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Sodium Modeling to Reduce Intradialytic Hypotension during Haemodialysis for Acute Kidney Injury in the Intensive Care Unit

Katherine E. Lynch[1], **Fatimah Ghassemi**[2], **Jennifer E. Flythe**[3], **Mengling Feng**[2,4], **Marzyeh Ghassemi**[2,5], **Leo Anthony Celi**[2,6], and **Steven M. Brunelli**[7]

[1]Division of Nephrology, Beth Israel Deaconess Medical Center, Boston, MA

[2]Harvard-Massachusetts Institute of Technology Division of Health Sciences and Technology, Cambridge, MA

[3]Division of Nephrology and Hypertension, University of North Carolina Kidney Center, Chapel Hill, NC

[4]Institute for Infocomm Research, Agency for Science, Technology and Research, Singapore

[5]The Computer Science and Artificial Intelligence Laboratory, Massachusetts Institute of Technology, Cambridge, MA

[6]Divsion of Pulmonary, Critical Care, and Sleep Medicine, Beth Israel Deaconess Medical Center, Boston, MA

[7]DaVita Clinical Research, Minneapolis, MN

Abstract

Aim—Intradialytic hypotension often complicates haemodialysis for patients with acute kidney injury (AKI), and may impact renal recovery. Sodium modeling is sometimes used as prophylaxis against intradialytic hypotension in the chronic haemodialysis population, but there is little evidence for its use among critically ill patients with AKI.

Methods—A retrospective cohort with AKI requiring intermittent haemodialysis in the intensive care unit from 2001–2008 was used to study the association of prophylactic sodium modeling and multiple outcomes. Outcomes included a composite of in-hospital death or dialysis dependence at hospital discharge, as well as intradialytic hypotension, ultrafiltration goal achievement, and net ultrafiltration volume. Associations were estimated using logistic regression, mixed linear models, and generalized estimating equations adjusting for demographic and clinical characteristics.

Results—191 individuals who underwent 892 sessions were identified; sodium modeling was prescribed in 27.1% of the sessions. In adjusted analyses, sodium modeling was not significantly associated with intradialytic hypotension (p=0.67) or with the ultrafiltration goal achievement (p=0.06). Sodium modeling during the first dialysis session was numerically associated with lower risk for the composite of in-hospital death or dialysis dependence: adjusted OR (95% CI) 0.39 (0.15–1.02; p=0.06); however, this association did not reach statistical significance.

Corresponding author: Katherine Lynch, 330 Brookline Ave, Libby 2, Boston, MA 02215, Phone: 617-632-9880, Fax: 617-632-9890, kelynch@bidmc.harvard.edu.

Conclusion—We did not observe statistically significant associations between sodium modeling and improved outcomes among AKI patients receiving intermittent dialysis in the intensive care unit. However, suggestive findings warrant further study.

Keywords

Acute renal failure; haemodialysis; haemodynamics; intradialytic hypotension; sodium modeling

Introduction

Acute kidney injury (AKI) requiring haemodialysis (HD) in the intensive care unit (ICU) is associated with morbidity and mortality.[1] Intradialytic hypotension (IDH) is an inherent risk of HD and is exacerbated by the haemodynamic instability that often accompanies AKI in the ICU. IDH affects an estimated 30% of dialysis treatments among critically ill patients with AKI.[2] Evidence suggests that IDH impairs, and at times precludes renal recovery,[3–5] and is also independently associated with greater in-hospital mortality.[3]

IDH-mitigating interventions for end-stage renal disease patients include cool dialysate,[6] albumin administration,[7] sequential ultrafiltration (UF)-HD,[8] and sodium modeling.[9] Existing data suggest that sodium modeling mitigates IDH in the setting of routine ambulatory dialysis for end-stage renal disease.[9–17] Specifically, sodium modeling has been shown to decrease the number of hypotensive episodes during dialysis,[10–12, 15, 17, 18] decrease the number of nursing interventions required for IDH,[10, 11, 18] and decrease the number of symptoms attributed to hypotension.[9, 10, 13, 15] Compared to non-modeled dialysis protocols, sodium modeling has been associated with higher mean arterial pressures[10, 17] and higher post-HD blood pressure.[9, 18] The beneficial effects of sodium modeling are thought to be mediated by blunted fluid shifts between the intravascular and intracellular spaces.[12, 19, 20]

