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Behaviour of phosphate removal with different dialysis schedules

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Phosphate metabolism in chronic renal failure

Even though hypophosphataemia has been reported occasionally in chronic renal failure patients on dialysis treatment [1,2], phosphate (Pi) retention, often associated with increased serum Pi, is the most common finding in this clinical setting. Pi retention is secondary to reduced or null renal excretion, and dialysis removal is often, but not always, insufficient as compared with a variably reduced intestinal absorption of Pi [3–5].

The main metabolic consequences of phosphate retention have been related to: (i) a possible direct [6] and indirect (mediated by calcium and calcitriol reduction) [7,8] stimulation of parathyroid hormone; (ii) a direct involvement in extraosseous calcifications [9]; and (iii) a detrimental effect on renal function [10], that can still be maintained at a significant level in continuous ambulatory peritoneal dialysis (CAPD) patients.

Before addressing the problem of Pi removal by dialysis treatment, it might be useful to recall some points on Pi body distribution. Of the more than 650 g of Pi contained in a medium-sized man, ~85% is contained in bone, 14% in the cells and only 1% or less is in the plasma. It is also important to bear in mind that the bulk of intracellular Pi is represented by organic phosphate (nucleoside phosphate compounds, phosphorylated enzymes, 2,3-diphosphoglycerate, phosphocreatine, etc.) at 10–100 times the concentration of inorganic phosphate with which it is in equilibrium. The inorganic intracellular phosphate is in turn in equilibrium with the extracellular Pi, with an intracellular/extracellular ratio of ~0.6 [11]. As a consequence, any variation in plasma Pi concentration can affect both intracellular inorganic and organic phosphate content.

Phosphate removal in CAPD

Phosphate retention is also a major problem in CAPD patients. In fact, the obligatory protein losses via peritoneal fluid makes a reduction of phosphate dietary intake impractical, the protein content of the diet being strictly linked to that of phosphate.

Weekly phosphate removal in CAPD has been reported to be ~70 mmol, with 4×2 l exchanges per day [12]. This value is quite similar to that found in 35 of our CAPD patients (65.5 ± 40.6 mmol/week), and is ~20 mmol per week less than in haemodialysis (HD) (84.3 ± 19.1 mmol/week). However, in our CAPD patients, urinary excretion (48.8 ± 21.4) substantially contributes to Pi balance, representing ~40% of the total Pi removed, while in most HD patients this route of Pi excretion is negligible. We found that urinary Pi excretion was linearly related to glomerular filtration rate (GFR) values, evaluated as the mean of creatinine and urea clearances in our CAPD patients (uPi mmol/day $= -1.11 + 1.39 \times$ GFR; $r = 0.91$, $P < 0.001$), stressing the importance of the preservation of residual renal function in maintaining a good metabolic balance in CAPD.

When we considered the factors affecting the dialytic removal of phosphate in our CAPD patients by means of a multiple regression analysis (Table 1), we found that plasma Pi concentration plays the main role. Another important factor is represented by the glucose concentration in the dialysate, and its influence on Pi removal was independent of ultrafiltration rate. Finally, Pi removal by peritoneal dialysis was greatly affected by dialysate volume, with a calculated removal of ~95 mmol/week at a dialysate volume of 12 l per

Table 1. Stepwise multiple regression analysis of daily Pi dialysis removal (mmol/day), taken as dependent variable, in 35 CAPD patients in relation to the following predictor independent variables: serum Pi concentration (mmol/l), glucose dialysate inlet concentration (%), dialysate inlet volume (l/day)

Predictor variable	Coefficient	Student's *t*	*P*-value
Serum Pi	2.94	3.02	0.0037
GluDi	3.49	2.68	0.0090
QDi	0.77	2.93	0.0047

Overall $F = 9.041$, $P < 0.0001$.

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day. These data are in agreement with the results of a study by Winchester and co-workers who reported a value of ~105 mmol/week, with 4 × 3 l exchanges [13].

