Estimating phosphate removal in haemodialysis: an additional tool to quantify dialysis dose

Jean-Pierre Gutzwiller1,2, Daniel Schneditz3, Andreas R. Huber2, Christian Schindler4, Felix Gutzwiller5 and Carlos E. Zehnder6

1Division of Nephrology, Kantonsspital Liestal, University of Basle, Switzerland, 2Central Laboratory and Division of Nephrology, Kantonsspital Aarau, Switzerland, 3Institute of Physiology, University of Graz, Austria, 4Institute for Social and Preventive Medicine, University of Basle, Switzerland, 5Institute for Social- and Preventive Medicine, University of Zürich, Switzerland and 6Clinica Las Condes, Santiago, Chile

Abstract
Background. Half of the dialysis population suffers from hyperphosphataemia, which is now recognized as a major factor of haemodialysis (HD) morbidity and mortality. Current control is focussed on reducing dietary phosphate intake and diminishing absorption using phosphate binders, whereas control and quantification of phosphate removal by HD is undervalued. The aim of this prospective study was to develop a simple, bedside formula to estimate dialytic phosphate removal in stable HD patients.

Methods. This was a prospective, randomized trial. Phosphate and urea elimination were assessed in a representative group of patients at two dialysis centres using randomly different dialysers (1.3–2.4 m²). Quantification was performed by partial dialysate collection, concentration measurements in blood and effluent dialysate spot samples, and $K_t/V_{urea}$ during standard high-flux HD. Multiple linear regression analyses were used in 77% of all data sets to generate an equation to predict phosphate removal. The formula was validated in the remaining 23% of data sets, in the same group of patients using a large capillary filter, and in diabetic patients treated with a small dialyser at different blood flows (200, 250, and 300 ml/min).

Results. A formula allowing quantification of phosphate removal within one HD session was developed in 18 of 74 patients during 41 treatments (137 out of 177 data sets) and was determined as:

$$M_{PO4pred} = 0.1t - 17 + 50c_{ds60} + 11c_{bs60},$$

where $t$ is treatment time in min, $c_{ds60}$ and $c_{bs60}$ are phosphate concentrations in dialysate and plasma measured 60 min into HD in mmol/l, and $M_{PO4pred}$ is estimated phosphate removed in mmol. The precision was remarkable ($r^2 = 0.92–0.94$). The comparison of phosphate and $K_t/V_{urea}$ showed a significant association ($r^2 = 0.28$), albeit with remarkable scatter.

Conclusions. We present the first approach to quantify phosphate removal during high-flux HD by a bedside formula. Only 28% of the variation in phosphate removal was explained by $K_t/V_{urea}$. It appears that other factors not adequately accounted for by $K_t/V_{urea}$ affect phosphate removal. Therefore, we propose an individual control and quantification of phosphate removal in HD.

Keywords: dialysis dose; haemodialysis; hyperphosphataemia; phosphate kinetics

Introduction
Patient morbidity and mortality remains an important issue in haemodialysis (HD). Expected life span is 7–10 years for patients starting HD at the age of 40–44 years, and 4–5 years for those starting dialysis at 60–64 years of age [1]. One of the major mortality risk factors newly emphasized is hyperphosphataemia, which continues to affect about half of the dialysis population, putting patients at significant risk of secondary hyperparathyroidism, vessel and soft tissue calcifications, and death [2,3]. Hyperphosphataemia has also been linked to haemodynamic disturbances such as hypertension, coronary calcifications [4], and left ventricular hypertrophy [5,6], which are discussed to contribute significantly to the high incidence of cardiac death in the dialysis population.

Strategies to control phosphate balance include restriction of phosphate intake determined by diet, reduction of intestinal absorption by phosphate binders, and removal of phosphate by HD. It is very
difficult to achieve dietary phosphate restriction in patients with appropriate protein intake. In addition, phosphate-binding agents are not taken regularly. The problem to control phosphate absorption in a clinical setting is given in the following example: phosphate intake with liberal western diet is approximately 25–40 mmol day (800–1200 mg day), with 60–86% absorption in the intestine [7]. Therefore, 15–35 mmol phosphate must be eliminated per day, equivalent to 35–82 mmol per thrice weekly HD. A 4-h high-flux HD removes approximately 30 mmol of phosphate per treatment [8]. Each mmol of phosphate in excess of that value requires four capsules (400 mg) of Ca\(^{2+}\)-acetate [9], which may require an average of 48 capsules per day. This may lead to serious Ca\(^{2+}\) overload. Surprisingly, control and quantification of phosphate removal by HD is underestimated [10]. However, enhanced phosphate removal by HD must not be dismissed and quantification of phosphate removed by dialysis is mandatory to analyse phosphate balance. Current approaches are cumbersome and the mechanistic structure of phosphate kinetic models is in debate.

