
Quantitating Dialysis in the Home Hemodialysis Patient: A Simple and Practical Approach

Nancy J. Coulis,¹ Barbara A. Gray,¹ Carl S. Saiphoo,² Sheldon W. Tobe,² M. Arif Manuel²

Dialysis Nurses¹; Division of Nephrology,² Sunnybrook Health Science Centre, University of Toronto, Toronto, Canada

Home hemodialysis is the most cost-effective form of dialysis and is associated with the lowest mortality. Home hemodialysis patients are usually highly motivated, independent, and actively employed. Because of the minimal supervision they require and the fact that they are not in a controlled environment, it is easy to overlook the measurement of their dialysis adequacy. We studied 6 home hemodialysis patients and demonstrated that blood urea measured 30 min before the end of dialysis (Ct-30) is equivalent to that measured 30 min after the end of dialysis (Ct+30). The Kt/V results using Ct-30, Kt/V(Ct-30), were almost equivalent to Kt/V(Ct+30) ($p = 0.5$). The Kt/V Kt/V(Ct) using blood urea measured at the end of dialysis (Ct) significantly overestimated Kt/V(Ct-30) and Kt/V(Ct+30) ($p = 0.007$). The calculated percent reduction of urea (PRU) was about 5% less when using Ct-30 compared with Ct ($p = 0.001$).

Taking blood samples 30 min before the end of dialysis for urea kinetics is more convenient for the home dialysis patients, since no other technical aspects of dialysis need their attention. The samples can be delivered to the laboratory the following day, because the blood may be stored in heparinized tubes at 4°C without deterioration of urea and creatinine concentrations. The Kt/V(Ct-30) was almost equal to Kt/V(Ct+30), so there is no longer any concern for the errors introduced by urea rebound. The blood pump must be reduced to 80 mL/min for about 10 sec to eliminate the errors due to fistula and cardiopulmonary recirculation. A simple programmable calculator will facilitate the calculation of accurate results using the Daugirdas second-generation formula.

(Home Hemodial Int, Vol. 2, 34–37, 1998)

Key words

Urea kinetics, rebound, home hemodialysis, Kt/V

Introduction

Despite considerable advances in renal replacement therapy, accurate quantification and delivery of dialysis has remained an enigma for the nephrologist (1–4). Urea kinetic modeling

(UKM) uses urea as a marker for net protein catabolism and for assessing the adequacy of dialysis (5,6). Despite the well-documented value of UKM as a predictor of patient survival and as a measure of adequacy of dialysis (7), it is still underutilized because of its perceived complexity (8). Several simplified formulas and nomograms have been used to estimate Kt/V, but only a few of them have been accepted into clinical practice (9–13). Some do not correct for interdialytic urea generation, volume changes, and the double-pool effect (14). A recent analysis of these formulas showed that for the same set of blood urea nitrogen values, the calculated Kt/V can vary from 1 to 1.5 (15). Of particular concern is the widespread use of the urea reduction ratio, since the predicted Kt/V can range from 0.86 to 1.13 (tenth and ninetieth percentile) for a urea reduction ratio of 58% (16). Using direct dialysis quantification to calculate both dialyzer clearance and Kt/V is a more accurate technique, since the mass transfer represents the actual removal of solutes during the dialysis (17). Zehnder and Blumberg (18) reported that standard blood-side clearances using single-pool UKM tend to overestimate the urea removed by 28%–32% when compared with direct dialysis quantification.

There are a number of barriers to obtaining accurate Kt/V results. Some have been mentioned above, but others include incorrect blood sampling techniques, the rebound phenomenon, the effect of ultrafiltration, and, finally, laboratory errors.

When patients are treated in a home hemodialysis program, there are even greater barriers to accurate UKM. While these patients are usually highly motivated, they do need to be instructed to take blood samples correctly and ensure that the samples arrive in the laboratory the following day for measurement of urea concentrations. To obtain accurate results, the method must be simple enough and not add to the treatment burden they already endure.

