

Potassium Removal during Conventional Hemodialysis and Predilution Online Hemodiafiltration at Two Dialysate Potassium Concentrations

Konstantinos S. Mavromatidis^{1*}, Irini M. Kalogiannidou¹, Emine S. Impis¹,
Pelagia A. Kriki²

¹Renal Unit “Dimokriton”, Komotini, Thrace, Greece

²Nephrology Clinic, “Democritus” University of Thrace, Alexandroupolis, Greece

Email: *mavromatidisk@gmail.com

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Abstract

The balance of potassium, which is normally regulated mainly by the amount ingested with food and the kidneys, in hemodialyzed patients also depends on the amount removed through the dialysis filter. Of course, both the increase in its levels in the blood (hyperkalemia) and its decrease (hypokalemia) are important. However, for most doctors, the greatest risk lies in the increase in its levels, although in hemodialyzed patients, hypokalemia is also a significant risk factor for death. In this prospective study, 10 patients (6M, 4F), aged 61 to 88 years old (median 75 years), who had been on dialysis for 6 to 567 months (mean $\pm$ SD = 148 ± 197), were included. The amount of potassium removed during dialysis was determined depending on the potassium of the dialysate (2.0 or 3.0 mmol/L), both in conventional hemodialysis (Groups A and B) and in predilution online hemodiafiltration (Groups C and D) and was found to be significantly higher in both cases at the lower potassium concentration of the dialysate (in conventional hemodialysis 61.7 ± 26.7 Vs 36.0 ± 17.3 , $p = 0.005$ and in online hemodiafiltration 66.9 ± 18.6 Vs 23.6 ± 17.0 , $p = 0.0005$). As can be seen, a numerically greater potassium removal was recorded in online hemodiafiltration. Regarding the glucose of the dialysate, even though everyone used a glucose dialysate, and a varying amount of glucose gain or loss was found in the patients, this did not appear to affect the levels of potassium removed with each dialysate potassium and each method. It is concluded that the dialysate potassium, both in conventional hemodialysis and in predilution online hemodiafiltration, significantly affects its removal amount (more in the latter) and the amount of glucose gain or lost during the

session (in dialysis with both methods used), does not affect the potassium removed through the filter.

Keywords

Dialysate Potassium, Dialysate Glucose, Conventional Hemodialysis, Predilution Online Hemodiafiltration, Potassium Removal

1. Introduction

Both hyperkalemia and hypokalemia can increase the risk of atrial fibrillation and other arrhythmias, manifestations that are very common in hemodialyzed patients, but also of sudden death. The frequency of atrial fibrillation, the most common arrhythmia in hemodialyzed patients, increases as renal function deteriorates. In fact, the highest rates are found in the latter, where paroxysmal episodes were found in 40% of cases [1]. A strong association of arrhythmias, and especially atrial fibrillation, with hemodialysis has been found, which suggests that the rapid removal of electrolytes and fluids during the session can cause cardiac instability [2].

Potassium balance in hemodialyzed patients is one of the most important problems that patients and nephrologists must regulate, so that no risks arise for the health of the former [3]. Patients with the proper potassium diet contribute significantly to this effort, but also nephrologists influence the amount of potassium removed during the dialysis session by regulating the potassium in the dialysate [4].

It is obvious that a lower dialysate potassium contributes to the elimination of a greater amount of potassium than a higher. However, a lower dialysate potassium poses risks, such as arrhythmia due to patient factors (such as a history of atrial fibrillation or ischemic heart disease), although some believe that there is no correlation with the presence of risk factors [5] [6]. Also, when nephrologists choose a low potassium concentration of dialysate, resulting in a very large potassium gradient between the patient's serum and the dialysate, which contributes to the abrupt reduction in the patient's postdialysis serum potassium, which is also arrhythmogenic [7]. A retrospective study found a dialysate potassium concentration of 3 mmol/L is independently associated with a significantly lower incidence of atrial fibrillation compared with a potassium dialysate concentration of 2 mmol/L [8].