Evidence on sodium modeling's effectiveness in outpatient chronic HD patients cannot be generalized to sicker, less stable patients in the ICU with AKI. However, if haemodynamic benefits were confirmed in this population, sodium modeling may be particularly beneficial because the effects of supra-physiological dialysate sodium may be largely mitigated among ICU patients who typically have little oral intake. There have been few studies examining the effect of sodium modeling in the AKI population, and most have examined sodium modeling co-administered with other interventions; thereby there is no evidence regarding the independent effect of sodium modeling on outcomes. Based on the paucity of evidence, there is no general recommendation for use of sodium modeling among ICU patients dialyzed for AKI. We undertook this study to evaluate the association of sodium modeling use in AKI patients in the ICU with the occurrence of IDH, ability to meet UF goals, and the composite of in-hospital death or dialysis dependence at discharge.

Subjects and Methods

Study Design

This study was approved by the Beth Israel Deaconess Medical Center (BIDMC) Institutional Review Board. Data was obtained from the Multiparameter Intelligent Monitoring in Intensive Care II (MIMIC-II) database[21, 22] and from structured abstraction of patient health records. The MIMIC-II database contains over 25,000 adult ICU admissions at BIDMC between 2001 and 2008. Detailed data were collected for every patient admitted to the ICU for this period.

This study included adult patients who underwent at least one intermittent HD session for the treatment of AKI while in the ICU. Patients with pre-existing end-stage renal disease, defined as a need for chronic renal replacement therapy prior to admission or a pre-admission estimated glomerular filtration rate (eGFR) <15 mL/min/m^2, were excluded.

Exposures, Outcomes, and Covariates

Sodium modeling was ascribed if dialysate sodium began >140 mEq/L and was thereafter reduced during the course of dialysis. In some cases, the dialysis prescription only included the label “sodium modeling” without specification of precise sodium values; these were also ascribed as sodium modeling. Determination of sodium modeling was made by manual review of the dialysis records from the inpatient chart.

We considered the following outcomes on a session-by-session basis: the occurrence of IDH (defined as a systolic blood pressure <80 mmHg or a 50 mmHg drop from the pre-HD blood pressure[23]), net UF volume, and UF goal achievement. Data on these outcomes were obtained by chart review. For some treatments (24.3% of sessions), the UF goal was prescribed as a range (eg, 2–3 L): in these instances attainment of the UF goal was based on the high end of the range.

Time-varying covariates were extracted from the data present prior to the start of the dialysis session being considered. Laboratory data and pre-HD blood pressures were drawn from the proximate values prior to the start of the HD session. Sequential organ failure assessment (SOFA) scores were calculated daily from individual components. Vasopressor use, ventilator support, ICU type, day of hospitalization, and prior use of continuous renal replacement therapy (CRRT) were determined by their presence at the start of dialysis. Total urine output was determined from the 24 hours prior to the start of the session. Dialysis prescriptions, prior use of CRRT, and pre-HD blood pressures were obtained from review of the inpatient medical record. Baseline eGFR was calculated (when possible) using the mean outpatient serum creatinine measured within one year of hospitalization (365 to 7 days prior to admission).[24] All other data were drawn from the MIMIC database.

Clinical outcomes, considered on a per-patient basis, included the composite of in-hospital death or dialysis dependence at time of discharge (primary outcome), in-hospital death, and dialysis dependence at hospital discharge. Outcomes were obtained by chart review. In per-patient analyses, sodium modeling exposure was based on each patient’s first HD treatment

in the ICU. Analyses considered the same covariates as above, considering each as of the time of the first ICU dialysis session.

Statistical Analyses

Baseline characteristics were described as means with standard deviations, medians with a range from quartile 1 to quartile 3, or counts with percentages. For per-session analyses, baseline characteristics were compared between sessions with sodium modeling and sessions with stable dialysate sodium using linear, logistic, and multinomial logistic regression (depending on data type) with a clustered variance estimators. For per-patient analyses comparisons between groups were made using t-tests, Wilcoxon rank-sum tests, and Chi-square tests, as dictated by data type.

