was to propose daily hemodialysis to patients with comorbidities, we followed a hemodialysis schedule of "gentle" short daily treatments with relatively low Qb and an individually tailored maximum weight loss per hour. The increased intake of salt and water therefore led patients to choose either to increase the maximum weight loss per hour or to increase dialysis time. Preference was given to the second option, following the motto "on dialysis, the more, the better." The approach led to an increasing flexibility in the dialysis schedule. With this policy, the daily hemodialysis prescription changed progressively from a constant schedule with equal time for each session, to a "minimum requirement."

TABLE IV   Relative error in assessment of weekly Kt/V$_{urea}$, EKR$_c$,[a] and average hourly Kt/V$_{urea}$, calculated according to the Daugirdas II formula and single-pool EKR$_c$. Data from 1 – 5 dialysis sessions were averaged for each patient.

Relative error for Kt/V$_{urea}$ (Daugirdas II) and EKR$_c$													
Patient	1	2	3	4	5	6	7	8	9	10	11	12	13
1 session	12.1%	5.3%	24.0%	5.2%	9.7%	7.9%	11.1%	14.5%	12.9%	10.0%	3.6%	12.5%	7.8%
2 sessions	10.8%	4.8%	21.4%	4.7%	8.6%	7.0%	9.9%	12.9%	11.5%	8.9%	3.2%	11.1%	7.0%
3 sessions	**5.3%**	**2.3%**	**10.6%**	**2.3%**	**4.3%**	**3.5%**	**4.9%**	**6.4%**	**5.7%**	**4.4%**	**1.6%**	**5.5%**	**3.4%**
4 sessions	3.9%	1.7%	7.7%	1.7%	3.1%	2.5%	3.6%	4.6%	4.1%	3.2%	1.2%	4.0%	2.5%
5 sessions	2.4%	1.1%	4.8%	1.1%	1.9%	1.6%	2.2%	2.9%	2.6%	2.0%	0.7%	2.5%	1.6%
Relative error for average hourly Kt/V$_{urea}$ (Daugirdas II)													
Patient	1	2	3	4	5	6	7	8	9	10	11	12	13
1 session	8.5%	10.2%	8.1%	5.3%	9.7%	7.7%	12.3%	15.8%	14.4%	8.2%	3.5%	7.5%	8.5%
2 sessions	7.6%	9.1%	7.2%	4.7%	8.7%	6.8%	11.0%	14.1%	12.9%	7.3%	3.2%	6.7%	7.6%
3 sessions	**3.8%**	**4.5%**	**3.6%**	**2.3%**	**4.3%**	**3.4%**	**5.4%**	**7.0%**	**6.4%**	**3.6%**	**1.6%**	**3.3%**	**3.8%**
4 sessions	2.7%	3.2%	2.6%	1.7%	3.1%	2.5%	3.9%	5.1%	4.6%	2.6%	1.1%	2.4%	2.7%
5 sessions	1.7%	2.1%	1.7%	1.1%	1.9%	1.5%	2.5%	3.2%	2.9%	1.6%	0.7%	1.5%	1.7%

[a] Because Daugirdas Kt/V is the origin of EKR$_c$, the relative error is the same.
EKR$_c$ = corrected equivalent renal clearance.

TABLE V   Relative error in assessment of weekly Kt/V$_{urea}$ and average hourly Kt/V$_{urea}$, calculated according to the Lowrie formula. Data from 1 – 5 dialysis sessions were averaged for each patient.