We previously demonstrated that using blood taken at the beginning and 30 min before the end of dialysis for calculating Kt/V avoids many of the errors mentioned above, including the phenomenon of rebound, and will provide results equivalent to those obtained when using equilibrated blood urea (19). The rebound phenomenon is mainly the result of reequilibration of the intercompartmental imbalance created by retarded diffusion of urea from a poorly cleared second pool during dialysis (20). Redistribution of urea from different compartments is determined by variations in regional blood flows and transcellular urea mass transfer coefficients (21). Dialysis-induced protein hypercatabolism seems to play a

Correspondence to:

M. Arif Manuel, MD, Rm A-239, A-Wing, Sunnybrook Health Science Centre, 2075 Bayview Ave., Toronto, Ontario M4N 3M5 Canada.

minor role (20). Rebound is directly related to the efficiency of the dialysis procedure (22). An accurate estimate of Kt/V would require measurement of the blood urea level approximately 30–60 min after the end of dialysis to give a true equilibrium sample at which time postdialysis rebound is almost complete.

The aim of this study is to describe our method of performing UKM in a small group of home hemodialysis patients, without adding significantly to the technical aspects of dialysis these patients need to learn.

Materials and methods

Six patients, who have been on home hemodialysis for at least 6 months, were asked to participate in the study. Two of our home dialysis training nurses visited the patients at home and took four blood samples in heparinized tubes during each of the three dialysis sessions (C0, C-30, Ct, and C+30) over a period of one week so that we obtained three sets of data per patient. The fourth study was done by the patients, without supervision, during one dialysis, but the Ct and C+30 samples were omitted. The samples were stored in the refrigerator and delivered to the dialysis unit the following day. In order to determine whether there was deterioration in the samples, blood was taken from 12 patients treated in our in-center program. These samples were assayed for urea and creatinine immediately and 24 hours later after storage at 4°C.

The second-generation formula of Daugirdas was used to calculate Kt/V.

Statistical methods

Statistical analysis was done with Minitab statistical software (Minitab Inc., release 11, U.S.A.). The data are expressed as mean and standard deviation. Student's paired *t*-tests were used to determine the difference between means, and alpha was set at 0.05. Linear regression was used to determine the relation between data sets.

Results

All 6 patients completed four sets of studies. Table I shows the blood urea and kinetic parameter results. The urea concentration 30 min before the end of dialysis (Ct-30) was not significantly different from the urea concentration 30 min after dialysis (Ct±30) (9.4±2.6 vs 9.5±2.5, mean±SD, *p* = 0.94); however, the urea concentration at the end of dialysis (Ct) was lower, but did not quite reach significance (9.4±2.6 vs 8.2±2.4, *p* = 0.13). The calculated Kt/V urea using the predialysis and Ct-30 (Kt/V(Ct-30)) was 1.19±0.15 compared with 1.16±0.13 for Ct+30 (Kt/V(Ct+30)) (*p* = 0.50). However, the Kt/V(Ct-30) was significantly different from Kt/V(Ct) (1.19±0.13 vs 1.34±0.16, *p* = 0.007). The PRU(Ct-30) was also significantly different from PRU(Ct) (63.5% vs 67.9%, *p* = 0.001).

Table II shows the mean±SD values for kinetic parameters at different sampling times. The results at Ct-30 and Ct+30 were not significantly different from each other, but did differ

significantly from those at Ct. Table III shows the mean difference in urea and creatinine concentrations measured immediately and after 24 hours. The mean difference in urea concentration was -0.125 (95% CI, 0.59–0.34, *p* = 0.58), and for creatinine the mean difference was -0.44 (95% CI, -10.2–9.3, *p* = 0.93).

Figure 1 shows the correlation between Ct-30 and Ct+30 ($r^2 = 0.971$, $y = -0.44 + 1.04x$), and Figure 2 shows the Bland-Altman plot of the mean difference in urea concentration at Ct-30 and Ct+30, which was -0.24 mmol/L. All the data points fell within 2 SDs with one exception.

Figure 3 shows an excellent correlation between Kt/V(Ct+30) and Kt/V(Ct-30) with an $r^2 = 0.864$, $y = 0.05 + 0.99x$. Figure 4 compares the Kt/Vpru(Ct) with Kt/Vpru(Ct-30) and shows that the Kt/V using blood urea taken at the end

TABLE I Statistical comparison of kinetic parameters

	Mean	SD	Mean	SD	<i>p</i> value
Ct-30 vs Ct+30	9.4	2.6	9.5	2.5	0.94
Ct-30 vs Ct	9.4	2.6	8.2	2.4	0.13
Kt/V(Ct-30) vs Kt/V(Ct) ^a	1.19	0.15	1.34	0.16	0.007
Kt/V(Ct-30) vs Kt/V(Ct+30) ^a	1.19	0.15	1.16	0.13	0.50
PRU(Ct-30) vs PRU(Ct)	63.5%	3.7	67.9%	3.5	0.001

^a Second-generation formula of Daugirdas.