Utilizing the data from the relationship between urinary Pi excretion and GFR values, together with the data from multiple regression analysis (Table 1), we can roughly predict that the dialysate inlet volume needed to obtain a null Pi balance and a serum Pi concentration of 1.5 mmol/l, in the case of a dietary Pi intake of ~1 g, an intestinal Pi absorption of 50% and a residual renal function of ~4 ml/min, will be 11.7 and 7.7 l/day respectively, with a dialysate glucose concentration of 1.36 and 2.25% respectively. However, in the case of a residual renal function near zero, all the other conditions being equal, the necessary dialysate inlet volume should be 17.7 and 13.5 l/day respectively, with a dialysate glucose concentration of 1.36 and 2.25% respectively.

In conclusion, a better Pi removal in CAPD can be achieved by increasing either the dialysate volume or the glucose concentration. However, when the residual function is almost completely reduced, a presumably zero balance of Pi could be obtained only at the expense of an extremely high (and not easily achievable) dialysate volume.

Kinetics and factors affecting removal of phosphate during extracorporeal dialysis treatment

The kinetics of Pi removal during extracorporeal dialytic treatment (ECDT) deserves further consideration. In fact, Pi behaviour during ECDT is characterized by at least two peculiar and as yet not completely defined aspects: (i) the reduction of plasma Pi during traditional ECDT follows a more complex kinetic behaviour than that observed with other molecules (e.g. urea, creatinine), secondary to different removal from intra- and extracellular pools; and (ii) a long-lasting post-dialysis rebound, again quite different from that of other substances, and not simply consistent with the post-dialysis redistribution phenomenon [14,15].

With regard to the first aspect, two decades ago, Cristinelli *et al.* [16] observed that plasma Pi declined during the first 2 h of acetate dialysis, according to a two-compartment model, characterized by a first presumably extracellular distribution volume of ~16.6 l and a second presumably intra-plus extracellular volume of ~46 l. The same authors noted that, in the last 2 h of dialysis, Pi concentration tended to increase. Although this trend towards a late intradialytic increase in Pi is not always observed in types of ECDT other than acetate dialysis, the multi-compartmental behaviour of Pi decay has been a constant finding [17,18].

The second peculiar aspect of Pi kinetics is represented by phosphate rebound. This phenomenon, extensively studied by Sugisaki *et al.* [19,20], is characterized by the following peculiarities: (i) it may sometimes begin to occur before the end of dialysis treatment; (ii) it seems to be related to a threshold Pi concentration, which once reached, sees plasma Pi begin to rebound; and (iii) it lasts until a concentration very close to the pre-treatment value is reached, and this takes ~6–10 h. This might imply that plasma Pi concentration is maintained around a threshold value which is much more dependent on the equilibration constants between the different body pools than on Pi input from the intestine.

This complex behaviour of Pi is based mainly on two peculiar conditions: (i) there are multiple Pi pools (bone, muscle, Pi deposits in soft tissues, red blood cells, etc.) which equilibrate with the central plasma pool by as yet incompletely defined equilibrium constants; and (ii) the generation rate of Pi in the intracellular pool(s) is quite variable and may change several fold (30–300 times) during ECDT [17,18].

Taking into account all these considerations, it is evident that however complex the model used to interpolate Pi behaviour during ECDT is, it will still remain an oversimplification of natural events. As a consequence, when addressing the problem of Pi handling by ECDT, it is more convenient to deal with the quantification of Pi removal.