Multiple imputation was used to estimate missing data for all covariates with missing data. Missing exposure and outcome data were not imputed, but values of exposure and outcome variables were included in imputation models as recommended.[25] Multiple imputation was completed using chained equations. Models were created to predict the missing values for variables using ordered logistic regression, linear regression, and predictive mean matching as appropriate.

The unadjusted and adjusted associations between sodium modeling and the binary outcomes of IDH occurrence and UF goal achievement were evaluated using generalized estimating equations. Mixed effects linear regression was used to evaluate the association between sodium modeling and net UF amount achieved. A sensitivity analysis evaluated an alternative definition of IDH to include a systolic blood pressure <80 mmHg or a 50 mmHg drop from the pre-HD blood pressure and/or start of vasopressors during the dialysis session.

Our final per-session model included covariate terms for pre-HD systolic blood pressure, vasopressor use, age, sex, race (white versus nonwhite), diabetes, hypertension, systolic congestive heart failure, cirrhosis, serum albumin, BUN, respiratory support, ICU location (medical versus surgical ICU), sequential UF-HD, cooled dialysate use, albumin given with dialysis, urine output in the 24 hours prior to the dialysis (oliguric (≤400 mL) versus non-oliguric), prior CRRT, total SOFA score, day of hospitalization, and initial high UF goal. To test the robustness of findings, we conducted sensitivity analyses in which estimates were adjusted for pre-HD systolic blood pressure, vasopressor use, and a propensity score for sodium modeling; the latter was estimated via a pooled logistic regression model that considered all remaining covariates.

Unadjusted and multivariable adjusted associations between sodium modeling during the first HD session and the composite of all-cause mortality and dialysis dependence at time of discharge were assessed using logistic regression. Secondary outcomes included each component of the composite outcome separately. The final multivariable model for these analyses contained the same covariates as the per-session analyses, except the UF goal was not included as a covariate for the per-patient analyses (as the UF goal for the initial dialysis session is likely unrelated to later outcomes) and baseline eGFR (<60 versus ≥60 mL/min) was included as a covariate given its association with likelihood of renal recovery after AKI. Analogous to the per-session analyses, sensitivity analyses were conducted where estimates

were adjusted for pre-HD systolic blood pressure, vasopressor use, and a propensity score for sodium modeling. All analyses were completed using Stata SE, version 12.0 (College Station, TX).

Results

Patient Characteristics

Among all adult ICU stays within the MIMIC-II database, 191 individuals were identified who had at least one intermittent HD session during their ICU stay. They had mean age of 62 years, 39% were female, 73% were white, 33% had a history of diabetes, 54% systolic heart failure, and 13% cirrhosis. The most common classes of admission diagnoses were cardiovascular (28%), infectious (25%), AKI (14%), and gastrointestinal (8%). The majority of patients (55.0%) were located in a medical (versus surgical) ICU.

Per-session analyses

The 191 patients underwent a total of 899 intermittent dialysis sessions while in the ICU. Out of the 899 HD sessions, 7 sessions lacked documented dialysate sodium and therefore were excluded, leaving a total of 892 HD sessions for the per-session analyses. The median [p25, p75] number of HD sessions contributed per patient was 3 [2, 6]; the range was 1 to 31 sessions. Two hundred and forty-two (27.1%) of the 892 sessions were prescribed sodium modeling prior to the start of HD.

IDH was observed for 95 (10.7%) sessions. The median [p25, p75] UF goal was 2.25 [1.5, 3] liters. The UF achieved during the entire session had a median [p25, p75] of 2 [1, 3] liters. UF goal was achieved in 546 (61.2%) of sessions.

There were notable differences in baseline characteristics. Compared to a stable dialysate sodium prescription, sodium modeling was associated with a lower prevalence of hypertension and diabetes, lower serum albumin and BUN, a longer length of stay at the time of the session, more use of vasopressors and cool dialysate, lower pre-HD systolic and mean arterial blood pressures, a higher likelihood of oliguria in the preceding 24 hours prior to HD, a longer prescribed duration of dialysis, and a longer achieved dialysis time (Table 1).

