Chhabra and Davenport
Renal Replacement Therapy (2024) 10:31
https://doi.org/10.1186/s41100-024-00548-w

Renal Replacement Therapy

RESEARCH

Open Access

Does using a higher dialysate sodium concentration result in lower sodium losses with dialysis treatments?

Roohi Chhabra[1] and Andrew Davenport[1*]

Abstract

Introduction Many dialysis centres prescribe a uniform dialysate sodium (DialNa) concentration, but as there is no consensus on the choice of a universal DialNa, we wished to determine dialysate sodium balance comparing DialNa of 140 and < 140 mEq/L.

Methods Waste dialysate was continuously collected during sessions and thoroughly mixed, and sodium was measured in both the waste and fresh dialysate. Sodium removal was calculated as the difference in concentrations, dialysate flow rate, session time and ultrafiltration.

Results Dialysate sodium balance was measured during 139 dialysis treatments (34 DialNa 140 versus 105 DialNa < 140, median 136 mEq/L), in 111 patients, 63% male, mean age 64.0 ± 16.2 years and 33.3% diabetic. There was no difference using the higher DialNa [net loss median 482 (238–573) versus 312 (124–599) mEq], ultrafiltration losses [226 (131–280) versus 204 (125–290)mEq] and non-ultrafiltration losses [217 (0–384) versus 173 (−90 to 350) mEq]. We also compared haemodiafiltration and haemodialysis (118 versus 23 sessions), and there were no differences in net loss [311 (91–608) versus 381 (167–597)], ultrafiltration [212 (127–290) versus 169 (110–258)mEq] and non-ultrafiltration losses [180 (−51 to 386) versus 192 (−74 to 387)mEq].

Conclusions Although most dialysis centres prescribe a universal dialysate sodium concentration, there is no consensus on the optimum universal concentration. We found no difference in net dialysate sodium balance when comparing patients dialysing with a dialysate sodium concentration of 140 or < 140 mEq/L. Similarly, we found no differences in dialysate sodium balance between haemodiafiltration and haemodialysis sessions.

Keywords Haemodialysis, Sodium, Haemodiafitration, Dialysate, Blood pressure, Ultrafiltration

Introduction

The original haemodialysis machines did not have ultrafiltration control, and so fluid and sodium removal during dialysis was achieved by an osmotic gradient generated by a high glucose and low sodium (126.5–130 mEq/L) dialysate [1]. Following improvements in both dialyser and dialysis machine technology [2], dialysate sodium concentrations increased by consensus to 140 mEq/L [3].

For most haemodialysis patients, sodium balance depends upon dietary sodium intake and sodium removal during dialysis sessions, so ideally, the choice of dialysate sodium would be individualised [4]. However, in clinical practice, most dialysis centres choose a standard dialysate sodium concentration for the majority of their patients [5]. Although choosing a higher dialysate sodium concentration may reduce the risk of intra-dialytic hypotensive episodes, it could potentially result in

*Correspondence:
Andrew Davenport
a.davenport@ucl.ac.uk
[1] UCL Department of Renal Medicine, Royal Free Hospital, University College London, Rowland Hill Street, London NW3 2PF, UK

a positive sodium balance, with consequent increase in inter-dialytic weight gain, blood pressure, left ventricular hypertrophy, ultrafiltration requirements and possible emergency admission with cardiac failure [6]. Whereas, conversely choosing a lower dialysate sodium concentration has been reported to lead to reduced inter-dialytic weight gains and lower blood pressure in interventional studies but increased risk of intra-dialytic hypotension [7, 8] and excess mortality in observational studies [9]. Due to the controversy of what would be the optimum uniform dialysate sodium concentration for most patients, a meta-analysis of 23 studies (76,635 subjects) reported that there was no definite evidence that choosing a uniform high or low dialysate sodium concentration had any major hard or surrogate endpoints for dialysis patients [10]. To resolve this conundrum, an international trial has been undertaken, comparing patient outcomes randomised to dialysing with a dialysate sodium of 137 or 140 mEq/L [9], and we decided to review dialysate sodium removal in patients dialysing with a sodium of 140 mEq/L or lower.

