

## Comparison of Prescribed and Measured Dialysate Electrolyte Levels in the Hemodialysate

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### ABSTRACT

**Background.** The measured electrolyte composition of the dialysate (D) should be in close approximation to that of the hemodialysis prescription. However, to the best of our knowledge, no studies have compared prescribed and measured hemodialysate electrolyte levels other than sodium ( $\text{Na}^+$ ) and calcium ( $\text{Ca}^{++}$ ).

**Objective.** To determine the difference between the measured and prescribed electrolyte concentrations in the hemodialysate and the factors responsible for it.

**Methods.** In this retrospective study, data from biochemical analyses of the hemodialysate, acid concentrate and product water were collected. Data on a fraction of samples with measured electrolyte concentrations within the permitted range of the prescribed value were collected, and the reasons for the discrepancy between the prescribed and measured values were analysed.

**Results.** In our study, 91.87%, 59.22%, 54.41% and 6.84% of the samples had  $\text{DNa}^+$ ,  $\text{DK}^+$ ,  $\text{DCa}^{++}$  and  $\text{DMg}^{++}$  values, respectively, within the range of the prescribed concentrations. The  $\text{Ca}^{++}$  content in the acid concentrate (Part A) and changes in the prescribed  $\text{DNa}^+$  or DB (part of the dialysate contributed by Part B, which contained sodium chloride and sodium bicarbonate in our study) were responsible for the discrepancy between the prescribed and measured  $\text{DCa}^{++}$  values. For an 8 mmol/L (5.7%) reduction in the prescribed  $\text{DNa}^+$ , the measured  $\text{DCa}^{++}$  was reduced by  $9.07\% \pm 1.68\%$ . A reduction in the prescribed DB by 8 mmol/L led to an increase in the measured  $\text{DCa}^{++}$  of  $10.31\% \pm 2.02\%$ . High measured  $\text{DMg}^{++}$  and  $\text{DCa}^{++}$  values were observed in certain dialysate samples owing to higher-than-expected magnesium and calcium contents in the acid concentrate. With an 8 mmol/L (5.7%) reduction in the prescribed  $\text{DNa}^+$ , the measured  $\text{DK}^+$  decreased by  $10.56\% \pm 3.56\%$ .  $\text{DNa}^+$  was correlated with the dialysate conductivity ( $R = 0.919$ ) and increased with decreasing prescribed DB.

**Conclusion.** The calcium in the acid concentrate and the prescribed  $\text{DNa}^+$ /DB were responsible for the discrepancy between the prescribed and measured  $\text{DCa}^{++}$ . The prescribed  $\text{DNa}^+$  change was responsible for the discrepancy between the measured and prescribed  $\text{DK}^+$ . Furthermore, a strong correlation was observed between the dialysate conductivity and  $\text{DNa}^+$  in our study, where the dialysate conductivity increased with decreasing DB, while  $\text{DNa}^+$  remained constant.

**KEYWORDS:** Measured dialysate electrolyte, Faulty acid concentrate, Dialysate conductivity, Measured dialysate calcium, Measured dialysate sodium

## Introduction

In India, end-stage renal disease is present in approximately 130,000 patients, 120,000 of whom are on hemodialysis (HD) [1]. HD requires a large volume of freshly prepared dialysate (D) to remove uremic solutes and electrolytes, such as potassium and phosphorus, and to add bicarbonate. The three components of the hemodialysate are acid concentrate (Part A), base concentrate (Part B) and Association for the Advancement of Medical Instrumentation (AAMI) standard product water, which are mixed in a proportionating ratio [2]. The acid concentrate contains chloride salts of sodium ( $\text{Na}^+$ ), potassium ( $\text{K}^+$ ), calcium ( $\text{Ca}^{++}$ ) and magnesium ( $\text{Mg}^{++}$ ); dextrose monohydrate; and acetic acid/citric acid, whereas the base concentrate contains  $\text{NaHCO}_3$  (sometimes along with  $\text{NaCl}$ ) [2].

The measured concentration of electrolytes in the hemodialysate should be close to the prescribed concentration. The final dialysate sodium ( $\text{DNa}^+$ ) should be within  $\pm 2.5\%$  of the prescribed concentration, whereas the measured dialysate  $\text{Ca}^{++}$ ,  $\text{K}^+$  and  $\text{Mg}^{++}$  should be within  $\pm 5\%$  of the prescription [3]. If any component of the hemodialysate (acid concentrate, base concentrate or AAMI standard water) has an improper composition, it can affect the electrolyte composition of the hemodialysate and lead to adverse clinical outcomes [4, 5]. Few studies have compared the prescribed and measured  $\text{DNa}^+$  and  $\text{DCa}^{++}$  [6, 7]. The difference between the measured and prescribed  $\text{DNa}^+$  depends on the type of HD machine and the method of  $\text{DNa}^+$  estimation [8]. However, no studies have compared the prescribed and measured electrolyte concentrations other than  $\text{Na}^+$  and  $\text{Ca}^{++}$  in the haemodialysate. An improperly functioning water treatment plant can contribute to the discrepancy between the measured and prescribed dialysate electrolyte concentrations. For example, a malfunction in the softener can increase the concentration of  $\text{Ca}^{++}$  in reverse osmosis permeate and dialysate, resulting in a condition known as hardwater syndrome [9, 10].