Relative error for Kt/V$_{urea}$ (Lowrie)													
Patient	1	2	3	4	5	6	7	8	9	10	11	12	13
1 session	10.6%	6.8%	22.1%	5.5%	10.0%	6.9%	9.7%	2.5%	13.5%	11.0%	4.8%	9.3%	9.4%
2 sessions	9.4%	6.1%	19.7%	5.0%	8.9%	6.1%	8.6%	2.2%	12.0%	9.7%	4.3%	8.3%	8.2%
3 sessions	**4.7%**	**3.0%**	**9.7%**	**2.5%**	**4.4%**	**3.0%**	**4.2%**	**1.1%**	**5.9%**	**4.8%**	**2.1%**	**4.1%**	**4.2%**
4 sessions	3.4%	2.2%	7.1%	1.8%	3.2%	2.2%	3.1%	0.8%	4.3%	3.5%	1.5%	2.9%	3.0%
5 sessions	2.1%	1.3%	4.4%	1.1%	2.0%	1.3%	1.9%	0.5%	2.7%	2.2%	0.9%	1.9%	1.8%
Relative error for average hourly Kt/V$_{urea}$ (Lowrie)													
Patient	1	2	3	4	5	6	7	8	9	10	11	12	13
1 session	8.7%	5.9%	8.6%	5.6%	10.0%	8.57%	11.5%	8.2%	16.6%	10.5%	4.8%	9.0%	9.2%
2 sessions	7.7%	5.3%	7.7%	5.0%	8.9%	7.6%	10.2%	7.3%	14.8%	9.3%	4.3%	8.0%	8.2%
3 sessions	**3.8%**	**2.6%**	**3.8%**	**2.5%**	**4.4%**	**3.7%**	**5.0%**	**3.6%**	**7.3%**	**4.6%**	**2.1%**	**3.9%**	**4.2%**
4 sessions	2.7%	1.9%	2.7%	1.8%	3.2%	2.7%	3.6%	2.6%	5.3%	3.3%	1.5%	2.9%	2.9%
5 sessions	1.7%	1.2%	1.7%	1.1%	2.0%	1.7%	2.3%	1.6%	3.3%	2.1%	0.9%	1.8%	1.8%

At the start of our daily hemodialysis program, the targeted efficiency was a weekly Kt/V$_{urea}$ at least equal to the weekly Kt/V$_{urea}$ previously achieved on conventional hemodialysis. Owing to the kinetic features of daily treatment, overall higher dialysis doses were delivered [4]. The dialysis dose was further increased by most patients, to compensate for the free diet or to obtain good metabolic control, with a lesser need for drug therapy. These superior results in terms of compliance were clinically rewarding, but the choice of flexible scheduling posed a great challenge in measuring delivered dialysis dose.

The present study therefore aimed to assess Kt/V$_{urea}$ variability and to identify the minimum number of sessions required for a reliable assessment of weekly dialysis efficiency—precise enough to be used clinically, but also feasible for home hemodialysis patients. Because the focus was not on the "ideal" kinetic formula, but on the entity of variation, we choose three simple and widely used calculations: the Lowrie formula (for its mathematical simplicity), the Daugirdas II formula (for its wide use), and the Casino EKR$_c$ (because it could be calculated "the easy way," by plotting data on the graph) [4,18,19]. These methods are all easily performed in a standard clinical setting.

Variation among sessions was measured both as standard deviation of Kt/V$_{urea}$ and as standard deviation of "average hourly Kt/V$_{urea}$," a parameter obtained by dividing Kt/V$_{urea}$ per session by the dialysis time. This parameter is an oversimplification, because it presupposes a constant Kt/V$_{urea}$ value over the hours of dialysis, which in turn presupposes a linear decrease in urea, instead of the well-known exponential one. However, within the time range chosen (2 – 3 hours), at relatively low Qb (250 – 350 mL/min), with standard Qd (500 mL/

min), standard dialyzer surface (1.6 – 1.8 m^2), and low weight loss per hour (0.8 – 1.2 kg), average hourly Kt/V$_{urea}$ reduced the effect of variability owing to the flexible treatment time (Table II). To assess weekly efficiency, average hourly Kt/V$_{urea}$, calculated from the given number of sessions, may be multiplied by the hours of dialysis performed in the week.

On the basis of relative error analysis (Tables IV and V), the policy of averaging data from 3 sessions per week is proposed, as this approach keeps the relative error below 10% for average hourly Kt/V. This level of relative error was chosen as a reasonable goal, taking into account the baseline variability of laboratory assessment of urea [17]. Even if, from the theoretic point of view, the Daugirdas II formula should reduce the variability because it takes into account time of treatment and weight loss, this effect was not observed in our study. Further research is needed to identify the main sources of variability in short daily hemodialysis. Because variability was less dependent on the kinetic formula chosen, the policy of averaging ≥ 3 dialysis sessions may apply to various urea kinetic formulas.

Conclusions

Daily hemodialysis with a flexible schedule was implemented with the goal of increasing compliance and the efficiency of dialysis; however, frequent modification of dialysis time posed a tremendous challenge for efficiency assessment.

This study—begun out of the need to reconcile patient freedom with accurate measurement and control of treatment efficiency—assessed variability of delivered dialysis dose per session and established the minimum number of sessions needed to calculate weekly dialysis efficiency (weekly Kt/V$_{urea}$ or EKR$_c$). The policy of averaging data from 3 hemodialysis sessions is an empirical compromise between reasonable relative error (< 10%) and practical feasibility for home dialysis patients.

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