A basic goal of dialysis is to remove potassium accumulated between sessions and maintain serum potassium levels within the normal range, although nephrologists are more concerned with high serum potassium values [9]. However, both lower and higher serum potassium concentrations have the potential to cause arrhythmias, while big potassium removal and its rate of removal, together with lower potassium dialysate, may increase the risk of hypokalemia, as well as arrhythmias. It could be considered to emphasize ways to avoid intradialytic and

post-session hypokalemia, instead of the current strategy, which emphasizes avoiding hyperkalemia between sessions. The optimal way to regulate potassium in these patients is not easy and there are no clear guidelines for this.

The existing data on potassium kinetics in hemodialysis and its methods are not sufficient, and it is not clear whether there are differences between conventional hemodialysis and predilution online hemodiafiltration (HDF). We therefore studied prospectively with two methods (conventional hemodialysis and predilution online HDF), the amount of potassium removed with two different dialysate potassium concentrations (2.0 and 3.0 mmol/L).

2. Patients-Methods

2.1. Patients

This prospective, interventional study was performed in Renal Unit “Dimokriton” (one center), Komotini, Greece, from January 2026 to August of 2026. The study examined the removal of potassium from the body during conventional hemodialysis and predilution online HDF using different potassium concentrations in the dialysate (2.0 or 3.0 mmol/L).

The study included patients who were at least 6 months in dialysis, who were on a program 3 times a week, of at least 4 hours/session. All patients were stabilized. Excluded from the study patients who were <18 years old, pregnant women, those with malnutrition, those with arrhythmias or a major cardiac event 3 months before the beginning of the study and those with active infections, heart failure and those who were hemodynamically unstable during dialysis session. Those with pre-session serum potassium < 4.0 mmol/L, with diabetes, and taking beta-blockers or T₄ were excluded from the study. All patients had the ability to provide blood from their vascular access of 400 ml/min (both from native arteriovenous anastomosis and from a permanent jugular vein hemodialysis catheter).

2.2. Methods

Each patient underwent one session of conventional hemodialysis with potassium dialysate of 2 mmol/L (Group A) and another one with 3 mmol/L (Group B). The same patients underwent one session of predilution online HDF using dialysate with potassium concentrations 2 mmol/L (Group C) and 3 mmol/L (Group D). All sessions were made on Wednesday or Thursday under the same situations (surface area of filters, duration of each session, blood pump supply, dialysate supply, substitution volume for predilution online HDF), and the distance between them was one week. All patients underwent dialysis sessions with Nikkiso DBB EXA machines.

The filters used were high flux polyethersulfone (Elisio 21H, Nipro) for predilution online HDF, with a surface area of 2.1 m², and Elisio 21L (low flux filter) for conventional hemodialysis with surface area also of 2.1 m². All patients were dialyzed with the same dialysate in terms of sodium (140 mmol/L), calcium (1.5 mmol/L), bicarbonates (33 mmol/L), glucose (5.6 mmol/L), acetate 3 mmol/L, and

magnesium (0.75 mmol/L [1.8 mg/dl]). All patients used vemicparin (2500 - 3500 IU/session) as an anticoagulant for dialysis needs. The blood pump (blood supply) was 400 ml/min, while the dialysate supply was 500 ml/min for all. The substitution volume for the predilution online HDF was the 50% of blood pump (*i.e.* 200 ml/min). The duration of each dialysis session was 4 hours.

Blood samples were taken from the arterial fistula (or from arterial catheter line) before the beginning of dialysis session and at the end of the session (2 minutes after reducing the blood pump to 50 ml/min), for analysis of serum urea, glucose and potassium.