Methods

We measured the dialysis session sodium balance during a single treatment session in adult dialysis patients attending for routine out-patient treatments, who had been established on dialysis with a stable dialysate prescription for more than 3 months between February and May 2022. Patients who had recent hospital admissions were excluded, as were patients who could not complete food questionnaires or provide valid written informed consent. The dialysis session details were obtained from the TeamOn electronic software (Fresenius MC, Bad Homburg, Germany), which measured the dialysis session time to the nearest minute. All patients dialysed with Fresenius 5008H dialysis machines and a polysulfone dialyser (Fresenius MC, Bad Homburg, Germany), using ultrapure quality dialysis water. Dialysate conductivity was regularly calibrated and delivered dialysate sodium checked by indirect ion electrode (Roche Cobas, analyser, Basle, Switzerland), having previously been tested by flame photometry and ion electrophoresis [12, 13]. Ultrapure dialysate was used for dialysis machine rinsing and washback, with patients straight connected to the dialysis machine and then 300 mL washback regulated by the TeamOne software. Patients were allowed a 180 mL drink during the dialysis session and were provided with one sandwich, which they were advised to eat after the session [14]. The ultrafiltration volume was set 500 mL above the desired with loss to allow for straight connection, washback and food and drink consumed during the session. We attached a drain connector in the form of T piece tubing to the waste dialysate drain and continuously collected waste dialysate throughout the dialysis session into a pre-washed plastic container. At the end of the dialysis session, the waste dialysate was thoroughly mixed and sodium concentration measured in both the waste and fresh dialysate [15]. The net sodium removal during the dialysis session was calculated as the difference in concentrations and the dialysate flow rate, session time and ultrafiltration. We divided sodium balance into that obtained from ultrafiltration and the remainder as non-ultrafiltration losses. Dialysis session urea clearance (Kt/Vurea) was determined, and dietary protein intake was estimated by calculating normalised nitrogen appearance rate (nPNA), using standard equations [16]. To estimate dietary sodium intake, all patients completed the scored salt questionnaire (SSQ) which has been adapted for UK diet and has been validated in patients with chronic kidney disease [17]. Patient demographics and routine laboratory investigations were obtained from hospital computerised records.

The dialysis centre joined the international RESOLVE study and dialysis sodium balance was remeasured between May and July 2023 using a dialysate sodium of 140 mEq/L [11].

Statistical methods

Data are presented as mean ± standard deviation, median (interquartile range) or percentage. Standard statistical tests were used to analyse data, including the D'Agostino and Pearson normality test, *t*-test, paired *t*-test, Mann Whitney *U* test, Wilcoxon rank sum pair test and chi square test (χ^2), with appropriate post hoc adjustment for small numbers and multiple testing. Univariate correlations were determined using Spearman rank coefficient. All analyses were performed using GraphPad Prism v 10.2 (Graphpad software, San Diego, CA) and SPSS version 28 (IBM, Armonk, NY). A two-tailed p value < 0.05 was considered statistically significant.

Ethics approval and consent to participate

This study was conducted under the approval of the UK National Research Ethics Service (approval number 21/NI/0059) and in the spirit of the 'Declaration of Helsinki.' All patients provided written informed consent. The analysis and reporting were conducted in compliance with UK National Health Service (NHS) guidelines for reporting medical studies.

Results

We measured the single session dialysis sodium balance during 139 dialysis treatments, in 111 patients, 63% male, mean age 64.0 ± 16.2 years, 33.3% diabetic and dialysis vintage 34 (22–62) months. Initially, 105 patients dialysed with a dialysate sodium of < 140 mEq/L

and one with a dialysate sodium of 140 mEq/L. Following the introduction of the RESOLVE study [11], dialysis sodium balance was rechecked in a further 33 patients, including 23 patients who had a previous dialysis session balance measured when dialysing with a dialysate sodium of < 140 mEq/L.