Dialysis efficiency is widely assessed by urea kinetic modelling, however, the increase in dialysis efficiency pushed forward by urea kinetics was made without considering possible limitations of other solute transport characteristics within the body. It is likely that an increase in efficiency accompanied by a reduction of treatment time will lead to pitfalls regarding other substances such as phosphate.

Therefore, the aim of this study was to derive a simple statistical model predicting phosphate removal based on a minimum of concentration measurements. The model should be valid for a variety of treatment modalities and a standard dialysis population.

Subjects and methods

This was a prospective, randomized study. It was divided in three parts: A, B, and C. Part A was designed to generate a phosphate model based upon data obtained in high-flux HD using three capillary dialysers with similar surfaces and standard treatment modes. The model was developed using stepwise multiple linear regression analysis considering phosphate removal as dependent variable and markers of potential clinical importance, such as plasma phosphate, effluent dialysate spot phosphate concentrations, Kt/V\(_{\text{urea}}\) and dialysis time, as predictor variables. Phosphate mass removal (M\(_{\text{PO4}}\)) was assessed by partial dialysate collection. Parallel determinations of urea kinetics and urea removal were performed for comparisons. Seventy-seven per cent of the data were used for the model generation. The remaining 23% were used to test the precision of the model.

In part B, the model generated in part A was further validated in a new data-set obtained in the same population using the same treatment mode except for a high-flux dialyser with a larger surface area.

In part C, the model was tested in diabetic patients from another dialysis unit to rule out a centre effect, using the usual dialysate of this centre, a capillary high-flux dialyser with smaller surface area, and different blood flows.

Patients

Patients enrolled in the first two study parts were selected from the HD unit of Aarau. This unit, with 12.000 dialyses a year, is one of the largest in Switzerland and covers about 7% of the Swiss population. Patients enrolled for study part C were selected from the HD unit in Liestal, covering another 5% of the Swiss population. All studied patients were at least one year on HD, stable, and well nourished. Absence of access recirculation was confirmed by monthly screening. Residual renal function was assumed as negligible. Patients gave written informed consent to participate in this study, which was in accordance with the Helsinki Declaration of 1975, as revised in 1983.

Study design

Part A. Eighteen patients were selected to obtain the data set for developing the phosphate model. Haemodialysis was performed thrice weekly following the standard procedures at the first dialysis unit with an effective blood flow rate corrected for pre-pump blood pressure of 300 ml/min and a dialysate flow of approximately 500 ml/min using two H4008 (Fresenius Medical Care (FMC), Bad Homburg, Germany) dialysis machines. Ultra-pure bicarbonate buffered dialysate with Na\(^{+}\) 140.0, HCO\(_{3}^{-}\) 40.0, Mg\(^{2+}\) 0.5 and Ca\(^{2+}\) 1.5 mmol/l was obtained by on-line filtration of mixed dialysate (Biasafe, FMC). Potassium concentration in the dialysate was between 1.0 and 2.0 mmol/l according to plasma potassium concentrations. Dialysate did not contain glucose. Ultrafiltration rates and treatment times were prescribed according to clinical need (4–5 h). Dialyser reuse was not practised.

Data were obtained from a randomized, crossover design using three different high-flux dialysers with similar characteristics. Dialyser I: polymethylmethacrylate 2.01 m\(^2\) (Arylane H9, Hospal, Meyzieu, France); II: polyethylene 2.00 m\(^2\) (AM-FP-1000, Asahi Medical Co, Choya-ku, Tokyo, Japan); III: polysulfone 1.80 m\(^2\) surface area (HF 80, Fresenius AG, Bad Homburg, Germany).