We studied six patients on regular dialysis treatment, sequentially treated with two different types of ECDT: 4 h bicarbonate dialysis (BD; Q_B 300, Q_D 500 ml/min; cuprophane filter of 1.3 m^2) and 3.5 h haemodiafiltration (HDF; Q_B 300, Q_D 500 ml/min, Q_{SF} 42 ml/min with Na bicarbonate as buffer; PAN 1.7 m^2). During each of these ECDTS, in two midweek dialysis sessions, total (TR), extracellular (ECR) and intracellular removal of Pi (ICR) were measured and calculated at 45 min, 90 min and at the end of the dialysis session by collecting a dialysate sample volume corresponding to an exact ratio of the total dialysate volume (Quantispal). The accuracy of the system relies on the constancy of the ratio (±2%). Approximate evaluation of TR, ECR and ICR was performed according to the following calculations:

$$TR = QDo \times PiDo$$

$$ECR = VDPi \times \Delta sPi$$

$$ICR = TR - ECR$$

where QDo = total dialysate fluid spent at different collection times; PiDo = Pi concentration in the dialysate fluid, measured after a 5-fold concentration of the collected and acidified dialysis fluid; VDPi = distribution volume of Pi calculated as 20% of dry body weight; ΔsPi = change in Pi plasma Pi concentration during each collection period. Table 2 shows the results of this study, pooling the data of 24 dialysis treatments (BD + HDF). Three points are worthy of consideration: (i) the total amount of Pi removed in the first 90 min (first plus second period) exceeds the amount removed in the time left; (ii) the ECR in the first 45 min was apparently greater than the TR: this could be explained either by an influx of Pi into the intracellular space, probably secondary to changes in pH, or,

Table 2. Total (TR), extracellular (ECR) and intracellular Pi removal (ICR), at 45 min, 90 min and at the end of dialytic treatment

	0–45 min	45–90 min	90 min–end	Global
TR mmol	8.78±3.1	7.97±2.2	14.7±3.4	31.4±5.8
ECR mmol	11.4±6.3	3.24±2.0	2.15±1.99	16.8±5.1
ICR mmol	−2.6±4.1	4.72±2.2	12.5±3.68	14.62±4.0

The global removal is the sum of the three collection periods. The data were obtained by pooling the results of 24 dialytic treatments performed on six HD patients (mean±SD).

alternatively, by a possible overestimation of the effective VDPi which, during the first 45 min, might be lower than that estimated; (iii) the intracellular contribution to Pi removal is null (when not negative) during the first 45 min, then reaches the values of ECR during the second 45 min period, and finally constitutes the major, if not the only, source of Pi removal for the remaining time of dialysis. The total ICR accounts for about half of the total Pi removed by dialysis treatment.

When we considered the factors affecting Pi removal, pooling the data of all collection periods, we found that the removal rate of Pi was linearly dependent on plasma Pi concentration and, to a lesser extent, on dialyser clearance values, calculated as $(QDo \times CDo) \times 2/(Co+Ct)$ (Figure 1). No relationship was evident between Pi removal and ultrafiltration rate in the patients we studied. Jindal *et al.* found only a marginal effect of increasing ultrafiltration from 0 to 50 ml/min on Pi clearances [21], confirming that the predominant role in Pi removal during ECDT is played by diffusive processes.

In addition, in our study, we were not able to find any influence of serum Ca concentration, Ca dialytic balance, serum levels and intradialytic changes of pH and bicarbonate on Pi dialytic removal. On the other hand, Pi removal rate (PiRR) was directly related to the potassium removal rate (KRR): PiRR mmol/min $= 0.011 + 0.12 \times$ KRR mmol/min; $r = 0.697$, $P < 0.001$. This finding reinforces the suggestion that the intracellular contribution in Pi removal during ECDT has a primary role.

Impact of dialysis equipment and schedules on Pi removal in ECDT

As regards the impact of different kinds of membranes on Pi removal, no major difference has been reported. Kramer *et al.* reported in 1992 [22] substantially overlapping values of Pi clearance as regards polysulfone, polyamide and polyacrylonitrile, with the only exception being slightly lower values for AN69 polyacrylonitrile.

On the other hand, the increase in membrane surface has been demonstrated to significantly affect Pi clearance. In the study of Jindal *et al.* [21], a 30% increase in Pi clearance was evident by changing PAN and PS surface membranes respectively from 1.2 to 1.6 and from 1.3 to 1.9 m^2.