Dialysate conductivity is a valuable tool for monitoring the delivered  $\text{DNa}^+$  as it is correlated with  $\text{DNa}^+$  (1 mS/cm of dialysate conductivity is approximately 10 mmol/L  $\text{DNa}^+$  in the haemodialysate) [11]. To the best of our knowledge, this study is the first to examine the discrepancy between measured and prescribed dialysate electrolytes other than  $\text{Na}^+$  and  $\text{Ca}^{++}$ . This study aimed to compare the measured and prescribed electrolyte concentrations in the haemodialysate and to determine the factors responsible for the differences.

## Methodology

### Study design

Retrospective single-centre study

### Study period

From July 1st, 2020, to January 15th, 2021.

### Inclusion criterion

Data on all dialysis solutions with available measured dialysate electrolyte values were included in the study.

### Exclusion criterion

Dialysate solutions with missing prescribed dialysate electrolyte data were excluded.

### Study protocol

Data collection commenced after clearance from the hospital ethics committee of the Pondicherry

Institute of Medical Sciences (PIMS), Puducherry (Reg. No. ECR/400/Int/Py/2013). All data on dialysis solution electrolytes (measured and prescribed), including  $\text{Na}^+$ ,  $\text{Ca}^{++}$ ,  $\text{K}^+$ ,  $\text{Mg}^{++}$ ,  $\text{Cl}^-$  and  $\text{HCO}_3^-$  concentrations, as well as dialysate conductivity over the prescribed duration, were collected from the hospital records of the Nephrology Department. Data regarding the chemical analysis of reverse osmosis (RO) water and acid concentrate were acquired from hospital records. Data on the analysis methods for dialysis solution electrolytes were obtained from the Biochemistry Department of PIMS.

The distribution of dialysate sample data based on prescribed dialysate electrolytes was examined, and the fraction of samples with data on the measured dialysate electrolyte concentrations was determined. Fractions of dialysate samples whose  $\text{DNa}^+$  values were within the permitted limits of the prescribed  $\text{DNa}^+$  (with  $\pm 2.5\%$ ) were documented. The number (percentage) of dialysate samples with measured dialysate electrolytes other than  $\text{Na}^+$  ( $\text{K}^+$ ,  $\text{Ca}^{++}$ ,  $\text{Mg}^{++}$ ) within the permitted limits of the prescribed respective electrolyte (with  $\pm 5\%$ ) was recorded. The measured  $\text{DCa}^{++}$  distributions in the four subgroups ( $<1.25$  mmol/L, 1.25-1.5 mmol/L, 1.5-1.75 mmol/L and  $>1.75$  mmol/L) were explored. The alterations in  $\text{DCa}^{++}/\text{DK}^+$  with changes in  $\text{DNa}^+$  or DB (Part B contained NaCl and  $\text{NaHCO}_3$ ) were investigated. The correlation between the measured  $\text{DNa}^+$  and dialysate conductivity was studied.

### Statistical analysis

The data distributions of the prescribed and measured dialysate electrolytes were presented as numbers and percentages. The fraction of dialysate samples with electrolytes within the recommended range was expressed as a percentage. Changes (numbers and percentages) in  $\text{DCa}^{++}/\text{DK}^+$  with alterations in  $\text{DNa}^+$  or DB (including NaCl in the base concentrate) were presented as the mean  $\pm$  SD/median  $\pm$  IQR based on the normality of the data, as determined using the Kolmogorov-Smirnov test. The Pearson correlation coefficient was used to evaluate the association between the measured  $\text{DNa}^+$  and the dialysate conductivity. A p-value of  $<0.05$  was considered to indicate statistical significance.