Ct-30 = blood urea concentration 30 min before the end of dialysis (mmol/L); Ct = blood urea concentration at the end of dialysis (mmol/L); Kt/V(Ct-30) = Kt/V using urea 30 min before the end of dialysis; Kt/V(Ct) = Kt/V using urea at the end of dialysis; Kt/V(Ct+30) = Kt/V using urea 30 min after dialysis; PRU(Ct-30) = percent reduction of urea, using urea 30 min before the end of dialysis; PRU(Ct) = percent reduction of urea, using urea at the end of dialysis.

TABLE II Kinetic parameters at different blood sampling times (Mean±SD)

	Patient component ^a Ct-30 (4th study)	Nurses' component of the study		
		Ct-30	Ct	Ct+30
Urea (mmol/L)	10.1±3.0	9.4±2.6	8.2±2.4	9.5±2.5
Kt/V _{daug}	1.18±0.18	1.19±0.15	1.34±0.16	1.16±0.13
PRU	63.0±3.7%	63.5±3.7%	67.9±3.5%	62.6±3.1%
Kt/V _{pru}	1.32±1.7	1.34±0.15	1.5±0.14	1.31±0.12

^a Results were calculated on the Ct-30 samples. (Ct and Ct+30 samples were omitted by the patients.)

Ct-30 = blood taken 30 min before the end of dialysis (mmol/L); Ct = blood taken at the end of dialysis (mmol/L); Ct + 30 = blood taken 30 min after the end of dialysis (mmol/L); Kt/V_{daug} = Daugirdas second-generation formula; Kt/V_{pru} = according to Jindal *et al.* (9).

TABLE III Difference in urea and creatinine concentration after storage at 4°C.

	Mean Difference	SD	95% CI	<i>p</i> value ^a
Urea (mmol/L)	-0.125	±0.88	-0.59–0.34	0.58
Creatinine (mmol/L)	-0.44	±18.3	-10.2–9.3	0.93

^a Paired *t*-test.

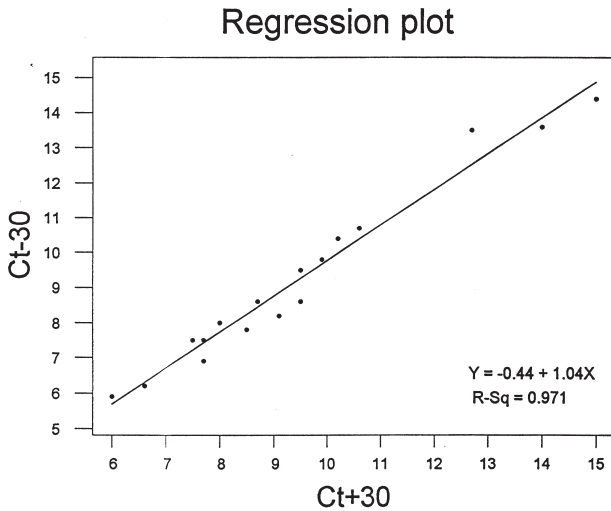


FIGURE 1 Correlation between blood urea concentration taken 30 min before the end of dialysis (Ct-30) and 30 min after the end of dialysis (Ct+30) in mmol/L; $y = -0.44 + 1.04x$, $r^2 = 0.97$.

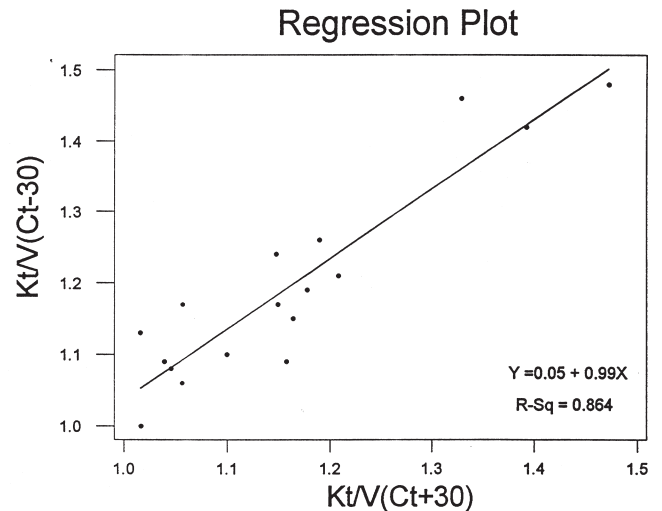


FIGURE 3 Kt/V values were calculated using the second-generation formula of Daugirdas and blood urea taken 30 min before the end of dialysis Kt/V(Ct-30) and 30 min after the end of dialysis Kt/V(Ct+30).