The ultrafiltrate was collected in a specially made volumetric barrel, where its volume was determined. After the end of the session and after thoroughly stirring the ultrafiltrate with an electric stirrer for 10 minutes, a sample was taken to determine the urea, glucose (to evaluate the amount of glucose gain or lose each patient during each dialysis session) and potassium. The urea reduction ratio (URR) has been calculated by the following equation: $URR = (Urea_{Pre} - Urea_{Post}) / Urea_{Pre} \times 100$. The Daugirdas II formula [10] was used to evaluate the adequacy of hemodialysis (Kt/V). For the determination of potassium in the ultrafiltrate, a modified equation of Blumberg *et al.* was used: $[K_{Ultrafiltrate} (mmol) = V_{Ultrafiltrate} (ml) \times K_{Ultrafiltrate} (mmol) - V_{(Dialysate + Substitution volume)} (ml) \times K_{(Dialysate)} (mmol)]$ [11], *i.e.* from the amount of potassium was in the ultrafiltrate and subtracted during predilution online HDF: $[120 L + 48 L \text{ of dialysate}] \times 2 \text{ or } 3 = 336 \text{ or } 504 \text{ mmol/4-hour session}$ and for conventional hemodialysis: $120 L \text{ of ultrafiltrate} \times 2 \text{ or } 3 = 240 \text{ or } 360 \text{ mmol/4-hour session}$.

The Abbott Alinity C analyzer was used to determine the parameters studied. Serum urea and glucose were determined by an enzymatic method, while potassium by an ion-selective electrode.

2.3. Statistical Analysis

Data were analyzed using SPSS for Windows (edition 22.0, IBM SPSS Statistics. IBM Corp., Armonk, New York, USA). Quantitative data are presented as mean and standard deviation (mean $\pm$ SD). Comparison of quantitative data between groups was made using t-test for dependent and independent samples and with χ^2 -test. Statistically significant changes were considered with a significance level of $p < 0.05$.

2.4. Ethical Committee

This prospective study was conducted in accordance with the Declaration of Helsinki and the Ethical Guidelines for Medical and Health Research Involving Human Subjects and was approved by the Scientific Council of the General Hospital of Komotini, Greece (05/01/2026, registration number 3/2026). The patients included in the study agreed to sign their consent to participate, after being thoroughly informed about the protocol.

3. Results

Ten patients (6M, 4F), aged 61 to 88 years old (median 75 years), who had been

on dialysis for 6 to 567 months (mean $\pm$ SD = 148 ± 197 months), were included in this prospective study. The primary diseases of the patients were: Unknown 3, hypertensive nephrosclerosis 3, glomerulonephritis 2, polycystic kidney disease 1 and lithium toxicity 1. Residual renal function was present in 3 (with GFR 2.6, 2.8 and 3.2 ml/min respectively). For the needs of dialysis, 6 had an internal arterio-venous anastomosis and 4 had a permanent right jugular vein catheter.

In conventional hemodialysis, despite having Kt/V and URR that did not differ significantly ($p = \text{NS}$) during the sessions between groups A and B, patients presented a statistically significant difference in postdialysis serum potassium levels (3.4 ± 0.2 Vs 3.7 ± 0.2 , $p = 0.0003$), while the potassium removed during the sessions in group A was almost 2-fold, compared to that removed in group B (61.7 ± 26.7 Vs 36.0 ± 17.3 , $p = 0.005$). The only patient who had the lowest serum potassium level (4.1 mmol/L) before the beginning of the dialysis session among all patients had a postdialysis serum potassium level of 2.9 mmol/L (**Table 1**).

Table 1. Contains the Kt/V, the URR, the serum potassium levels pre and post conventional hemodialysis session, and the amount of glucose removed during the dialysis session (95% Confidence Interval for mean values of all the above parameters), as well as their statistical analysis (t-test and χ^2 test).

Groups	Kt/V	URR (%)	Serum potassium (pre session) (mmol/L)	Serum potassium (postdialysis) (mmol/L)	Amount of potassium removed (mmol)	Amount of glucose removed (mg)
Mean $\pm$ SD (Group A)	1.79 ± 0.37	77.9 ± 6.5	4.5 ± 0.7	3.4 ± 0.2	61.7 ± 26.7	4 gain glucose 6 lost glucose
Mean $\pm$ SD (Group B)	1.83 ± 0.37	78.4 ± 6.1	5.0 ± 0.6	3.7 ± 0.2	36.0 ± 17.3	4 gain glucose 6 lost glucose
p=	NS	NS	NS	0.0003	0.005	NS

In predilution online HDF, patients again despite having Kt/V and URR that did not differ significantly during the study ($p = \text{NS}$), in group C was again found statistically significantly lower postdialysis serum potassium levels after the session (3.4 ± 0.2 Vs 3.8 ± 0.2 , $p = 0.001$), while significantly greater (approximately 3-fold) was the amount of potassium removed in group C, compared to the amount removed in group D (66.9 ± 18.6 Vs 23.6 ± 17.0 , $p = 0.0005$) (**Table 2**).