## Results

Data on 177 hemodialysate samples with available measured dialysate electrolyte values over the 6-month study period were collected from hospital records. Prescribed dialysate electrolyte data were missing for 30 samples. Hence, they were excluded, and the remaining 147 samples were included in the study. Data on the measured dialysate  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Ca}^{++}$  and  $\text{Mg}^{++}$  concentrations and conductivity were available in 81, 136, 147 and 147 reports, respectively. The predominantly prescribed  $\text{DNa}^+$  and  $\text{DK}^+$  concentrations were 140 mmol/L and 2 mmol/L, respectively. Details of the prescribed  $\text{DNa}^+$  and  $\text{DK}^+$  concentrations are presented in Tables 1 and 2, respectively. In all samples, the prescribed  $\text{DCa}^{++}$  and  $\text{DMg}^{++}$  concentrations were 1.5 mmol/L (6 mg/dL) and 0.375 mmol/L (0.9 mg/dL), respectively. In our HD unit, all HD machines are set to the proportionating ratio of acid concentrate : base concentrate : product water = 1:1.83:34. The composition of the acid concentrate per litre, as mentioned in the container, was as follows:

- NaCl: 181 g;  $\text{Na}^+$ : 71.77 g
- $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$ : 8 g;  $\text{Ca}^{++}$ : 2176 mg
- KCl: 5.5 g;  $\text{K}^+$ : 2898 mg
- $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ : 2.75 g;  $\text{Mg}^{++}$ : 325 mg

The NaCl contents per litre of the dialysate contributed by the acid concentrate (Part A) and base concentrate (Part B) were 84 mmol and 20 mmol, respectively. A total of 1.83 litres of the base

concentrate contributed 20 mmol and 35 mmol of NaCl and NaHCO<sub>3</sub>, respectively, per litre of the final dialysate (a total of 55 mmol/L).

DNa<sup>+</sup> and DK<sup>+</sup> were estimated using the ion-selective electrode method. DCa<sup>++</sup> and DMg<sup>++</sup> were determined using the BAPTA method and the colourimetric method with chlorophosphonazo-3, respectively, on the Cobas Integra 400 plus. Ca<sup>++</sup> and Mg<sup>++</sup> were estimated in RO water and acid concentrate using the EDTA titration method.

The number of samples with measured DNa<sup>+</sup>, DK<sup>+</sup>, DCa<sup>++</sup> and DMg<sup>++</sup> values within the permitted range of the prescribed electrolyte concentrations is furnished in Figure 1. Although DCa<sup>++</sup> values were not within the permitted range of the prescribed electrolyte concentrations for 45.59% of the samples, only 6.8% and 1.36% of the samples had DCa<sup>++</sup> values >1.75 mmol/L and <1.25 mmol/L, respectively.

The samples with measured DCa<sup>++</sup> values >1.75 mmol/L had higher than the prescribed DCa<sup>++</sup> and DMg<sup>++</sup> values because of the higher-than-expected Ca<sup>++</sup> and Mg<sup>++</sup> contents in the acid concentrate, as mentioned in Table 3. The acid concentrate was changed immediately after the problem was identified, and the issue was subsequently resolved. Chemical analysis of the RO water revealed that Ca<sup>++</sup> and Mg<sup>++</sup> concentrations were within the recommended limits.

A total of 24 dialysate samples were collected, with a set of four samples obtained from separate HD machines. From each HD machine, four sets of dialysate samples with the same acid and base concentrate solution but different DNa<sup>+</sup> and DB prescriptions were acquired. The number of DB options in the HD machines ranged from -8 to +8, with -8 indicating a decrease in Part B outflow, thereby reducing its contribution to the final dialysate by 8 mmol/L of Na<sup>+</sup>, typically in the form of NaHCO<sub>3</sub>. However, in our study, Part B contained NaHCO<sub>3</sub> and NaCl at a ratio of 35:20. A change in Part B, which contributes to the dialysate (DB), to -8 reduces the Na<sup>+</sup> output from Part B. This alteration causes a decrease in DNa<sup>+</sup> contributed by Part B to the final haemodialysate from 55 mmol to 47 mmol per litre of the hemodialysate, maintaining the ratio of NaHCO<sub>3</sub>:NaCl (35:20). The four sets of samples from each machine were as follows:

- DNa<sup>+</sup> 140 mmol/L; DB 55 mmol/L
- DNa<sup>+</sup> 140 mmol/L; DB 47 mmol/L
- DNa<sup>+</sup> 132 mmol/L; DB 55 mmol/L
- DNa<sup>+</sup> 132 mmol/L; DB 47 mmol/L

The above 24 samples were collected when the patients were not undergoing HD.

In 100% of the sample pairs with a DB of 55 mmol/L, a reduction in DNa<sup>+</sup> of 8 mmol/L within the pair led to a decrease in DCa<sup>++</sup> of >5% (mean ± SD of absolute change: -0.53333 ± 0.088763). Similarly, in 100% of the sample pairs with a DNa<sup>+</sup> of 140 mmol/L, a reduction in DB from 55 mmol/L to 47 mmol/L increased the DCa<sup>++</sup> by >5% (mean ± SD of absolute change: 0.55 ± 0.1). The above details are provided in Table 4.