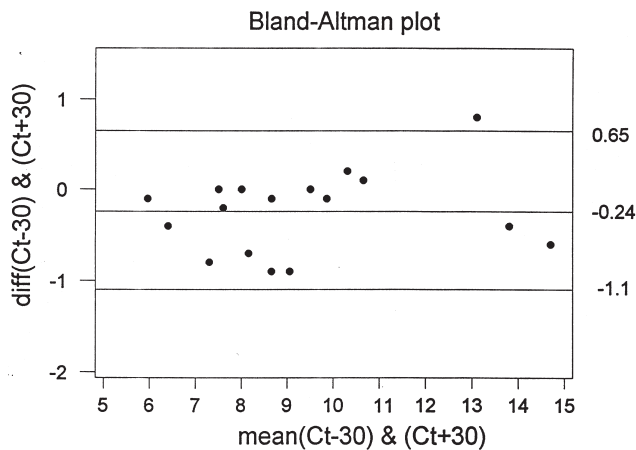


FIGURE 2 Bland-Altman plot showing the mean of blood urea concentration at 30 min before and 30 min after the end of dialysis compared with the differences between these values.

of dialysis consistently overestimates the Kt/V using blood urea taken 30 min before the end of dialysis by about 0.2 Kt/V units on average.

Discussion

We have demonstrated that accurate Kt/V results can be obtained in home hemodialysis patients by using blood samples taken before dialysis (C0) and 30 min before the end of dialysis (Ct-30) to perform the calculations. We and others (19,23) previously demonstrated that blood urea concentrations 30 min before the end of dialysis are almost equivalent to those taken 30 min after dialysis and that this is a convenient

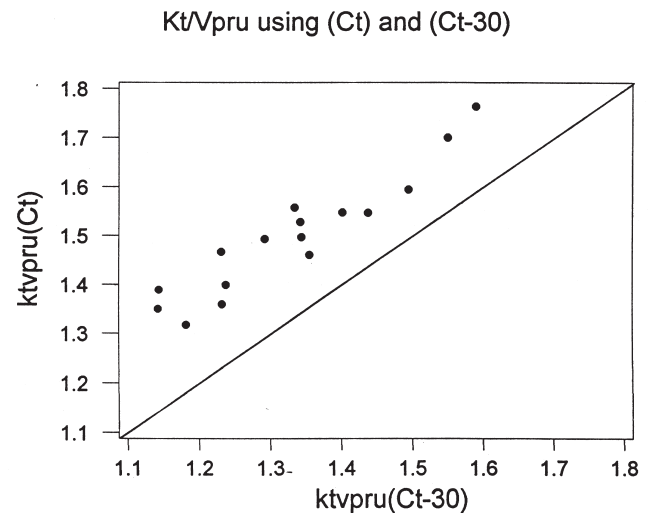


FIGURE 4 Comparison of the Kt/V using blood urea taken 30 min before the end of dialysis (Kt/Vpru(Ct-30)) and blood urea taken at the end of dialysis (Kt/Vpru(Ct)) using the method of Jindal *et al.* (9).

way of allowing for the errors introduced by the phenomenon of rebound. Since it is very difficult to convince patients to stay for an extra 30–60 min after dialysis when rebound is almost complete, this method can also be conveniently applied to in-center dialysis units. Regardless of the method used to calculate Kt/V, the results with Ct-30 will always be lower than those with Ct (postdialysis). For example, in Figure 4 the Kt/Vpru using blood urea at the end of dialysis consistently overestimates the Kt/Vpru using blood urea taken 30 min before the end of dialysis.

Although the double-pool correction of the Daugirdas second-generation formula gave results almost equal to the equilibrated Kt/V ($Kt/V(Ct+30)$), it is more convenient for the patient at home to take the samples before they discontinue dialysis, simply because there are more technical procedures at the end of dialysis that require their attention. As a group, home hemodialysis patients are highly independent and motivated and very interested in the quality of their treatment. They are more likely to accept changes in their dialysis when confronted with their results. Blood sampling techniques can be taught during their training, and the importance of urea kinetics can then be emphasized. Blood samples can be stored in the refrigerator for 24 hours without any deterioration of the urea and creatinine.