Table 1 Comparison of dialysis sessions with a dialysate sodium (Na) concentration of < 140 and 140 mEq/L, respectively

Variable	Dialysate Na < 140	Dialysate Na 140
Number of patients	105	34
Number of sessions	105	34
Dialysate Na mEq/L	136 (136–138)	140 (140–140)
Male (%)	71 (67.6)	15 (44.1)*
Age (years)	65.5 ± 16.2	67.9 ± 16.0
Diabetic (%)	34 (32.4)	8 (23.5)
White ethnicity (%)	35 (33.3)	8 (23.5)
Vintage (months)	34 (23–60)	34 (19–96)
Pre-dialysis weight (kg)	69.6 ± 16.7	74.8 ± 16.9
Weight loss (kg)	1.2 (0.8–1.9)	1.5 (0.9–2.1)
Percent weight loss	1.97 (1.27–2.77)	2.05 (1.34–2.91)
Session time (min)	213 (186–241)	210 (184–231)
Kt/Vurea	1.59 ± 0.09	1.61 ± 0.08
nPNA (g/kg/day)	1.36 ± 0.54	1.35 ± 0.45
Haemodiafiltration (%)	89 (84.8)	29 (85.3)
Convection volume (L)	16.0 (12.1–19.5)	16.3 (12.0–20.8)
Temperature (°C)	35 (35–35)	35 (35–35.5)
Pre-dialysis MAP (mmHg)	100.9 ± 20.3	101.3 ± 17.8
Post-dialysis MAP (mmHg)	90.6 ± 14.6	92.7 ± 17.6
Haemoglobin (g/L)	108 (99–117)	116 (109–117)
Albumin (g/L)	38.7 ± 5.1	36.9 ± 2.7
C reactive protein (g/L)	7 (2–12)	5 (3–7)
NTproBNP (pmol/L)	5352 (2183–18,104)	5694 (1811–18,966)

Kt/Vurea, sessional urea clearance; nPNA, normalised dietary protein intake; MAP, mean arterial pressure; NTproBNP, N-terminal brain natriuretic protein. Data are expressed as integer, mean (standard deviation), median (interquartile range) or percentage. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$ versus < 140 mEq/L

We initially compared dialysis sessions when patients dialysed with a dialysate sodium concentration of < 140 or 140 mEq/L. Apart from slightly more males dialysing with a lower dialysate sodium concentration, patient demographics and sessional dialysis treatments were similar (Table 1). As expected, the total amount of dialysate sodium delivered with a dialysate sodium concentration of 140 mEq/L was greater and so was the amount of dialysate sodium recovered in the effluent dialysate. Although the total amount of sodium removed was greater with the higher dialysate concentration, this was not significantly different, and there was no difference in ultrafiltration or non-ultrafiltration sodium loss whether the dialysate sodium was < 140 or 140 mEq/L. However, comparing serum sodium measurements, then the serum sodium was lower both pre- and post-dialysis in those dialysing with a lower dialysate sodium concentration (Table 2). Dietary sodium intake was assessed using SSQ scores. The mean SSQ score was 51.9 ± 18.7. There was no difference in the estimated dietary sodium intake between those patients dialysing with a sodium concentration < 140 compared with those dialysing with a dialysate of 140 mEq/L (51.7 ± 18 versus 51.3 ± 17.7).

There was no univariate correlation between the sodium gradient (serum sodium–dialysate sodium concentration) and total sodium content of the waste dialysate ($p = 0.48$), sodium removed ($r = 0.15$, $p = 0.09$) or with either the ultrafiltration dialysate sodium loss ($p = 0.65$) or non-ultrafiltrtaion sodium loss ($p = 0.11$).