In unadjusted analyses, sodium modeling use was associated with a significantly greater risk of IDH (OR (95% CI) 1.70 (1.02–2.84); Table 2). Upon adjustment for baseline imbalances there was no significant difference in occurrence of IDH (OR (95% CI) 0.88 (0.49–1.59)); results were essentially identical in propensity score adjusted models. Using the alternative definition of IDH, which included the start of vasopressors during the dialysis session in addition to the blood pressure cutoffs, an additional 24 sessions were classified as meeting the definition for IDH. However, the association between sodium modeling and IDH was not significantly changed using the more liberal definition of IDH (data not shown).

In unadjusted analysis, sodium modeling was associated an increased odds of failing to achieve the UF goal (OR (95% CI) 1.67 (1.18–2.37); Table 2). Upon multivariable

adjustment, this association was modestly attenuated and no longer statistically significant (OR (95% CI) 1.47 (0.99–2.20)).

There was no association between sodium modeling and the amount of UF achieved in unadjusted or multivariable adjusted analyses (Table 2). Multivariable adjustment and propensity score adjusted models yielded similar results.

Per-patient analyses

In total 120 of 191 individuals met the composite endpoint of in-hospital death or dialysis dependence upon discharge: 48 (25.1% of total) died; 72 (50.4% of those surviving to discharge) required ongoing dialysis at the time of discharge. Hospice care (comfort-measures only) was chosen by 8 of the 48 who died in hospital, 6 of the 72 who were discharged with continued need for dialysis, and 1 of the 71 patients who was discharged with renal recovery.

Thirty (15.7%) individuals were prophylactically prescribed dialysate sodium modeling. Patients prescribed sodium modeling (versus not) were less likely to be white, diabetic, were more likely to be cirrhotic and have greater use of vasopressors and cool dialysate. Patients prescribed sodium modeling had lower pre-HD systolic and mean arterial blood pressures, and achieved a longer duration of dialysis (Table 3).

In unadjusted analyses, there were no statistically significant associations between use of sodium modeling and the composite outcome (OR (95% CI) 0.63 (0.29–1.38)), or its individual components (Table 4). Upon adjustment for baseline differences, there was suggestion that sodium modeling was associated with lower risk of the composite outcome, however this association did not achieve statistical significance (OR (95% CI) of 0.39 (0.15–1.02); p=0.06). A similar pattern of association was observed for individual components of the composite endpoint.

Discussion

Ongoing discussion surrounds the choice between CRRT and intermittent HD, and for those receiving intermittent HD for AKI there is little evidence to recommend specific dialysis prescriptions to improve clinical outcomes. In this study of 191 patients with AKI who underwent intermittent HD in the ICU, we did not observe statistically significant associations between use of sodium modeling with IDH, attainment of UF goal, total UF volume, or the composite outcome of all-cause mortality and dialysis dependence at time of discharge.

Two prior randomized controlled trials have sought to evaluate the impact of sodium modeling on outcomes among patients with AKI. Paganini et al. examined the combination of sodium and UF modeling and found a decrease in required nursing interventions and blood volume changes when compared to fixed UF and sodium prescriptions.[26] In a study combining dialysate cooling, sodium modeling, and UF modeling with use of sustained low-efficiency dialysis, the intervention group had significantly fewer hypotensive episodes despite achieving significantly higher UF volumes.[27] However, due to issues of small sample

size and co-interventions, prior data have not adequately assessed the independent effects of sodium modeling per se in the context of intermittent HD.