Table 2. Contains the Kt/V, the URR, the serum potassium levels pre and postdialysis predilution online HDF session, and the amount of glucose removed during the dialysis session (95% Confidence Interval for mean values of all the above parameters), as well as their statistical analysis (t-test and χ^2 test).

Groups	Kt/V	URR (%)	Serum potassium (pre session) (mmol/L)	Serum potassium (postdialysis) (mmol/L)	Amount of potassium removed (mmol)	Amount of glucose removed (mg)
Mean $\pm$ SD (Group C)	1.79 ± 0.34	78.5 ± 5.6	5.3 ± 0.4	3.4 ± 0.2	66.9 ± 18.6	4 gain glucose 6 lost glucose
Mean $\pm$ SD (Group D)	1.79 ± 0.35	77.9 ± 6.2	5.1 ± 0.8	3.8 ± 0.2	23.6 ± 17.0	4 gain glucose 6 lost glucose
p=	NS	NS	NS	0.001	0.0005	NS

No difference was found in potassium removal with conventional hemodialysis, compared to predilution online HDF with dialysate potassium of 2 mmol/L (61.7 ± 26.7 Vs 66.9 ± 18.6 , $p = \text{NS}$), nor with predilution online HDF with dialysate potassium of 3.0 mmol/L (36.0 ± 17.3 Vs 23.6 ± 17.0 , $p = \text{NS}$).

It is noted that patients who lost or glucose gain during the session (both with dialysate potassium concentration 2 mmol/L and 3 mmol/L), both in conventional hemodialysis and in predilution online HDF, did not show any statistically significant difference in total potassium removed (χ^2 test, $p = \text{NS}$ in both cases). Also, we found very low potassium removal (<10 mmol/session) in one patient in conventional hemodialysis with a dialysate potassium of 3 mmol/L and in 4 patients with predilution online HDF and a dialysate potassium of 3 mmol/L.

In the regression analysis (multiple regression models), the amount of potassium removed was positively associated with dialysate potassium ($p < 0.006$) and negatively associated with pre-session serum potassium levels ($p < 0.014$), whereas it was not associated with dialysate glucose. The model was statistically significant (Adjusted R-squared 0.545 and Sig. 0.000).

No patient complained about anything during the study due to changes in serum potassium and glucose concentration.

4. Discussion

Dialysate potassium concentration < 2.0 mmol/L is associated with a 2-fold increased risk of cardiac arrest, which is more common during the first dialysis session of the week (Monday or Tuesday) [6]. The causes of these deaths, which occur during the session and immediately after its end, are overhydration and the level of various factors (mainly potassium), which are the highest of the week [12] [13]. In fact, the increased risk is thought to be related to large removal of water (hypovolemia, hypotension) and electrolytes (mainly potassium), which occur during this period [14]. The long interval between sessions is often associated with a significant increase in serum potassium levels, as well as low plasma pH levels, a parameter that contributes to elevated serum potassium levels (due to the movement of potassium from the intracellular to the extracellular space, in exchange for hydrogen ions). The resulting hyperkalemia could be the determining factor for fatal bradyarrhythmia during the session after this interval.