Phosphate and urea kinetic analyses were performed during the mid-week treatment (i.e. on a Wednesday or Thursday). Phosphate and urea removal were measured by partial dialysate and ultrafiltrate collection as described previously [11–15]. The collection system was calibrated before each study. The mean ratio \(f = V_d/V_u\) of total dialysate volume \(V_d\) to collected volume \(V_u\) was 24.9 ± 0.02 (mean ± SEM). The total amount of phosphate (M\(_{\text{PO4}}\)) and urea (M\(_{\text{urea}}\)) removed was determined by the sum of the solutes in dialysate and ultrafiltrate collected during the first, second, and subsequent treatment hours. In addition, a dialysate spot sample (eds, dialyser outlet) was taken 15, 60, 120, 180, and 240 min into the treatment and at the end of HD. Blood samples were drawn direct from the AV-fistula at the beginning and at the end of HD and from the arterial line in hourly intervals for the measurement of blood urea as well as plasma phosphate. Blood sampling at the end of HD was performed 5 min after the completion of treatment following the recommendations of the NKF-DOQI Clinical Practice Guidelines for Haemodialysis adequacy [16].

Part B. In this part, the 18 patients were treated and evaluated with the same schedule as in part A, except for a polysulfone dialyser with 2.4 m\(^2\) surface area, Dialyser IV (HdF 100S, Fresenius AG, Bad Homburg, Germany).
Part C. Nine non-obese and stable diabetic patients gave written informed consent to be treated with the same schedule as in part A, except for a dialyser with 1.3 m² surface area (Dialyser V, F60, Fresenius AG, Bad Homburg, Germany), a dialysate bath with 5.5 mmol/1 glucose and 38 mmol/1 bicarbonate. They were randomly treated in a crossover design with blood flow rates of 200, 250, and 300 ml/min.

Biochemistry

Plasma was separated by centrifuge within 1 h after collection, and phosphate was analysed in plasma and dialysate using an autoanlyser (Dimension RXL, Dade-Behring, Marburg, Germany) according to a modification of Fiske of the classic phosphomolybdate method after precipitation with lithium dodecylphosphate. Urea was measured in heparin-plasma and dialysate according to the urease-glutamate dehydrogenase technique on the Dimension RxL. Coefficients of variation were less than 2.5%.

Calculations

Total dialysate plus ultrafiltrate volume (Vd, in l) was calculated from the volume (Vc) obtained from partial dialysate collections and from the calibration factor (f) determined at the beginning of each study. Ultrafiltrate volume was calculated from patient’s weight reductions during dialysis; mass of urea and phosphate removed (Murea, MPo4) was calculated from the mean solute concentration in the collected dialysate and from Vd.

Single pool Kt/Vurea was calculated using the second-generation formula of Daugirdas [17].

Data collected in this way were used for developing an equation by statistical modelling. Since phosphate mass removal was estimated at 2, 3, and 4 h, each 4-h treatment gave three data sets. Dialysis sessions lasting 5 h gave an additional data set.

Model

Stepwise multiple linear regression was performed using independent treatment variables such as plasma and effluent dialysate phosphate concentrations to predict the amount of phosphate removed. The r² was aimed to be about 0.9 in order to guarantee individual prediction.

Statistics

Data are presented as mean ± SD in tables and mean ± SEM in figures, respectively. A probability (P) less than 0.05 was considered as significant. Comparison of treatment efficiency in three treatments using different dialysers (I, II, and III) was done by ANOVA for repeated measurements. Binary variables between groups (gender, diabetes) were compared by χ²-test. Comparison of predicted to measured phosphate removal was performed according to the method described by Bland and Altman [18]. Analysis was done using Stata v. 6.0 software (Stata Corporation, College Station, Texas, USA).

Results

Eighteen subjects of the population on HD of Aarau (74 patients) participated in study part A and were treated with dialysers I, II, and III, yielding 54 treatments. One treatment was excluded because the vascular access clotted, therefore, 53 treatments were available for the final analysis. In part B, the 18 treatments were evaluated. Nine patients were studied in part C, each with the same filter V at three different blood flows, yielding 27 treatments. One patient missed one study because of acute pancreatitis, three measurements were discontinued because of technical problems and an error in the dialysate bath composition, leaving 23 treatments for final analysis.

Part A—model generation

Physical and treatment characteristics of the study group were representative of the remaining dialysis population (Table 1). There was no difference between groups except for a lower frequency for diabetes (28.5% vs 46.6%) and a lower pre-dialysis phosphate concentration (1.44 vs 1.68 mmol/l, P < 0.01) in the study group.

Treatment characteristics as well as urea (Murea) and phosphate mass removal (MPo4) for dialysers I, II, and III were not different (Table 2, Figures 1 and 2).

During HD, both urea and phosphate decreased in blood/plasma and in the collected dialysate, however, with different time courses. While urea concentration and urea removal kept decreasing with time by an exponential relationship (Figure 1), phosphate concentration rapidly dropped during the first two hours of treatment, but remained stable thereafter (Figure 2).