We performed per-session analyses to examine whether use of sodium modeling was associated with IDH and the ability to achieve UF. Sodium modeling was not significantly associated with a decreased risk of IDH. An issue with the outcome of IDH arises from a lack of validated definition in an AKI population. IDH is poorly defined even among chronic HD patients with a variety of definitions used in previous studies.[28–30] In chronic HD patients, IDH definitions often include a requisite intradialytic drop in blood pressure +/− absolute nadir blood pressure levels and the development of symptoms of hypotension or the need for intervention.[29] In an ICU population where many patients are intubated or minimally responsive (who cannot report symptoms) and among whom ambient blood pressure levels tend to be lower irrespective of dialysis, such definitions are less applicable. Additionally, in the ICU there is the opportunity to use vasopressors to mitigate IDH and when we added new vasopressor use during dialysis to the definition of IDH, this resulted in 24 additional sessions being classified as having IDH. However, the results from the analysis were unchanged. We chose a definition of nadir systolic blood pressure ≤80 mmHg or 50 mmHg drop from the baseline blood pressure based on precedent from the Hemodiafe study which was conducted among AKI patients in the ICU.[23] With this strict definition of IDH, only 10.7% of sessions met the definition. However, the ideal definition of IDH has not been determined and this analysis is limited by lack of a validated definition for IDH among AKI patients in the ICU.

Use of sodium modeling was not associated with greater likelihood of achieving the UF goal. In fact, failure of UF goal achievement was more common in the setting of sodium modeling, although this association was not statistically significantly after multivariable adjustment. We acknowledge the likely possibility that this analysis was residually confounded by the non-recorded patient differences that may have affected a provider's decision to prescribe sodium modeling. Unless data to the contrary become available, sodium modeling cannot be endorsed as a means to enable attainment of UF goals. Similar considerations apply for net UF volume, for which no directional association with sodium modeling was observed.

Despite having a larger sample size than prior studies, our study was underpowered to detect an association between sodium modeling and the primary composite endpoint. Our power calculations were based on an assumption of more prevalent sodium modeling prescriptions and an assumption that there would be more intermittent HD sessions in the ICU during the time period of the study. Instead, we found fewer sodium modeling prescriptions and fewer intermittent HD sessions than expected as a significant portion of AKI patients received CRRT only while in the ICU. Additionally, from Tables 1 and 3, it is evident that the patients who received sodium modeling tended to be sicker than patients who did not. Unadjusted estimates in Tables 2 and 4 show point estimates that do not favor the use of sodium modeling. With multivariable adjustment, these point estimates are attenuated, and in some cases shift to suggest benefit from sodium modeling. The sodium modeling groups achieved a longer duration of dialysis than the groups with a stable dialysate sodium level. Dialysis time is likely on the causal pathway between sodium modeling and clinical

outcomes, and therefore we chose not to adjust for dialysis time in our analyses. Although we attempted to include important confounders and adjust for confounding by indication, we acknowledge that adjustment is incomplete. Potential benefits of sodium modeling are likely to be underestimated due to residual confounding. Therefore, our findings cannot fully rule out a benefit from sodium modeling.

Several other limitations of the present study bear note. First, limited sample size and data limitations necessitated that sodium modeling be considered monolithically; therefore we were unable to examine whether individual sodium modeling protocols performed differentially. Second, we lacked of baseline eGFR for many patients. Given its importance to the outcome of renal recovery, missing values were imputed using multiple imputation to try to minimize bias; however imputation is based on multiple assumptions that cannot be verified empirically. Third, per-patient analyses considered exposure status as of the first HD treatment rendered in the ICU. This choice was made to minimize the potential for time-dependent confounding where hypotension in one treatment begets sodium modeling in a subsequent treatment. However, this approach imparts exposure misclassification (i.e., some patients will have varied between use of sodium modeling and stable sodium in subsequent dialysis sessions), which may have spuriously underestimated any associated benefits or harm related to sodium modeling. Fourth, we did not have access to long-term renal outcomes; some of the patients discharged on dialysis may have later recovered renal function. Fifth, due to inconsistent weighing practices we were unable to evaluate for interdialytic weight gain differences between the sodium modeling and stable dialysate sodium groups. Lastly, in many other countries intermittent HD is rarely used in the ICU, limiting the external validity of these results to those countries where intermittent HD is used in this setting.

In conclusion, for patients with AKI undergoing intermittent HD in the ICU, our analyses do not show a statistically significant benefit for use of sodium modeling. A prospective interventional trial may be warranted given the suggestion of a possible association between the use of sodium modeling and greater likelihood of dialysis-free hospital survival. Based on the event rates and effect size observed in this study, estimates indicate that a sample size of 313 subjects to each of two trial groups (sodium modeling versus stable sodium) would be necessary.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Table 1

Association between sodium modeling and covariates at the per session level (N=892).