Twenty-three patients had dialysis session measurements with both a dialysate sodium concentration of 140 mEq/L and a lower concentration: 56.5% male, 17.4% diabetic and 87% receiving haemodiafiltration with a dialysis vintage of 48 (22–75) months. The total dialysate

Table 2 Comparison of serum and dialysate sodium with dialysis sessions using a dialysate sodium (Na) concentration of < 140 and 140 mEq/L, respectively

Variable	Dialysate Na < 140	Dialysate Na 140
Dialysate Na (mEq/L)	136 (136–138)***	140 (140–140)
Pre-dialysis Na (mEq/L)	138 ± 3	140 ± 4***
Post-dialysis Na (mEq/L)	137 ± 2	140 ± 2**
Pre-Post Se Na (mEq/L)	1 (−1 to +3)	0 (−3 to +2)
PreSe Na-Dial Na (mEq/L)	1 (−1 to +3)	0 (−2 to +2)
Dialysate Na delivered (mEq)	14,291 (12,510–15417)	14,750 (13,000–16710)*
Dialysis Na loss (mEq)	356 (219–420)	482 (238–573)
Ultrafiltration Na loss (mEq)	301 (210–373)	266 (215–345)
Non ultrafiltration Na loss (mEq)	56 (−49 to 146)	136 (−50 to 259)

Se Na, serum sodium; Dial Na, dialysate sodium. Ultrafiltration sodium losses adjusted for dialysis machine priming and washback. Data are expressed as integer, mean (standard deviation), median (interquartile range) or percentage. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$ versus < 140 mEq/L

sodium delivered was greater with the higher dialysate sodium, as were the pre- and post-dialysis session serum sodium, and although the total amount of sodium in the waste dialysate was not statistically greater, non-convective sodium losses were higher (Table 3).

We then compared haemodiafiltration and haemodialysis sessions to determine whether there was a difference between modalities (Table 4). Apart from dialysis vintage there were no significant differences, and although dialysate sodium removal appeared to be greater with haemodiafiltration, this did not reach statistical significance ($p = 0.052$).

Discussion

Most dialysis patients are advised to reduce their daily dietary sodium intake to prevent excessive thirst and increased inter-dialytic weight gains and so limit the amount of sodium required to be removed during thrice weekly dialysis sessions. Apart from dialysis, sodium is lost in urine, sweat, faeces and breath, but once anuric, these other potential sources of sodium loss are generally minor compared with dialysis, unless patients are strenuously exercising or working in very hot climates. As most sodium is removed by ultrafiltration during dialysis, less importance has been placed on diffusional losses and the use of lower sodium dialysates [3]. Due to concerns in our own centre about the possibility of diffusional sodium gains in patients randomised to a dialysate sodium higher than their serum sodium concentration [10], we measured sodium in the waste dialysate in patients dialysing with a dialysate sodium of < 140 and 140 mmol/L. As expected, the total amount of sodium delivered in the fresh dialysate was greater, as was that recovered in the waste dialysate. However, there was no difference in the ultrafiltration loss or non-ultrafiltration sodium losses, whether the dialysate sodium was 140 mEq/L or lower. Although there was slightly more relative ultrafiltration loss with the higher dialysate sodium, there was no correlation between the serum to dialysate gradient and either total waste dialysate sodium loss or non-ultrafiltration sodium loss. This may reflect that most patients were treated with post-dilutional haemodiafiltration, with dialysate being directly returned into the patient. We only measured dialysate sodium losses during a single session, but our results suggesting no difference in sodium losses support the results from a cross-over study switching patients to a lower dialysate sodium, which did not demonstrate any difference in inter-dialytic weight gains or blood pressures [8, 18]. Similarly, we found no difference in estimated dietary sodium intake using sodium frequency questionnaires between those dialysing with a sodium of less than 140 and those using a dialysate sodium of 140 mEq/L. We did note that patients established on lower dialysate sodium concentrations had

Table 3 Comparison of changes in serum and dialysate sodium in patients who both dialysed with a dialysate sodium (Na) concentration of < 140 and 140 mEq/L, respectively