Table 1. Characteristics of the study population and the remaining HD population (mean ± SD). (Centre A)

<table>
<thead>
<tr>
<th></th>
<th>Study population (n = 18)</th>
<th>Remaining population (n = 56)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female (%)</td>
<td>50</td>
<td>55</td>
<td>0.69</td>
</tr>
<tr>
<td>Diabetics (%)</td>
<td>22</td>
<td>47</td>
<td>0.07</td>
</tr>
<tr>
<td>Age (years)</td>
<td>61.9 ± 13.5</td>
<td>66.0 ± 13.6</td>
<td>0.27</td>
</tr>
<tr>
<td>Pre-dialysis weight (kg)</td>
<td>73.7 ± 16.3</td>
<td>70.0 ± 16.9</td>
<td>0.42</td>
</tr>
<tr>
<td>Ultrafiltration (l)</td>
<td>2.0 ± 0.8</td>
<td>2.2 ± 0.7</td>
<td>0.36</td>
</tr>
<tr>
<td>Haemoglobin (g/l)</td>
<td>120.5 ± 8.1</td>
<td>116.3 ± 10.8</td>
<td>0.14</td>
</tr>
<tr>
<td>Pre-dialysis K⁺ (mmol/l)</td>
<td>4.7 ± 0.4</td>
<td>4.8 ± 0.4</td>
<td>0.21</td>
</tr>
<tr>
<td>Pre-dialysis PO₄³⁻ (mmol/l)</td>
<td>1.44 ± 0.31</td>
<td>1.68 ± 0.35</td>
<td>0.01</td>
</tr>
<tr>
<td>Albumin (g/l)</td>
<td>36.2 ± 3.2</td>
<td>36.6 ± 3.4</td>
<td>0.65</td>
</tr>
<tr>
<td>Kt/Vurea (Daugirdas)</td>
<td>1.65 ± 0.24</td>
<td>1.66 ± 0.35</td>
<td>0.93</td>
</tr>
</tbody>
</table>
of 18±2, 17±2, and 19±4% during the third, fourth, and fifth hour, respectively, maintaining constant blood concentrations (Figure 2). Phosphate elimination improved from 29.8±0.4 to 36.4±0.5 mmol (P<0.0001) by increasing dialysis time from 4 to 5 h.

Phosphate removal improved with increasing Kt/V urea, but the relationship was unsatisfactory (r² = 0.28, P<0.0001) (Figure 3). Treatment characteristics for dialysers I, II, or III were not different (Table 2).

Table 2. Treatment characteristics of patients dialysed with filter I, II, and III. (Centre A)

<table>
<thead>
<tr>
<th></th>
<th>Filter I (n = 17)</th>
<th>Filter II (n = 18)</th>
<th>Filter III (n = 18)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-dialysis weight (kg)</td>
<td>72.9±3.9</td>
<td>73.8±4.0</td>
<td>73.0±3.8</td>
<td>0.27</td>
</tr>
<tr>
<td>Dialysate flow (Qd) (ml/min)</td>
<td>519.0±7.4</td>
<td>514.9±3.7</td>
<td>511.0±4.7</td>
<td>0.42</td>
</tr>
<tr>
<td>Ultrafiltrate volume (l)</td>
<td>1.9±0.2</td>
<td>2.1±0.2</td>
<td>2.0±0.2</td>
<td>0.52</td>
</tr>
<tr>
<td>Initial blood urea (mmol/l)</td>
<td>18.2±1.3</td>
<td>18.4±1.6</td>
<td>17.3±1.1</td>
<td>0.42</td>
</tr>
<tr>
<td>Initial plasma phosphate (mmol/l)</td>
<td>1.38±0.12</td>
<td>1.46±0.13</td>
<td>1.25±0.08</td>
<td>0.17</td>
</tr>
<tr>
<td>Phosphate clearance (ml/min)</td>
<td>169.2±6.6</td>
<td>155.0±4.5</td>
<td>167.9±4.2</td>
<td>0.10</td>
</tr>
</tbody>
</table>

Fig. 1. Blood and dialysate urea concentrations in study part A for 5 h dialysis treatments (6 subjects, 18 HDs, 3 treatments, error bars indicate standard error). The dotted line represents the exponential prediction model based on urea measurements. Dialyser I is represented by filled circles, dialyser II by white squares, and dialyser III by filled squares.