In all (100%) sample pairs with a DB of 55 mmol/L, a reduction in DNa<sup>+</sup> by 8 mmol/L within the pair led to a decrease in DK<sup>+</sup> of >5%. However, for all pairs with a constant DNa<sup>+</sup>, a reduction in DB from 55 mmol/L to 47 mmol/L did not lead to a similar direction of change in DK<sup>+</sup>. These details are presented in Table 4.

A strong correlation was observed between dialysate conductivity and DNa<sup>+</sup> (Pearson correlation coefficient = 0.919 at the 99% level of significance) (Figure 2). On keeping DNa constant in three pairs of dialysate samples, with DB changing within the pair from 55 to 47, the mean increase in dialysate conductivity was 0.3 mS/cm for an 8 mmol/L decrease in DB.

The proper functioning of the acid and base concentrate pumps was confirmed by the engineers of the relevant company. The conductivity metre of the HD machine was also verified to function correctly and was found to be within  $\pm 0.2$  mS/cm.

S. No.	Prescribed $\text{DNa}^+$ (mmol/L)	No. of samples (%)	No of samples with measured $\text{DNa}^+$ available (with %)	% of samples with measured $\text{DNa}^+$ within the permitted range of the prescribed $\text{DNa}^+$
1.	127	2 (1.36)	2 (100)	100
2.	128	5 (3.40)	5 (100)	100
3.	129	3 (2.04)	3 (100)	100
4.	130	11 (7.48)	11 (100)	90.99
5.	132	12 (8.16)	6 (50)	83.33
6.	133	3 (2.04)	3 (100)	66.67
7.	136	1 (0.68)	1 (100)	100
8.	137	1 (0.68)	1 (100)	100
9.	138	3 (0.68)	2 (66.67)	100
10.	140	104 (70.74)	45 (43.26)	88.88
11.	142	1 (0.68)	1 (100)	100
12.	145	1 (0.68)	1 (100)	100

Table 1. Distribution of dialysate samples based on the prescribed and measured  $\text{DNa}^+$

S. No.	Prescribed $\text{DK}^+$ (mmol/l)	No. of Samples	No of samples with measured $\text{DK}^+$ available (with %)	% of samples with measured $\text{DK}^+$ within allowed margin of prescribed $\text{DK}^+$
1.	2	131	120 (91.60)	61.66
2.	3	14	14 (100)	42.85
3.	3.5	2	2 (100)	50

Table 2. Distribution of dialysate samples based on the prescribed and measured  $\text{DK}^+$  values.

	Expected electrolyte value (mg/L)	Measured electrolyte value (mg/L)
Elemental $\text{Ca}^{++}$ per litre of the acid concentrate (in mg/L)	2176 mg	3290 mg
Elemental $\text{Mg}^{++}$ per litre of the acid concentrate (in mg/L)	325 mg	1010 mg

Table 3. Expected and measured  $\text{Ca}^{++}$  and  $\text{Mg}^{++}$  in the acid concentrate (per litre) for dialysate samples with a prescribed  $\text{DCa}^{++}$  of 1.5 mmol/L but measured  $\text{DCa}^{++} > 1.75$  mmol/L.

	Change in $\text{DCa}^{++}$ (%) mean $\pm$ SD	% of pairs seen $> 5\%$ change in $\text{DCa}^{++}$	Change in $\text{DK}^+$ (%) mean $\pm$ SD	% of pairs seen $> 5\%$ change in $\text{DK}^+$
With an 8 mmol/L fall in $\text{DNa}^+$	$-9.07 \pm 1.68^*$	Decrease in 100% pairs	$-10.56 \pm 3.56^{**}$	Decrease in 100% pairs
With an 8 mmol/L fall in DB total (including NaCl in the base concentrate)	$10.31 \pm 2.02$	Increase in 100% pairs	NA <sup>***</sup>	Increase in 41.66% pairs Decrease in 16.67% pairs

Table 4. Changes in the measured  $\text{DCa}^{++}$  with changes in the  $\text{DNa}^+$ /base concentrate rate. <sup>\*\*</sup>The minus sign suggests a decrease in the electrolyte concentration; <sup>\*\*\*</sup>NA (not applicable) due to an inconsistent response.

## Discussion

Post-dialysis concentrations of various electrolytes in the blood depend on the electrolyte composition of the hemodialysate. In maintenance hemodialysis potassium and phosphorus move from the patient's blood compartment to the dialysate, whereas bicarbonate moves from the dialysate to the blood compartment (Figure 3).