Variable	Dialysate Na < 140	Dialysate Na 140
Dialysate Na (mEq/L)	136 (136–138)	140 (140–140)
Pre-dialysis Na (mEq/L)	137 (136–139.5)	139.5 (137–143)*
Post-dialysis Na (mEq/L)	136 (135–138)	140 (139–141)***
Pre-Post Se Na (mEq/L)	1 (−1 to +3)	−1 (−3 to +2)
PreSe Na-Dial Na (mEq/L)	1 (−1 to +4)	−0.5 (−3 to +3)
Dialysate Na in (mEq)	14,280 (12,420–16080)	14,700 (13,020–16590)*
Dialysate Na out (mEq)	14,490 (12,659–15,532)	15,292 (13,277–1717)**
Dialysate Na loss (mEq)	312 (124–599)	482 (238–573)
Convective Na loss (mEq)	204 (125–290)	226 (131–280)
Non-convective Na loss (mEq)	173 (−90 350)	217 (0–384)
Sessional (Kt/V)	1.6 ± 0.09	1.62 ± 0.07
Session time (min)	210 (181–239)	215 (186–237)
Convection volume (L)	17.0 (12.5–21.7)	17.5 (14.2–21.7)
nPNA (g/kg/day)	1.33 (0.95–1.7)	1.3 (1.1–1.65)
Pre dialysis weight (kg)	70.3 ± 11.6	70.7 ± 13.3
Percent peri-dialytic (weight)	2.25 (1.42–2.88)	2.2 (1.78–3.22)
Pre-dialysis MAP (mmHg)	99.1 ± 13.8	99.1 ± 19.2
Post-dialysis MAP (mmHg)	99.1 ± 13.8	97.9 ± 17.0

Se Na, serum sodium; Dial Na, dialysate sodium; Kt/Vurea, sessional urea clearance; nPNA, normalised dietary protein intake; MAP, mean arterial pressure. Data are expressed as integer, mean (standard deviation), median (interquartile range) or percentage. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$ versus < 140 mEq/L

Table 4 Comparison of sodium balance with haemodiafiltration and haemodialysis sessions

Variable	Haemodialysis	Haemodiafiltration
Number of sessions	21	118
Dialysate Na (mEq/L)	138 (136–138)	138 (136–139)
Male (%)	12 (57.1)	74 (62.7)
Age (years)	*69.5 ± 16.5*	*63.7 ± 16.1*
Diabetic (%)	5 (23.8)	37 (31.4)
Dialysis vintage (mo.)	62 (39–94)	31 (20–60)**
Dialysate Na in (mEq/L)	14,432 (12,420–14169)	14,280 (12,555–15,750)
Total dialysate Na loss (mEq)	311 (91–608)	381 (167–597)
Convective Na loss (mEq)	109 (100–255)	212 (127–290)
Non-convective Na loss (mEq)	192 (−74 to 387)	180 (−51 to 386)
Session time (min)	213 (186–241)	210 (184–225)
Kt/Vurea	1.59 ± *0.09*	1.61 ± *0.08*
nPNA (g/kg/day)	1.50 ± *0.51*	1.33 ± *0.52*
Temperature °C	35 (35–35)	35 (35–35,5)
Pre-dialysis weight (kg)	69.5 ± *16.3*	74.8 ± *16.9*
Percent sessional weight loss	1.97 (1.27–2.77)	2.05 (1.3–2.9)
Pre-dialysis MAP (mmHg)	100.9 ± *20.3*	101.3 ± *17.3*
Post-dialysis MAP (mmHg)	90.6 ± *14.6*	96.8 ± *17.2*
Pre-dialysis Na (mEq/L)	138 (138–140)	138 (136–140)
Post-dialysis Na (mEq/L)	138 (138–139)	138 (136–139)
Pre–post Na (mEq/L)	0 (−1 to +1)	1 (−1 to +2)
Pre Se Na-Dial Na (Eq/L)	0 (−1 to +2)	1 (−1 to +3)

Kt/Vurea, sessional urea clearance; nPNA, normalised dietary protein intake; MAP, mean arterial pressure; NTproBNP, N terminal brain natriuretic protein. Data are expressed as integer, mean (standard deviation), median (interquartile range) or percentage. ** $p < 0.01$ versus < 140 mEq/L

lower pre- and post-dialysis sodium concentrations, suggesting a difference in sodium set point [19], and a cross-over study also reported a mean 2 mEq/L difference in post-dialysis serum sodium after 3 months using a lower dialysate sodium [20].