Fig. 2. Plasma and dialysate phosphate concentrations in study part A for 5 h dialysis treatments (6 subjects, 18 HDs, 3 treatments). Dialyser I is represented by filled circles, dialyser II by white squares, and dialyser III filled squares.

Fig. 3. Relationship between dose of delivered dialysis (Kt/V urea) and total mass of phosphate removed per dialysis (MPO4/dialysis) (study part A and B, 18 subjects, 71 treatments, 237 measurements). MPO4/dialysis = 12.52 × Kt/V urea + 7.39, r² = 0.28, P<0.0001. The 95% confidence area is defined by the solid lines.

Model generation. After stepwise regression, the best model to describe the removal of phosphate as a
function of treatment variables was found to be:

\[ M_{\text{PO4}} = 0.1t - 17 + 50c_{\text{ds60}} + 11c_{\text{b60}} \]  

(1)

where \( M_{\text{PO4}} \) is the predicted amount of phosphate removed per dialysis given in mmol/dialysis, time is given in min, \( c_{\text{ds60}} \) and \( c_{\text{b60}} \) are phosphate concentrations in effluent dialysate and plasma measured 60 min into dialysis in mmol/l, respectively.

The result of the regression leading to equation (1) is summarized in Table 3. Equation (1) was obtained in approximately 77% (137 out of 177 data sets) of the data sets and was used to predict the phosphate removal in the remaining 23% (40 out of 177 data sets). The predicted values using equation (1) compared to the values measured in the 23% of the data gave a Pearson correlation coefficient of 0.97. Bland–Altman analysis showed a small albeit systematic underestimation of 2 mmol dialysis, which was independent of the amount of phosphate removed (data not shown). The slope of the linear regression was close to unity \((M_{\text{PO4,pred}} = 0.92 \times M_{\text{PO4,meas}} + 0.01, r^2 = 0.94)\).

Part B

To validate equation (1) developed in the first part of the study, 18 treatments were repeated using dialyser IV. Comparison of predicted to the measured phosphate mass removal yielded a Pearson correlation coefficient of 0.97. The slope of the linear regression \((M_{\text{PO4,pred}} = 0.91 \times M_{\text{PO4,meas}} + 0.83, r^2 = 0.93)\) was close to unity. Bland–Altman analysis revealed a small albeit systematic underestimation of one mmol/dialysis, which was independent of the amount of phosphate removed (Figure 4).

Part C

Equation (1) was further evaluated in high-flux HD with variable blood flows in diabetic patients. Plasma phosphate was higher in this group (Table 4). Comparison of the predicted to the measured phosphate mass removal yielded a Pearson correlation coefficient of 0.94. The slope of the linear regression \((M_{\text{PO4,pred}} = 0.94 \times M_{\text{PO4,meas}} + 2.55, r^2 = 0.88)\) was close to unity. Bland–Altman analysis revealed a small albeit systematic overestimation of 1 mmol/dialysis, which was independent of the amount of phosphate removed.

Finally, a correlation of all 104 HD performed for all data sets showed an excellent correlation of 0.92 (Figure 5).
The purpose of this study was to present a simple formula to predict phosphate mass removal during high-flux HD as an additional and supplementary tool for individual dialysis prescription. The formula is based on treatment time and phosphate concentrations in plasma and effluent dialysate taken at 60 min of the HD session. The equation was developed from 77% of data collected in 53 standard dialysis treatments and successfully tested in the remaining 23%. Further, the precision of this formula was demonstrated using a more efficient dialyser. In spite of this change, the formula was capable to accurately predict phosphate removal. The systematic underestimation of 1 mmol formula was capable to accurately predict phosphate removal: a more efficient dialyser. In spite of this change, the formula was capable to accurately predict phosphate removal. The continuous decrease of urea elimination during the last hour of a five hour HD treatment compared to only 10% of total urea mass removal. The continuous decrease of urea elimination with time (Figure 1) is often used to dismiss an ineffective extension of dialysis duration. This argumentation cannot be applied to phosphate elimination (Figure 2). Phosphate removal data indicate that long dialysis sessions significantly contribute to enhanced phosphate elimination (36.4±0.5 mmol/5 h vs 29.8±0.4 mmol/4 h, P<0.0001). The importance of the factor time is documented by time as a linear variable in equation (1). This phenomenon can be explained by the fact that phosphate is mainly distributed in the intracellular space with a slow intra- to extracellular solute transfer rate. Increasing the time of the dialysis session is the best way to raise overall phosphate removal. The clinical importance of treatment time is documented in two recent studies where normal phosphate concentrations could be achieved without phosphate binders using nightly long-term HD [22,23].