During dialysis sessions, the potassium gradient between serum and dialysate leads to rapid changes, which may also contribute to the occurrence of arrhythmias and sudden death. Thus, an excessively high serum potassium levels before the session can lead to a very rapid change in serum potassium levels during the session (especially when the dialysate potassium is low), causing electric instability of the myocardium and the possible occurrence of life-threatening ventricular tachyarrhythmias immediately after the dialysis session [15]. In a population of 37,765 dialysis patients, investigators from the DOPPS (Dialysis Outcomes and Practice Patterns) group described an increased risk of sudden cardiac death outside of dialysis sessions associated with dialysate potassium concentrations < 1.5

mmol/L, compared with serum potassium concentrations ≥ 3.0 mmol/L. The risk increased by approximately 20% for each mmol/L lower dialysate potassium concentration [16]. It is therefore not surprising that the risks associated with low dialysate potassium are mainly observed in patients with low to normal serum potassium before the dialysis session (note that one of our patients with a serum potassium of 4.1 mmol/L before the beginning of the conventional hemodialysis session had a postdialysis serum potassium of 2.9 mmol/L). On the other hand, no study has shown a significant increase in the risk of sudden death or mortality associated with low dialysate potassium concentration in patients with predialysis serum potassium levels ≥ 5.0 mmol/L. In summary, while there are no randomized controlled data to identify the optimal dialysate potassium concentration, current evidence strongly supports the avoidance of low potassium levels in the dialysate (<2.0 mmol/L) in patients with predialysis serum potassium levels ≤ 5.0 mmol/L. Furthermore, postdialysis serum potassium levels represent the lowest levels compared to its weekly fluctuations and is considered by researchers [17], as well as by us, that its assessment would be useful for determining the risk of hypokalemia in hemodialyzed patients. In the study by Ohnishi *et al.* in Japanese patients, postdialysis serum < 3.0 mmol/L was found in 55% of those who had serum potassium before the beginning of the session < 4.0 mmol/L. This is attributed to the fact that almost all patients in Japan are dialysed with a common dialysate with potassium 2.0 mmol/L. In fact, they found that hypokalemia (postdialysis serum potassium < 3.0 mEq/L) is significantly associated with increased mortality ($p < 0.01$) [17].

Potassium moves freely through the filter membrane during the session, mainly from the patient's serum to the dialysate [18]. The concentration of potassium in the dialysate is of course a modifiable factor that can change the serum potassium concentration during the hemodialysis session and therefore potentially affects the risk of arrhythmias [19]. In fact, a higher risk of sudden death was found with a potassium dialysate of 1.0 mmol/L and an even higher risk with a potassium dialysate of 0 mmol/L [6]. A reduction in clinically significant arrhythmias (bradycardia, ventricular tachycardia or asystole) has been found with a dialysate potassium of 3.0 mmol/L compared with 2.0 mmol/L [20]. This is why several reviews have concluded that potassium dialysate < 2.0 mmol/L should be avoided, especially in patients with high serum potassium levels before the session, to avoid a rapid decrease in serum potassium levels [21] [22].

Agar *et al.* in 551 hemodialyzed patients (with a blood pump over 350 ml/min and dialysate potassium concentration from 0 - 3.0 mmol/L), found serum potassium levels before the beginning of the hemodialysis session of 5.3 ± 0.9 mmol/L, decreasing to 4.1 ± 0.7 mmol/L after 60 min of hemodialysis, while postdialysis serum potassium levels were 3.6 ± 0.7 mmol/L, approximately as we also found with dialysate potassium of 2 or 3 mmol/L. Patients with low dialysate potassium concentration had only slightly higher serum potassium concentrations before the session, but greater decreases in serum potassium concentration during the he-

modialysis session [18].