We then studied 23 patients who had dialysis sessions using a dialysate sodium of < 140 and a single session with 140 mEq/L. In this setting, pre-dialysis serum sodium concentrations did not differ, and although the total amount of sodium removed in the waste dialysate was not statistically greater with 140 mEq/L dialysate, non-ultrafiltration sodium losses appeared higher. Although using a higher sodium dialysate would suggest a lower or negative serum to dialysate sodium gradient, we found no differences. However, the potential gradient for diffusion was reduced as the post-dialysis serum sodium approached that of dialysate sodium concentration. Second, this was a single dialysis session with 140 mEq/L dialysate, and patients had not re-adjusted to a newer sodium set point by resetting pre-dialysis serum sodium.

There has been a debate as to whether sodium flux differs between convective and diffusive dialysis treatments, with reports of both a lower flux and similar sodium flux reported with convective treatments [21, 22]. This led to some researchers suggesting that the reduction in intradialytic hypotension they observed with convective therapies could have been due to lower sodium fluxes compared to haemodialysis [23]. However, we found no significant difference in total sodium losses with haemodiafiltration compared with haemodialysis and no differences in pre- and post-dialysis session blood pressures or serum sodium supporting the results of a multi-centre clinical trial [24].

Every study has several limitations. Sodium balance depends upon both intake and losses. We measured the net sodium removed with dialysis treatments and assessed dietary sodium intake by using the scored salt questionnaire (SSQ). The great majority of our patients were following a sodium restricted diet with 81% having SSQ scores of < 65, the standard cut-off point for assessing dietary sodium using our SSQ [24]. However, food intake may differ between dialysis and non-dialysis days, and both dietary diaries and SSQs also have limitations [25]. Compared with many other studies, the sessional weight loss was much lower, which may reflect lower dietary sodium intake, so we report lower convective sodium losses compared to others. However, non-ultrafiltration losses then become more important, and so if there was a difference in dialysate sodium balance with different dialysate concentrations, our study would have been more likely to demonstrate any such difference compared with others reporting higher amounts of ultrafiltration. All our dialysis treatments used cooled dialysate, and cold temperatures will reduce the rate of diffusion in in vitro, but whether a small drop in temperature has a clinically significant effect would appear to be less likely [26].

In clinical practice, patients with poor cardiac function, frail elderly patients with reduced dietary sodium intake and those with enteral sodium losses may be dialysed using a higher dialysate sodium compared with younger healthier patients [4, 27], which could introduce confounding when measuring dialysis sodium balance during a single session. However, in this study the change in dialysate sodium was made at a dialysis centre level due to centres entering a study comparing different dialysate sodium concentrations [11]. Although increasing the dialysate sodium has been reported to increase intra-dialytic weight gains, observational studies have suggested that increasing the dialysate sodium by 1 mEq/L was only associated with a marginal

increase in intra-dialytic weight gains [28]. We only measured dialysis sodium balance during a single dialysis session and as such cannot comment on patient outcomes. A recent large multinational observational study reported increased mortality for patients dialysing with lower dialysate sodium concentrations [9], and another from Japan also reported increased mortality for patients with a lower pre-dialysis calculated serum osmolality, using twice the serum sodium concentration [29].

Ideally, the dialysate sodium concentration should be individualised depending upon the amount of sodium in body tissues, dietary intake and sodium losses, including those with physical exercise. However, in clinical practice most dialysis centres have a preferred universal dialysate sodium concentration for the majority of patients. Measuring dialysis sodium balance during a single session, we did not demonstrate a reduction in net dialysate sodium removal by using a higher dialysate sodium concentration of 140 mEq/L compared with lower dialysate sodium concentrations. Patients dialysing with a lower dialysate sodium had lower pre-dialysis serum sodium concentrations, suggesting that over time, the dialysate sodium does affect the sodium set point or osmostat for patients. In addition, we did not find a difference in dialysate sodium balance between high-flux haemodialysis and haemodiafiltration.

Acknowledgements
We thank our patients and dialysis staff for their co-operation and dialysis technicians for designing and constructing dialysate collection.