High plasma phosphate concentration is a predictor of poor survival on dialysis and in this context, it is believed that hyperphosphataemia is a marker for under-dialysis [24].

Conventional dialysis utilizing high-flux dialysers removes close to 30 mmol phosphate during a 4 h treatment [25]. In order to reduce hyperphosphataemia, with the knowledge that patients' compliance to reduced phosphate diet prescriptions and phosphate binders intake is unsatisfactory, as outlined in the introduction, enhanced removal is required by HD. The current formula offers a practical approach to estimate the dialysis time to obtain a target phosphate removal:

\[ t = 10 \times (M_{\text{PO4}} - 50c_{d60} - 11c_{b60} + 17) \]  

(2)

Instead of employing cumbersome dialysate collection, the total amount of phosphate removed can be estimated from two samples and treatment time. Most importantly, samples are taken early in dialysis, soon enough to predict removal as a function of treatment time and to allow for the adjustment of dialysis prescription. The inclusion of phosphate concentration

Discussion

The purpose of this study was to present a simple formula to predict phosphate mass removal during high-flux HD as an additional and supplementary tool for individual dialysis prescription. The formula is based on treatment time and phosphate concentrations in plasma and effluent dialysate taken at 60 min of the HD session. The equation was developed from 77% of data collected in 53 standard dialysis treatments and successfully tested in the remaining 23%. Further, the precision of this formula was demonstrated using a more efficient dialyser. In spite of this change, the formula was capable to accurately predict phosphate removal. The systematic underestimation of 1 mmol formula was capable to accurately predict phosphate removal: a more efficient dialyser. In spite of this change, the formula was capable to accurately predict phosphate removal.
Phosphate removal in haemodialysis

in plasma and dialysate measured at the same time is an indirect measure of dialyser clearance. The plasma value at 60 min ($c_{p60}$) is a good measure of apparent mean phosphate concentration during the entire treatment, as calculated from the area under the curve and treatment time ($AUC/t$). The slope of the linear regression between $c_{p60}$ and $AUC/t$ was close to unity ($c_{p60} = 1.17 \times AUC/t - 0.12$) (data not shown).

A further advantage of this approach is given by the relative independence of dialyser clearance from the specifications given by the manufacturer. As such, the clearance determined by the 60-min concentrations reflects an effective value. This is also evident from results obtained in part B of the study, where a dialyser with increased phosphate clearance was used and precise estimates of phosphate elimination were obtained using equation (1). Intradialytic sampling is not common, but it eliminates the problems associated with post-dialysis rebound. Proper post-dialytic sampling is of special importance when dialysis is quantified by urea kinetic analysis [26].

Recently, two studies demonstrated that hyperphosphataemia is a strong predictor of mortality, independently of $Kt/V_{urea}$ [22,23].

$Kt/V_{urea}$ represents a fractional clearance and a dose normalized to initial conditions. It can be used to measure and to prescribe the dose of dialysis. A comparable concept is not available for phosphate kinetics since the exact amount of phosphate to be removed during dialysis is not known from a simple concentration measurement. This question remains to be studied in future. However, the first step into this direction is based on a manageable quantification of phosphate removal. To our knowledge this is the first approach to quantify dialysis dose using phosphate kinetics with a simple bedside formula. The formula developed in this paper explains 88–94% of the variation in phosphate removal in a representative dialysis population treated with high-flux dialysers, dialysate flow of 500 ml/min, and blood flow of 200, 250, and 300 ml/min and is valid for initial plasma phosphate levels between 0.56–2.31 mmol/l. In contrast, the predictive value of $Kt/V_{urea}$ on phosphate removal was poor. Target values for phosphate removal remain to be identified in future prospective trials.

In conclusion, we call for an individual control and quantification of phosphate removal in dialysis treatment.

Acknowledgements. We wish to thank all the staff of the dialysis units in Aarau and Liestal for their expert technical assistance. We also want to express our special thanks to Karen Noerby and the team of the Central Laboratory, Kantonsspital Aarau. Finally, we are in debt to Professor Werner Zimmerli for useful comments on the manuscript. Part of this study was supported by the Fond für Wissenschaft und Forschung, Kantonsspital Aarau, Switzerland.

References


Received for publication: 4.9.01
Accepted in revised form: 22.1.02