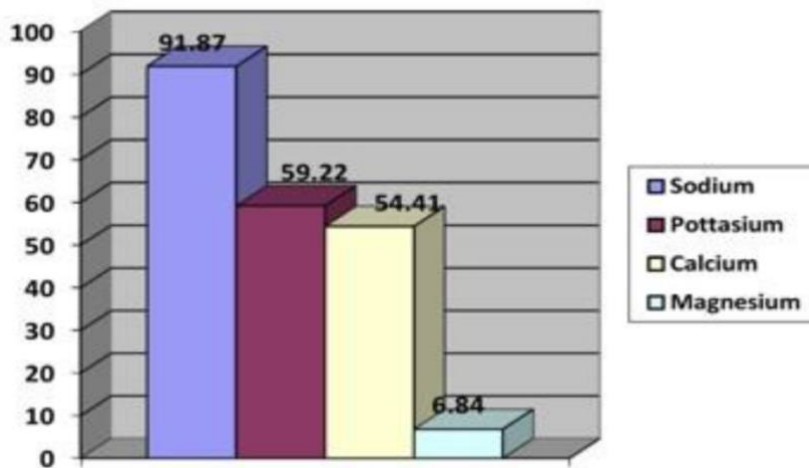


Figure 1. Percentage of samples with measured dialysate electrolytes within the permitted range of the prescribed dialysate electrolyte concentration.

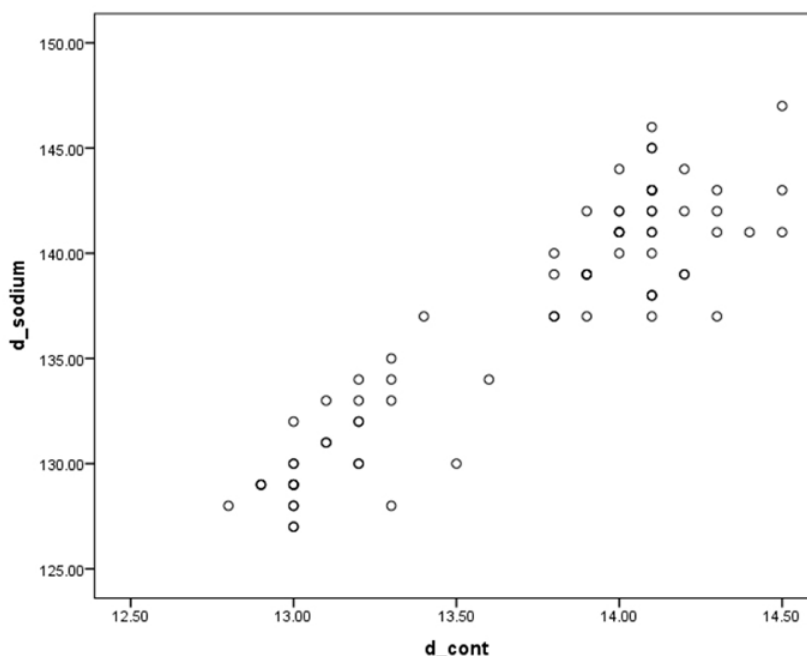
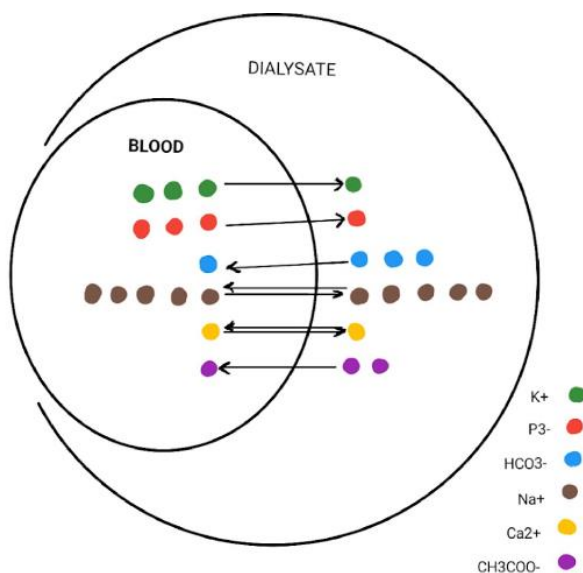


Figure 2. Correlation between DNa<sup>+</sup> and dialysate conductivity. Correlation between DNa<sup>+</sup> and dialysate conductivity (Pearson Correlation coefficient = 0.919 at 99% level of significance). X-axis is dialysate conductivity (d\_cont) and Y-axis is DNa<sup>+</sup> (d\_sodium).