Covariate	Sodium modeling (n = 242)†	Stable dialysate sodium (n = 650)†	P-value‡
Dialysate sodium (mmol/L)	NA	140 [140, 140]	NA
Age§ (years)	64.9 +/− 15.3	61.4 +/− 15.4	0.18
Female§	109 (45.0%)	220 (33.8%)	0.21
White race§ (vs. nonwhite)	144 (59.5%)	470 (72.3%)	0.15
Systolic congestive heart failure§	121 (50.1%)	343 (52.8%)	0.76
Hypertension§	17 (7.0%)	108 (16.6%)	0.02
Coronary artery disease	58 (23.9%)	122 (18.8%)	0.57
Diabetes§	42 (17.4%)	208 (32.0%)	0.009
Cirrhosis§	26 (10.7%)	53 (8.2%)	0.50
Serum albumin§ (g/L)	25 +/− 6 (n = 235)	26 +/− 6 (n = 632)	0.03
Serum sodium (mmol/L)	138 +/− 5 (n=241)	138 +/− 5	0.14
WBC (K/uL)	13.6 +/− 7.4 (n = 240)	13.4 +/− 6.8 (n = 647)	0.90
BUN§ (mmol/L)	25.7 +/− 10.4 (n = 240)	28.2 +/− 12.9	0.04
SOFA score§	13 +/− 2 (n = 180)	13 +/− 3 (n = 439)	0.93
Day of hospitalization§	30 [14, 55]	15 [8, 28]	0.003
Prior use of CRRT§	115 (47.5%)	257 (39.5%)	0.37
Pre-HD use of vasopressors§	63 (26.0%)	98 (15.1%)	0.05
Pre-HD systolic blood pressure§ (mmHg)	119 +/− 20	133 +/− 22 (n = 649)	<0.001
Pre-HD mean arterial pressure (mmHg)	78 +/− 15	85 +/− 15 (n = 649)	<0.001
Admission diagnosis category			
Cardiovascular	103 (42.6%)	199 (30.6%)	<0.001
Infectious	50 (20.7%)	160 (24.6%)	
Renal	11 (4.6%)	74 (11.4%)	
Other	78 (32.2%)	217 (33.4%)	
Respiratory Failure§	168 (69.4%)	392 (60.3%)	0.14
Medical ICU§ (vs. surgical)	124 (51.2%)	322 (49.5%)	0.85

Covariate	Sodium modeling (n = 242)†	Stable dialysate sodium (n = 650)†	P-value‡
Non-oliguric in the 24h prior to session§	36 (14.9%)	165 (25.4%)	0.03
Cooled dialysate§	29 (12.0%)	15 (2.3%)	<0.001
Sequential UF-HD§	9 (3.7%)	29 (4.5%)	0.66
Albumin use§	11 (4.5%)	16 (2.5%)	0.20
Initial UF goal§ (L)	2.5 [1.5, 3]	2 [1.5, 3]	0.98
Prescribed duration of dialysis (minutes)	210 [180, 210]	180 [180, 210] (n=649)	0.03
Achieved duration of dialysis (minutes)	202 [180, 230]	180 [150, 210]	0.01
Blood Flow (mL/min)	310 +/− 46	292 +/− 55	0.02
Dialysate Calcium (mEq/L)	2.5 [2.5, 2.5]	2.5 [2.5, 2.5]	0.95

†Unless otherwise noted; normally distributed continuous variables are presented as mean +/− standard deviation; non-normal continuous variables are presented as median [quartile 1, quartile 3]; categorical variables are presented as count (percent).

‡P-values were generated using linear, logistic, or multinomial logistic regression with a clustered variance estimator, dictated by data type.

§Variables included in the multivariable model.

Abbreviations: WBC, white blood count; BUN, blood urea nitrogen; SOFA, sequential organ failure assessment; CRRT, continuous renal replacement therapy; HD, hemodialysis; ICU, intensive care unit; UF, ultrafiltration.