Author contributions
R.C. collected and analysed data and approved final manuscript version. A.D. proposed project and obtained approvals and approved final manuscript version.

Funding
No external funding.

Data availability
Data were collected as part of a PhD thesis which will be stored in University College London Library. The anonymised data set with all identifiers removed is held on Royal Free Hospital servers. All reasonable applications for the data set will be considered in accordance with NHS procedures and practices.

Declarations

Ethics approval and consent to participate
Ethical approval was obtained from the national research ethics service (21/NI/0059). Written informed consent was obtained from all patients prior to study enrolment in keeping with the Helsinki accord. All patient data were anonymised prior to analysis. Retrospective audit complies with NHS HRA guidelines.

Consent for publication
Not applicable.

Competing interests
Neither author has any conflict of or competing interest.

Received: 26 January 2024 Accepted: 20 May 2024
Published online: 01 June 2024

References

1. Drukker W. Haemodialysis: a historical review. In: Maher JF, editor. Replacement of renal function by dialysis: a textbook of dialysis. Dordrecht: Springer; 1989. p. 20–86.
2. Davenport A. Can advances in haemodialysis machine technology prevent intradialytic hypotension? Semin Dial. 2009;22(3):231–6.
3. Locatelli F, Covic A, Chazot C, Leunissen K, Luño J, Yaqoob M. Optimal composition of the dialysate, with emphasis on its influence on blood pressure. Nephrol Dial Transplant. 2004;19(4):785–96.
4. Tangvoraphonkchai K, Davenport A. Why does the choice of dialysate sodium concentration remain controversial? Hemodial Int. 2018;22(4):435–44.
5. Hecking M, Karaboyas A, Rayner H, Saran R, Sen A, Inaba M, Bommer J, Hörl WH, Pisoni RL, Robinson BM, Sunder-Plassmann G, Port FK. Dialysate sodium prescription and blood pressure in hemodialysis patients. Am J Hypertens. 2014;27:1160–9.
6. Sandhu E, Crawford C, Davenport A. Weight gains and increased blood pressure in outpatient hemodialysis patients due to change in acid dialysate concentrate supplier. Int J Artif Organs. 2012;35(9):642–7.
7. Davenport A. Audit of the effect of dialysate sodium concentration on inter-dialytic weight gains and blood pressure control in chronic haemodialysis patients. Nephron Clin Pract. 2006;104(3):c120–5.
8. Marshall MR, Vandal AC, de Zoysa JR, Gabriel RS, Haloob IA, Hood CJ, Irvine JH, Matheson PJ, McGregor DOR, Rabindranath KS, Schollum JBW, Semple DJ, Xie Z, Ma TM, Sisk R, Dunlop JL. Effect of low-sodium versus conventional sodium dialysate on left ventricular mass in home and self-care satellite facility hemodialysis patients: a randomized clinical trial. J Am Soc Nephrol. 2020;31(5):1078–91.
9. Pinter J, Smyth B, Stuard S, Jardine M, Wanner C, Rossignol P, Wheeler DC, Marshall MR, Canaud B, Genser B. Effect of dialysate and plasma sodium on mortality in a global historical haemodialysis cohort. J Am Soc Nephrol. 2024;35(2):167–76.
10. Basile C, Pisano A, Lisi P, Rossi L, Lomonte C, Bolignano D. High versus low dialysate sodium concentration in chronic haemodialysis patients: a systematic review of 23 studies. Nephrol Dial Transplant. 2016;31(4):548–63.
11. Smyth B, Krishnasamy R, Jardine M, RESOLVE Study Global Team. Are observational reports on the association of dialysate sodium with mortality enough to change practice? Perspective from the RESOLVE Study Team. J Am Soc Nephrol. 2024;35(2):229–31.
12. Ekbal NJ, Consalus A, Persaud J, Davenport A. Reliability of delivered dialysate sodium concentration. Hemodial Int. 2016;20(Suppl 1):S2–6.
13. Persaud J, Thomas M, Davenport A. Indirect ion selective electrode methods potentially overestimate peritoneal dialysate sodium losses. Ther Apher Dial. 2014;18(4):321–5.
14. Davenport A. Survey of food offered to United Kingdom haemodialysis patients attending for dialysis sessions in main dialysis centres and satellite units and international comparison. Ren Replace Ther. 2023;9(1):10. https://doi.org/10.1186/s41100-023-00466-3.
15. Chhabra R, Davenport A. Is increased subjective thirst associated with greater interdialytic weight gains, extracellular fluid and dietary sodium intake? Artif Organs. 2024;48(1):91–7.
16. Depner TA, Daugirdas J. Equations for normalized protein catabolic rate based on two-point modeling of hemodialysis urea kinetics. J Am Soc Nephrol. 1996;7(5):780–5.
17. Gkza A, Davenport A. Estimated dietary sodium intake in haemodialysis patients using food frequency questionnaires. Clin Kidney J. 2017;10(5):715–20.
18. Thein H, Haloob I, Marshall MR. Associations of a facility level decrease in dialysate sodium concentration with blood pressure and interdialytic weight gain. Nephrol Dial Transpl. 2007;22:2630–9.
19. Santos SF, Peixoto AJ. Sodium balance in maintenance hemodialysis. Semin Dial. 2010;23(6):549–55.
20. Radhakrishnan RC, Varughese S, Chandran A, Jacob S, David VG, Alexander S, Mohapatra A, Valson AT, Gopal B, Palani C, Jose A, Antonisamy B, Tamilarasi V. Effects of individualized dialysate sodium prescription in