Few studies have compared the prescribed and measured DNa<sup>+</sup> and DCa<sup>++</sup> concentrations in the haemodialysate [6–8]. This study is likely to be the first to compare prescribed and measured hemodialysate electrolytes other than Na<sup>+</sup> and Ca<sup>++</sup>. The measured DNa<sup>+</sup> should be within 2.5% of the prescribed DNa<sup>+</sup>; for other electrolytes, the measured value should be within 5% of the prescribed values [3]. Compared with the study by Gul et al., where only 57% of the DNa<sup>+</sup> samples were within 2.5% of the prescribed value, in our study, 91.87% of the samples were within the permitted range ( $\pm 2.5\%$  of the prescribed DNa<sup>+</sup>) [3, 6]. In our research, data on measured dialysate HCO<sub>3</sub><sup>-</sup> and Cl<sup>-</sup> were not available, which could have explained the narrow difference between the prescribed and measured DNa<sup>+</sup>.



**Figure 3. Schematic representation of electrolyte movement between blood and dialysate during haemodialysis.**

Few studies have compared measured and prescribed  $DCa^{++}$ . In 54.41% of the dialysate samples, the measured  $DCa^{++}$  was within the permitted range of the prescribed  $DCa^{++}$  (i.e.,  $\pm 5\%$ ) [3]. In our study, only two samples exhibited  $DCa^{++}$  values of  $<1.25$  mmol/L. In both the dialysates prepared from Part A and Part B, when the prescribed  $DNa^+$  was 140, the measured  $DCa^{++}$  was 5.5 mmol/L, and when it was reduced to 132 meq/L, the measured  $DCa^{++}$  was  $<1.25$  mmol/L.  $DCa^{++} <1.25$  mmol/L should be avoided because it is associated with high mortality, and we have not used this dialysate for patient treatment. A total of 61.9% of the samples had  $DCa^{++}$  within the recommended range (1.25-1.5 mmol/L) [12]. Only 11 samples had  $DCa^{++}$  values  $>1.75$  mmol/L. Assessments attributed this observation to the higher-than-expected  $Ca^{++}$  concentration in the acid concentrate; hence, it was not used for patient treatment. Only one study has stated that a higher-than-expected  $Ca^{++}$  content in the acid concentrate is a cause of increased dialysate calcium [13]. The role of softener malfunction in high levels of measured  $DCa^{++}$  has been investigated [9]. Measured  $DCa^{++}$  higher than the prescribed value can result in severe dialysis-associated hypercalcaemia-related clinical features, such as encephalopathy, intra-dialytic hypertension, arrhythmias, vomiting and abdominal pain. These complications can be life-threatening, emphasising the significance of measuring dialysate electrolytes before using a new batch of Part A [9, 10, 13].

Another finding in our study was the effect of prescribed  $DNa^+$  and DB ( $NaHCO_3$  and  $NaCl$  in base concentrate) on  $DCa^{++}$  and  $DK^+$ . With a 5.7% reduction in the prescribed  $DNa^+$ , the measured  $DCa^{++}$  decreased by  $9.07\% \pm 1.68\%$ , which exceeds the percentage change in  $DNa^+$ . A 8 mmol/L reduction in prescribed DB led to an increase in measured  $DCa^{++}$  of  $10.31\% \pm 2.02\%$ . There was no difference between the prescribed and measured  $DNa^+$  values in these sets of samples.

The effects of alterations in the prescribed  $DNa^+$  or bicarbonate on measured  $DCa^{++}$  in blood-based renal replacement therapies have not been adequately investigated [7]. No studies seem to have examined the effects of changes in  $DNa^+$  or  $DHCO_3^-$  on  $DCa^+$  or  $DK^+$  in conventional haemodialysis. Moreover, none of the studies have reported that the degree of change in  $DCa^+$  or  $DK^+$  can be greater than that in  $DNa^+$ . Our study is the first to make these observations. The rates of change (%) in the measured  $DCa^{++}$  owing to changes in either  $DNa^+$  or DB are pretty close to each other, probably because of similar changes in the acid concentration pump rates, but in opposite directions. In 59.92% of the measured samples, the  $DK^+$  concentration was within the permitted range of the prescribed  $DK^+$  concentration, but none of the samples exhibited a  $DK^+$  concentration

of  $<1$  mmol/L, which is not recommended [14]. One possible cause for this discrepancy could be the higher or lower  $K^+$  in the acid concentrate than expected. Nonetheless, this reasoning is merely a conjecture, and data are not available to confirm it. In our study, a decrease in the prescribed/measured  $DNa^+$  of 5.7% reduced (mean  $\pm$  SD) the measured  $DK^+$  by  $10.56\% \pm 3.56\%$ , which surpassed the percentage change in  $DNa^+$ . The effects of alterations in the measured  $DK^+$  concentrations on the reduction in the prescribed DB were inconsistent, and the reasons could not be ascertained.