A further point to be considered is the impact of different kinds of dialysis treatment on Pi removal. Zucchelli *et al.* [23] did not find any difference in plasma Pi behaviour during acetate, bicarbonate dialysis and 'soft' (low reinfusion rate) haemodiafiltration; however, the rebound phenomenon was greater with acetate dialysis. In agreement with these findings, Bazzato *et al.* [24] found increased Pi content in red blood cells after acetate, but not after bicarbonate, dialysis, suggesting that acetate might increase the intracellular trapping of Pi with a greater post-dialysis rebound.

Attempting to quantify Pi removal in two different dialysis schedules, we assessed the difference in TR, ECR and ICR between BD and HDF in the six patients described above. Table 3 shows the results. A trend toward a higher TR of Pi in each collection period was evident, with total removal significantly

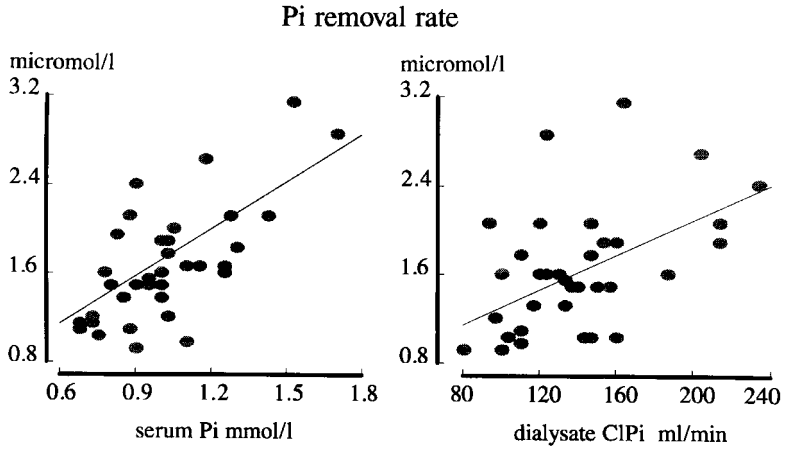

Fig. 1. Significant direct relationship between Pi removal rate and serum Pi levels (left): Pi RR μmol/l $= -0.014 + 0.17 \times$ sPi mmol/l, $r = 0.699$, $P < 0.001$). A weaker significant relationship was also found between Pi RR and dialyser Pi clearance (right): Pi RR μmol/l $= 0.047 + 0.0082 \times$ ClPi ml/min, $r = 0.501$, $P < 0.001$. The data have been obtained from all the collection periods of BD and HDF treatments in the six studied patients.

Table 3. Total (TR), extracellular (ECR) and intracellular Pi removal (ICR), at 45 min, 90 min and at the end of dialytic treatment in six patients studied on both bicarbonate dialysis (BD) and haemodiafiltration (HDF)

	0–45 min		45–90 min		90 min–end		Global	
	BD	HDF	BD	HDF	BD	HDF	BD	HDF
TR (mmol)	6.12±1.9	10.9±2.3	7.56±2.6	8.24±2.1	15.09±3.6	14.37±3.6	28.11±7.4	33.42±4.0
ECR (mmol)	5.88±0.44†	15.0±5.6	1.53±1.6**	4.34±1.4	0.72±2.1*	3.11±1.3	8.13±3.9*	22.45±4.4
ICR (mmol)	0.24±1.55	−4.5±4.2	6.0±1.5	3.86±2.3	14.37±2.5	11.25±4.0	19.98±1.2*	10.8±3.5

The global removal is the sum of the three collection periods. (mean±SD: *$P<0.05$; **$P<0.02$; †$P<0.01$).

greater in HDF. If we equate the excretion value in the last dialytic period for an equal duration of treatment, full Pi removal is ~25% greater in HDF than in BD. However, this greater Pi removal might be due simply to the different surface area of the membranes used in the two dialytic schedules, according to the data reported by Jindal *et al.* [21]. An unexplained finding was that in all the collection periods, the ECR in HDF was significantly greater than in BD, with a substantially greater global extracellular Pi extraction, reflected by greater change of serum Pi (Δ Pi: 1.25±0.22 in HDF, 0.85±0.20 in BD, $P<0.05$). The extrapolation of these values, on a weekly basis, gives values of ~85 mmol for BD and 100 mmol for HDF.