The literature data on the amount of potassium removed in a single session of conventional hemodialysis is limited. Ward *et al.* were the first to study 12 hemodialyzed patients (4 were diabetic, 2 of whom were receiving insulin, who, as is known, also have hyperkalemia when they have uncontrolled diabetes), with filters of 1.0 m² surface area, with a blood flow rate of 200 ml/min and a session duration of 4.0 - 4.5 hours, with dialysate bicarbonates of 35 mmol/L, glucose 11.0 or 0 mmol/L and potassium 2.0 or 3.0 mmol/L (depending on the patient's needs). Under these conditions, they found a greater loss of potassium with the dialysate without glucose compared to the dialysate with glucose (72.0 ± 26.4 vs. 54.5 ± 24.1 mmol, $p = 0.0358$), as we also found recently [23], adding that when glucose is added to the dialysate, the potassium in the dialysate must be lower in order to maintain its homeostasis [24]. Also, in the sessions without glucose in the dialysate, removal of glucose through the filter was found (it should be noted, however, that in the present study, where the dialysate contained glucose at a concentration of 5.6 mmol/L, we found a loss or of glucose gain in a varying number of patients in each group, a fact that did not play a specific role in the potassium removed during the session). This occurs because increased serum insulin levels affect the distribution of potassium in the body, which moves from the extracellular to the intracellular space, resulting in reduced potassium removal during the session [24]-[26], while inhibition or reduction of insulin secretion results in an increase in extracellular potassium [27]. Both Zehnder *et al.* in 12 stabilized hemodialyzed patients, they found that with a dialysate potassium of 2.0 mmol/L without glucose, 63.3 ± 5.2 mmol of potassium are lost in 4 hours of conventional hemodialysis (the filter they used had a surface area of 1.8 m², the blood pump was 300 ml/min, the dialysate pump was 500 ml/min and the bicarbonates in the dialysate were 40 mmol/L) [28], results with which we also agree in this study (loss of 61.7 ± 26.7 mmol with a dialysate potassium concentration of 2.0 mmol/L, which however contained glucose). The data of these two studies, although to some extent consistent with ours, have significant differences, such as in the first study the use of insulin (which affects the distribution of potassium), the potassium of the dialysate (which was not the same in everyone), the duration of the sessions (which was not the same in everyone), the dialysis conditions (they had filters with a surface area of 1.0 m² and a blood flow of 200 ml/min, compared to our filters with a surface area of 2.1 m² and a blood pump that was 400 ml/min in everyone), so it is impossible to transfer the data from that time to today. Accordingly, in the study by Zehnder *et al.* they used a dialysate with only 2.0 mmol/L potassium (and not 3.0 mmol/L), which obviously affects the removal of potassium from the filter [28].

Blumberg *et al.* also studied the amount of potassium removed during a single hemodialysis session in 14 non-diabetic hemodialyzed patients with hyperkalemia (serum potassium > 5.5 mmol/L). Of these, 6 received atenolol at a dose of 25 - 50 mg/24 hours (beta-adrenergic blockers prevent the entry of potassium intracellu-

larly and in cases of renal failure, may contribute to the occurrence of hyperkalemia), their patients ate during the session (a fact that may affect their insulin levels and serum potassium), while the potassium in the dialysate was 1.0 mmol/L (which is currently used very rarely and in special cases) [11], although in Spain it is often used [9]. This means that this study cannot be compared with ours in terms of the amount of potassium removed in one session, due to the differences reported.

Dolson *et al.* studied 15 hemodialyzed patients, of whom 6 had a tissue potassium deficit. It was found that with conventional hemodialysis the amount of potassium removed in those with normal tissue potassium, compared to those with a deficit, was significantly higher (70.5 ± 14.2 Vs 43.8 ± 5.9 mmol/session) ($p < 0.05$) [29]. In this study, we found very low potassium removal (<10.0 mmol) in one patient on conventional hemodialysis with a dialysate potassium of 3.0 mmol/L and in 4 patients with predilution online HDF and a dialysate potassium concentration also of 3.0 mmol/L. It is noted, of course, that some of them had signs of tissue hypokalemia (they were patients who had been very careful about their potassium intake for many years).

There are no data on the effect of large exchange volumes that occur in online HDF. Jaques *et al.*, who studied 141 patients, 21 of whom were on high flux dialysis and 120 were on postdilution online HDF, found mean potassium removal during the first of 74.3 ± 35.0 and 69.1 ± 34.2 mmol in the second, respectively ($p = \text{NS}$).

It is concluded that the dialysate potassium concentration, both in conventional hemodialysis and in predilution online HDF, significantly affects its removed amount (more in the latter) and the amount of glucose gain or lost during the session (in dialysis with both methods used), does not affect the potassium removed through the filter.

Limitations

The sample was small and selected, we exclude diabetic patients and patients with arrhythmias, all patients were from single-center, some of whom had residual renal function, and there was absence of systematic electrocardiographic arrhythmia monitoring.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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