References

- 1 Bass OE, Nolph KD, Maher JF. Dialysance and clearance measurements during clinical dialysis—a plea for standardization. *J Lab Clin Med* 1975; 86:378–85.
- 2 Sargent JA. Shortfalls in the delivery of dialysis. *Am J Kidney Dis* 1990; 15:500–10.
- 3 Movilli E. Simplified approaches to calculate Kt/V. It's time for agreement. *Nephrol Dial Transplant* 1996; 11:24–7.
- 4 Gotch FA, Yarian S, Keen M. A kinetic survey of US hemodialysis prescriptions. *Am J Kidney Dis* 1990; 15:511–15.
- 5 Sargent JA. Control of dialysis by a single-pool urea model: The National Cooperative Dialysis Study. *Kidney Int* 1983; 23(Suppl 13):S19–25.
- 6 Gotch FA, Sargent JA. A mechanistic analysis of the National Cooperative Dialysis Study (NCDS). *Kidney Int* 1985; 28:526–34.
- 7 Collins AJ, Ma JZ, Umen A, Keshaviah P. Urea index and other predictors of hemodialysis patient survival [published Erratum *Am J Kidney Dis* 1994; 24:157]. *Am J Kidney Dis* 1994; 23:272–82.
- 8 Delmez JA, Windus DW. Hemodialysis prescription and delivery in a metropolitan community. The St. Louis Nephrology Study Group. *Kidney Int* 1992; 41:1023–8.
- 9 Jindal KK, Manuel A, Goldstein MB. Percent reduction in blood urea concentration during hemodialysis (PRU). A simple and accurate method to estimate Kt/V urea. *ASAIO Trans* 1987; 33:286–8.
- 10 Daugirdas JT. The post:pre-dialysis plasma urea nitrogen ratio to estimate Kt/V and NPCR: Mathematical modeling [see comments in *Int J Artif Organs* 1990; 13:388]. *Int J Artif Organs* 1989; 12:411–19.
- 11 Barth RH. Direct calculation of KT/V. A simplified approach to monitoring of hemodialysis. *Nephron* 1988; 50:191–5.
- 12 Keshaviah PR, Hanson GL, Berkseth RO, Collins AJ. A simplified approach to monitoring in vivo therapy prescription. *ASAIO Trans* 1988; 34:620–2.
- 13 Daugirdas JT, Depner TA. A nomogram approach to hemodialysis urea modeling. *Am J Kidney Dis* 1994; 23:33–40.
- 14 Alloatti S, Bosticardo GM, Torazza MC, *et al.* Scant reliability of Co/Ct ratio in urea kinetic formulas. *Int J Artif Organs* 1989; 12:642–7.
- 15 Bosticardo GM, Avalue U, Giacchino F, Alloatti S. Comparison of a modified urea kinetic model direct dialysis quantification and classic urea kinetic modeling. *ASAIO J* 1995; 41:M798–800.
- 16 Sherman RA, Cody RP, Rogers ME, Solanchick JC. Accuracy of the urea reduction ratio in predicting dialysis delivery. *Kidney Int* 1995; 47:319–21.
- 17 Malchesky PS, Ellis P, Nosse C, Magnusson M, Lankhorst B, Nakamoto S. Direct quantification of dialysis. *Dial Transplant* 1982; 11:42–9.
- 18 Zehnder C, Blumberg A. Influence of dialyser clearance measurement accuracy on haemodialysis prescription based on Kt/V. *Nephrol Dial Transplant* 1994; 9:753–7.
- 19 Bhaskaran S, Tobe S, Saiphoo C, Moldoveanu A, Raj DS, Manuel MA. Blood urea levels 30 min before the end of dialysis are equivalent to equilibrated blood urea. *ASAIO J* 1997; 43:M759–62.
- 20 Pedrini LA, Zereik S, Rasmy S. Causes, kinetics and clinical implications of post-hemodialysis urea rebound. *Kidney Int* 1988; 34:817–24.
- 21 Schneditz D, Van Stone JC, Daugirdas JT. A regional blood circulation alternative to in-series two compartment urea kinetic modeling. *ASAIO J* 1993; 39:M573–7.
- 22 Spiegel DM, Baker PL, Babcock S, Contiguglia R, Klein M. Hemodialysis urea rebound: The effect of increasing dialysis efficiency. *Am J Kidney Dis* 1995; 25:26–9.
- 23 Canaud B, Bosc JY, Leblanc M, *et al.* A simple and accurate method to determine equilibrated post-dialysis urea concentration. *Kidney Int* 1997; 51:2000–5.