As regards Pi removal in haemofiltration, Winchester *et al.* [25] reported a weekly dialysis loss of ~80 mmol, very close to the BD removal values.

Again, assuming a Pi dietary intake of ~1 g/day, 50% intestinal Pi absorption and a null residual GFR function, in order to maintain a zero weekly Pi balance utilizing the operative parameters described above, we need to perform HDF treatment lasting at least 4 h three times a week (12 h in total) and a BD treatment lasting at least 5.5 h three times a week (total 16.5 h). However, on a more frequent dialysis treatment schedule, taking advantage of the greater removal rate of the first 2 h, we could utilize HDF treatment lasting 2 h five times a week (total 10 h) and BD treatment lasting 2 h 40 min five times a week (total 15.5 h).

In fact, owing to the extreme variability of dietary intake and intestinal absorption of phosphate, all these amounts of Pi removal might create a Pi balance ranging from highly positive to only slightly positive or even negative.

From all these data, the following conclusions can be drawn, regarding Pi removal in ECDT: (i) the peculiar kinetics of Pi in ECDT accounts for the fact that more than half the Pi removal takes place in the first 1.5 h, irrespective of the kind of dialysis schedule and mainly dependent on serum Pi concentration and the diffusive clearance of the dialyser; (ii) the intracellular compartment substantially concurs in the removal of Pi, especially in the late part of dialysis treatment, as indirectly demonstrated by a close correlation with potassium excretion; (iii) the surface but not the type of the membranes can influence Pi clearance and hence Pi removal; (iv) no substantial role for the buffer used has been demonstrated; and (v) the higher efficiency dialysis schedules might give some further advantage to Pi removal, but only if the time of the treatment is longer than 210 min.

Experimental attempts at dialysis manipulation to increase Pi removal

Considering that intracellular removal could be the rate-limiting factor in Pi removal during ECDT, all the studies aimed at increasing Pi removal by dialysis were based on the attempt to enhance Pi outflow from the intracellular space.

Haas *et al.* [26], submitting 13 patients to consecutive sessions of HF with either potassium-free or potassium-enriched (3.5 mmol/l) re-injection fluid, found a strikingly greater intracellular Pi removal during potassium-free HF. However, the total Pi removed was only slightly, and not significantly, greater. In the six patients we studied in both BD and HDF, we found that the intracellular K extraction was highly correlated to intracellular Pi extraction (Figure 2) (the intracellular K removal was calculated by the same method as Pi ICR). Of course, the manipulation of potassium concentration entails obvious clinical consequences, so

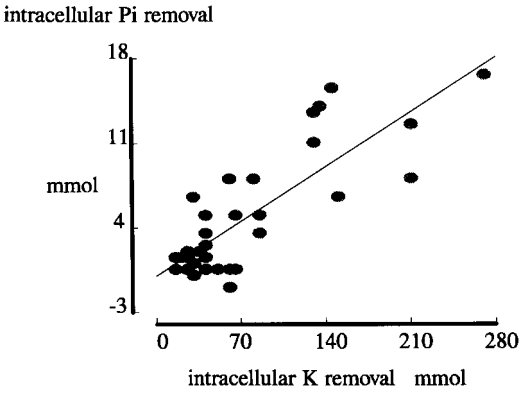

Fig. 2. Significant direct relationship between intracellular removal of Pi (Pi ICR) and K (K ICR): Pi ICR mmol = 0.14 + 0.069 × (K ICR mmol), $r=0.733$, $P<0.001$.

it cannot be considered as a handy way of enhancing Pi removal.