The percentage change in the measured  $DCa^{++}/DK^+$  when  $DNa^+/DB$  is altered is calculated as follows: a reduction of  $DNa^+$  by 8 mmol/L (5.7% change) with DB at 55 mmol/L ( $NaHCO_3$  35 mmol/L and NaCl 20 mmol) or a reduction of DB total by 8 mmol/L (47 mmol) with  $DNa^+$  maintained at 140 mmol/L, alters the acid concentrate pump rate and hence changes  $DCa^{++}$  and  $DK^+$  (reduction when  $DNa^+$  is decreased and increment when DB is lowered), as explained below.

#### Effect of the change in the prescribed $DNa^+$ on the measured $DCa^{++}$

When  $DNa^+$  is decreased by 8 mmol/L, the reduction in  $DNa^+$  is caused by a change in NaCl in Part A. The Part A pump rate changes as follows:

In our study, NaCl concentration contributed by Part A per litre of the final hemodialysate is 84 mmol.

Hence, a reduction in Part A pump rate upon an 8 mmol/L reduction in the prescribed  $DNa^+$  is calculated as follows:  $(8/84) \times 100 = 9.52\%$ .

The calculated % change in the acid concentrate pump rate (9.52%) is higher than the % change in the prescribed/measured dialysate sodium:  $8/140 = 5.7\%$  (% change in the acid pump rate depends on the contribution of NaCl by the acid concentrate).

When  $DNa^+$  is reduced by 8 mmol/L (5.7%), the acid concentrate pump rate is decreased by 9.52%. Hence, instead of 1 L, it should pump 0.904 L of the acid concentrate per 1.83 L of Part B and 34 L of product water output. Hence, the actual proportioning ratio becomes 0.9:1.83:34 (instead of 1:1.83:34), and the volume of the dialysate formed per 0.9 L of the acid concentrate should be 36.73 L.

Accordingly, the expected  $Ca^{++}$  content per 36.73 L of the dialysate when  $DNa^+$  is reduced by 8 mmol/L should be as follows:  $2176 \times (100 - 9.52)/100 = 1968.84$  mg (1 L of Part A contains 2176 mg of calcium).

Hence, the expected  $Ca^{++}$  concentration per litre of the dialysate should be  $1968.84/36.73 = 53.60$  mg/L = 5.36 mg/dL.

The expected difference between the measured  $DCa^{++}$  and the expected  $DCa^{++}$  ( $2176/36.8 = 5.91$  mg/L) is as follows:  $5.91 - 5.36$  mg/dL = 0.55 mg/dL (reduced by 9.30%).

#### Effect of a change in the prescribed DB ( $NaHCO_3 + NaCl$ in Part B) on the measured $DCa^{++}$

When  $DNa^+$  is 140 and DB is reduced by 8 mmol/L, there should be an increase at an acid concentrate pump rate of 9.52% to keep  $DNa^+$  unchanged.

Hence, instead of 1 L, the acid concentrate (Part A) pump should provide 1.095 L, and the base concentrate (Part B) should be 1.66 L instead of 1.83 L for 34 L of product water, with an actual proportioning ratio of 1.095:1.66:34. The total dialysate volume per 1.095 L of the acid concentrate should be 36.75 L. Accordingly, the expected  $Ca^{++}$  content per 36.75 L of the dialysate in the situation of DB reduction by 8 mmol/L:  $2176 \times (100 + 9.52)/100 = 2383.15$  mg.

Hence, the expected  $\text{Ca}^{++}$  concentration per litre of the dialysate should be  $2383.15/36.75 = 64.84$  mg/L = 6.48 mg/dL.

The difference between the measured  $\text{DCa}^{++}$  and the expected  $\text{DCa}^{++}$  is 5.91 mg/dL in the above 6.48 – 5.91 mg/dL = 0.57 mg/dL (increased by 9.6%)

#### Effect of changes in the prescribed $\text{DNa}^+$ on the measured $\text{DK}^+$

Accordingly, for a prescribed  $\text{DNa}^+$  reduction of 8 mmol/L (5.7% change), the  $\text{K}^+$  content per 36.73 L (as the acid concentrate should be reduced to 0.9 L instead of 1 L) of the dialysate  $2898 \times (100 - 9.52)/100 = 2622.11$ .

Expected potassium concentration per litre of hemodialysate should be  $2622.11/36.73 = 71.39$  mg/L =  $71.39/39 = 1.83$  mmol/L (molecular weight of potassium is 39). Expected reduction in measured  $\text{DK}^+$  in the above situation is  $(2-1.83/2) \times 100 = 8.5\%$ .