hemodialysis—results from a prospective interventional trial. Indian J Nephrol. 2020;30(1):3–7.
21. Shaldon S, Baldamus CA, Beau MC, Koch KM, Mion CM, Lysaght MJ. Acute and chronic studies of the relationship between sodium flux in hemodialysis and hemofiltration. Trans Am Soc Artif Intern Organs. 1983;29:641–4.
22. Gotch FA, Evans MC, Keen ML. Measurement of the effective dialyzer Na diffusion gradient in vitro and in vivo. Trans Am Soc Artif Intern Organs. 1985;31:354–8.
23. Di Filippo S, Manzoni C, Andrulli S, Tentori F, Locatelli F. Sodium removal during pre-dilution haemofiltration. Nephrol Dial Transplant. 2003;18(Suppl 7):31–6.
24. Locatelli F, Altieri P, Andrulli S, Bolasco P, Sau G, Pedrini LA, Basile C, David S, Feriani M, Montagna G, Di Iorio BR, Memoli B, Cravero R, Battaglia G, Zoccali C. Haemofiltration and hemodiafiltration reduce intradialytic hypotension in ESRD. J Am Soc Nephrol. 2010;21:1798–807.
25. Amalia RI, Davenport A. Estimated dietary sodium intake in peritoneal dialysis patients using food frequency questionnaires and total urinary and peritoneal sodium losses and assessment of extracellular volumes. Eur J Clin Nutr. 2019;73(1):105–11.
26. Marcelli D, Basile C. Does the relationship between measured and prescribed dialysate sodium matter in the nephrology community? Nephrol Dial Transpl. 2021;36(4):577–80.
27. Khatri P, Davenport A. Dialysis for older adults: Why should the targets be different? J Nephrol. 2024. https://doi.org/10.1007/s40620-023-01835-1.
28. Wong MM, McCullough KP, Bieber BA, Bommer J, Hecking M, Levin NW, McClellan WM, Pisoni RL, Saran R, Tentori F, Tomo T, Port FK, Robinson BM. Interdialytic weight gain: trends, predictors, and associated outcomes in the international dialysis outcomes and practice patterns study (DOPPS). Am J Kidney Dis. 2017;69(3):367–79.
29. Tsujimoto Y, Tsutsumi Y, Ohnishi T, Kimachi M, Yamamoto Y, Fukuhara S. Low Predialysis plasma calculated osmolality is associated with higher all-cause mortality: the Japanese dialysis outcomes and practice patterns study (J-DOPPS). Nephron. 2020;144(3):138–46.

Publisher's Note