Another attempt to increase Pi extraction was suggested by Veech [27] and was put into effect by Fischbach *et al.* [28] who tried to increase Pi intracellular removal by modelling intradialytic plasma pH during biofiltration (BF), inducing a moderate acidosis in the first hour of treatment and then correcting pH in the final part of the dialysis. These authors studied three children by this method and found a substantially greater Pi removal when comparing the modelled BF with the standard BF. The higher Pi was almost completely accounted for by increased intracellular Pi removal. On the other hand, a recent study by Harris *et al.* [29] was not able to confirm these results in a group of nine adult patients submitted to a bicarbonate-modelled HD. However, in this latter study, the levels of pH and bicarbonate in the first part of the dialysis were well above the acidotic values and much higher than in Fischbach's study. A multi-centre study is now in progress to assess the validity of this approach for Pi removal.

On the other hand, it must be borne in mind that an excessive, or too rapid, removal from the intracellular pool might create some potentially adverse effects on cellular metabolism [11], with possible consequences on clinical status. Some of these potential adverse effects are summarized as follows: (i) reduction of 2,3-diphosphoglycerate in red blood cells, impairing O_2 delivery to tissues; (ii) reduction of nucleoside 3-phosphate in muscle and heart cells, with a potential reduction in their performance; and (iii) reduction of many glycolytic enzymes (PFK-1, G3PDH) which further impair ATP production in a large number of cells. The real impact of these events on dialytic symptoms is far from being known.

Conclusions

A satisfactory dialytic schedule as regards Pi removal will be accomplished only when at least the following issues are clearly defined: (i) the assessment of the total balance of phosphate in uraemic patients also taking into account the Pi intestinal absorption, in order to obtain a near zero balance; (ii) the evaluation of the long-term impact of different Pi removal on parathyroid secretion, bone metabolism and soft tissue calcifications; and (iii) the evaluation of the impact of different Pi removal on cellular function (namely heart and muscle cells and red blood cells).

So far, much of this is only a matter of speculation, so there is a long way to go before a definite and appropriate dialytic prescription for Pi removal can be given to uraemic patients.