The measured reduction in  $\text{DCa}^{++}$  with decreasing  $\text{DNa}^+$  and the measured increase in  $\text{DCa}^{++}$  with decreasing DB total were 0.53333 (9.07%  $\pm$  1.68%) and 0.55 (10.31%  $\pm$  2.02%), respectively, which were close to the expected values (9.3% and 9.6% for decreases and increases in  $\text{DCa}^{++}$ , respectively, for the above-mentioned situation). The above calculation explains the mechanism behind the change in the measured  $\text{DCa}^{++}$  compared with the percentage change in  $\text{DNa}^+$  or DB.

The measured  $\text{DK}^+$  increased by 10.56%  $\pm$  3.56% with an 8 mmol/L decrease in  $\text{DNa}^+$ , which is quite close to the above calculation of the expected percentage change in  $\text{DK}^+$ . However, the change in  $\text{DK}^+$  with a change in DB is not consistent.

The above calculations describe the mechanism behind the change in  $\text{DK}^+$  with the change in the prescribed  $\text{DNa}^+$ ; nonetheless, there are certain differences between the expected and actual changes, which could not be explained.

The percentage change in  $\text{DCa}^{++}/\text{DK}^+$  due to the percentage change in  $\text{DNa}^+$  also depends on the  $\text{Na}^+$  contributed by the acid concentrate. In a dialysis solution in which the acid concentrate contributes 104 meq/L (unlike our study, which was 84 meq/L), if  $\text{DNa}^+$  is reduced by 8 mmol/L (5.7%), the expected change in the acid concentrate pump rate should be  $(8/104) \times 100 = 7.69\%$ , which is less than the expected value in our study of 9.52%. We do not have data related to the above-mentioned solution.

Similar to previous investigations, our study revealed that dialysate conductivity is strongly correlated with  $\text{DNa}^+$  ( $R = 0.919$ ) [15]. The hemodialysate conductivity increased by a mean of 0.3 mS/cm for an 8 mmol decline in DB, while keeping the prescribed  $\text{DNa}^+$  constant. For an 8 mmol drop in DB, there should be a 5.1 mmol drop in  $\text{NaHCO}_3$  and a 2.9 mmol fall in NaCl (base;  $\text{NaHCO}_3:\text{NaCl} = 5:20$ ). However, the acid concentrate pump should enhance its flow and increase the NaCl content by 8 mmol/L to keep  $\text{DNa}^+$  fixed despite the reduction in DB. Finally, NaCl should increase by 5.1 mmol/L, whereas  $\text{NaHCO}_3$  should decrease by 5.1 mmol/L as seen in the study with concomitant increase in  $\text{DK}^+$ ,  $\text{DCa}^{++}$  and  $\text{DMg}^{++}$  due to acid concentrate pump rate increase. The mean rise in the measured  $\text{DK}^+$ ,  $\text{DCa}^{++}$  and  $\text{DMg}^{++}$  values were 0.1 mmol/L, 0.15 mmol/L and 0.1 mmol/L, respectively. The molar conductivities of NaCl, KCl,  $\text{NaHCO}_3$ ,  $\text{CaCl}_2$  and  $\text{MgCl}_2$  were 103.67 mS/cm, 128.43 mS/cm, 72.54 mS/cm, 199.89 mS/cm and 180.29 mS/cm at 1 mmol, respectively [16]. From the above values, the expected increase in the dialysate conductivity is 0.219, which is quite close to the surge in the mean measured conductivity, i.e., 0.3 mS/cm. Not many studies have examined the possible reason behind the change in dialysate conductivity with a change in DB with fixed  $\text{DNa}^+$ .

## Conclusion

Measuring the dialysate electrolyte concentration is beneficial as discrepancies between the measured and prescribed dialysate electrolyte concentrations can occur, leading to adverse clinical outcomes. The factors contributing to the disparity between the measured and prescribed  $\text{DCa}^{++}$  values in our study were the improper electrolyte concentration in the acid concentrate and the alteration in the prescribed  $\text{DNa}^+/\text{DB}$  ratio. The cause of the difference in the measured  $\text{DK}^+$  concentration from the prescribed concentration was the change in the prescribed  $\text{DNa}^+$ . The measured dialysate magnesium was higher than the prescribed magnesium because of the higher-than-expected magnesium concentration in the acid concentrate. The dialysate conductivity was well correlated with  $\text{DNa}^+$  and increased with a reduction in the prescribed dose of DB, whereas  $\text{DNa}^+$  remained unchanged. Our findings emphasise the importance of measuring the dialysate electrolyte concentration in case of clinical suspicion and when using a new batch of Part A or Part B.

## Abbreviations:

D: Dialysate;  $\text{DNa}^+$ : Dialysate Sodium;  $\text{DK}^+$ : Dialysate Potassium;  $\text{DCa}^{++}$ : Dialysate Calcium;  $\text{DMg}^{++}$ : Dialysate Magnesium; DB: Dialysate contributed by part B; HD: Hemodialysis.

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