References

1. Kaye M, Vasilevsky M, Barber E. Correction of hypophosphatemia in patients on hemodialysis using a calcium-free dialysate with added phosphate. *Clin Nephrol* 1991; 35: 130–133
2. Tejeda A, Saffarian N, Uday K, Dave M. Hypophosphatemia in end stage renal disease. *Nephron* 1996; 73: 674–678
3. Farrington K, Mohammed MN, Newman SP, Varghese Z, Moorhead JF. Comparison of radioisotope methods for the measurement of phosphate absorption in normal subjects and in patients with chronic renal failure. *Clin Sci* 1981; 60: 55–63
4. Ramirez JA, Emmett M, White MG *et al.* The absorption of dietary phosphorus and calcium in hemodialysis patients. *Kidney Int* 1986; 30: 753–759
5. Wiegmann TB, Kaye M. Malabsorption of calcium and phosphate in chronic renal failure: ^{32}P and ^{45}Ca studies in dialysis patients. *Clin Nephrol* 1990; 34: 35–41
6. Nielsen PK, Feldt-Rasmussen U, Olgaard K. A direct effect *in vitro* of phosphate on PTH release from bovine parathyroid tissue slices but not from dispersed parathyroid cells. *Nephrol Dial Transplant* 1996; 11: 1762–1768
7. Slatopolsky E, Calgar S, Pennel JP *et al.* On the pathogenesis of hyperparathyroidism in chronic renal insufficiency in the dog. *J Clin Invest* 1971; 50: 492–499
8. Portale AA, Booth BE, Halloran BP, Morris RCJ. Effect of dietary phosphorus on circulating concentrations of 1,25-dihydroxy vitamin D and immunoreactive parathyroid hormone in children with moderate renal insufficiency. *J Clin Invest* 1984; 73: 1580–1589
9. Rostand SG. Myocardial calcification and cardiac dysfunction in chronic renal failure. *Am J Med* 1988; 85: 651–657
10. Lau K. Phosphate excess and progressive renal failure: the precipitation–calcification hypothesis. *Kidney Int* 1989; 36: 918–937
11. Bevington A, Brough D, Baker FE, Hattersley J, Walls J. Metabolic acidosis is a potent stimulus for cellular inorganic phosphate generation in uraemia. *Clin Sci* 1995; 88: 405–412
12. Delmez J, Slatopolsky E, Martin K, Gearing B, Harter H. The effects of continuous ambulatory peritoneal dialysis (CAPD) on parathyroid hormone (PTH) and mineral metabolism. abstract *Kidney Int* 1981; 19: 145
13. Winchester JF, Quijada VE, Rotellar C. Phosphate control in peritoneal dialysis patients. In: La Greca G, Ronco C, Feriani M, Chiaramonte S, Conz P, eds. *Peritoneal Dialysis* Wichtig, Milan: 1991; 327–331
14. Man NK, Chauveau P, Kuno T, Poignet JL, Yanai M. Phosphate removal during hemodialysis, hemodiafiltration, and hemofiltration. A reappraisal *Trans Am Soc Artif Intern Org* 1991; 37: 463–465
15. Maasrani M, Jaffrin MY, Fischbach M, Boudailliez B. Urea, creatinine and phosphate kinetic modeling during dialysis: application to pediatric hemodialysis. *Int J Artif Org* 1995; 18: 122–129
16. Cristinelli L, Mioni G, Cecchettin M *et al.* Analisi multicompartimentale del pool dei fosfati nel soggetto uremico dializzato. *Minerva Nefrol* 1976; 23: 292–300
17. Pogglitsch H, Petek W, Ziak E *et al.* Phosphorus kinetics during haemodialysis and haemofiltration. *Proc EDTA-ERA* 1984; 21: 461–468
18. Hou SH, Zhao J, Ellman CF *et al.* Calcium and phosphorus fluxes during hemodialysis with low calcium dialysate. *Am J Kidney Dis* 1991; 18: 217–224
19. Sugisaki H, Onohara M, Kunitomo T. Dynamic behaviour of plasma phosphate in chronic dialysis patients. *Trans Am Soc Artif Intern Org* 1982; 28: 302–307
20. Sugisaki H, Onohara M, Kunitomo T. Phosphate in dialysis patients. *Trans Am Soc Artif Intern Org* 1983; 29: 38–43
21. Jindal KK, McDougall J, Woods B, Nowakowski L, Goldstein MB. A study of the basic principles determining the performance of several high-flux dialyzers. *Am J Kidney Dis* 1989; 14: 507–511
22. Kramer BK, Pickert A, Hohmann C *et al. In vivo* clearance and elimination of nine marker substances during hemofiltration with different membranes. *Int J Artif Org* 1992; 15: 407–412
23. Zucchelli P, Santoro A. Inorganic phosphate removal during different dialytic procedures. *In J Artif Org* 1987; 10: 173–178
24. Bazzato G, Coli U, Landini S *et al.* Removal of phosphate either by bicarbonate dialysis or biofiltration in uremics. *Kidney Int* 1988; 33 [Suppl]: 180–183

25. Winchester JF, Rotellar C, Goggins M, Robino D, Rakowski TA, Argy WP. Calcium and phosphate balance in dialysis patients. *Kidney Int* 1993; 43 [Suppl]: 175–178
26. Haas T, Hillion D, Dongradi G. Phosphate kinetics in dialysis patients. *Nephrol Dial Transplant* 1991; 2 [Suppl]: 108–113
27. Veech RL. The untoward effects of the anions of dialysis fluids. *Kidney Int* 1988; 34: 587–597
28. Fischbach M, Hamel G, Simeoni U, Geisert J. Phosphate dialytic removal: enhancement of phosphate cellular clearance by biofiltration (with acetate-free buffer dialysate). *Nephron* 1992; 62: 155–160
29. Harris DCH, Yuill E, Chester DW. Correcting acidosis in hemodialysis: effect on phosphate clearance and calcification risk. *J Am Soc Nephrol* 1995; 6: 1607–1612