Table 2

Per-session outcomes by dialysate sodium prescription (modeling versus stable sodium value) prior to each session (n = 892).

	Sodium Modeling (N=242)	Stable dialysate sodium (N=650)
IDH		
N (%) affected sessions	36 (14.9%)	59 (9.1%)
Crude OR (95% CI)	1.70 (1.02–2.84) p=0.04	1 (ref)
Multivariable adjusted OR (95% CI) †	0.88 (0.49–1.59) p=0.67	1 (ref)
Propensity score adjusted OR (95% CI) ‡	0.87 (0.47–1.61) p=0.66	1 (ref)
Failure to achieve UF goal		
N (%) affected sessions	118 (48.8%)	228 (35.1%)
Crude OR (95% CI)	1.67 (1.18–2.37) p=0.004	1 (ref)
Multivariable adjusted OR (95% CI) †	1.47 (0.99–2.20) p=0.06	1 (ref)
Propensity score adjusted OR (95% CI) ‡	1.41 (0.94–2.10) p=0.10	1 (ref)
Achieved UF volume		
Mean +/− SD	2.00 +/− 1.29	2.13 +/− 1.37
Crude difference (95% CI)	0.08 (−0.13 to 0.29) p=0.46	0 (ref)
Multivariable adjusted difference †	−0.01 (−0.16 to +0.13) p=0.84	0 (ref)
Propensity score adjusted difference ‡	+0.19 (−0.05 to +0.42) p=0.12	0 (ref)

† Adjusted for pre-HD systolic blood pressure, vasopressor use, age, sex, race (white vs nonwhite), diabetes, hypertension, systolic congestive heart failure, cirrhosis, albumin, BUN, respiratory support, ICU location (MICU versus SICU), sequential UF-HD, cooled dialysate, albumin given with dialysis, urine output in the 24 hours prior to the dialysis (oliguric versus non-oliguric), prior CRRT, total SOFA score, day of hospitalization, and initial UF goal.

‡ Adjusted for pre-HD systolic blood pressure, vasopressor use, and a propensity score based on likelihood of sodium modeling prescription using age, sex, race (white vs nonwhite), diabetes, hypertension, systolic congestive heart failure, cirrhosis, albumin, BUN, respiratory support, ICU location (MICU versus SICU), sequential UF-HD, cooled dialysate, albumin given with dialysis, urine output in the 24 hours prior to the dialysis (oliguric versus non-oliguric), prior CRRT, total SOFA score, day of hospitalization, and initial UF goal.

Table 3

Association between sodium modeling and covariates at the patient level (N=191).

Covariate	Sodium modeling (n = 30) †	Stable dialysate sodium (n = 161) †	P-value‡
Dialysate sodium (mmol/L)	NA	140 [140, 140]	NA
Age§ (years)	61.3 +/− 17.2	62.5 +/− 15.5	0.66
Female§	13 (43.3%)	62 (38.5%)	0.62
White race§ (vs. nonwhite)	17 (56.7%)	123 (76.4%)	0.03
Systolic congestive heart failure§	12 (40.0%)	91 (56.5%)	0.10
Hypertension§	6 (20.0%)	32 (19.9%)	0.99
Coronary artery disease	4 (13.3%)	29 (18.0%)	0.53
Diabetes§	5 (16.7%)	57 (35.4%)	0.04
Cirrhosis§	7 (23.3%)	17 (10.6%)	0.05
Serum albumin§ (g/L)	28 +/− 6 (n = 26)	28 +/− 7 (n=149)	0.77
Serum sodium (mmol/L)	137 +/− 5	136 +/− 5	0.28
WBC (K/uL)	14.5 +/− 8.8	13.5 +/− 7.1	0.85
BUN§ (mmol/L)	31.1 +/− 11.1	32.1 +/− 15.7	0.78
SOFA score§	13 +/− 3 (n = 20)	13 +/− 3 (n = 100)	0.71
Day of hospitalization§	9 [4, 24]	8 [3, 16]	0.22
Prior use of CRRT§	7 (23.3%)	51 (31.7%)	0.36
Pre-HD use of vasopressors§	9 (30.0%)	21 (13.0%)	0.02
Pre-HD systolic blood pressure§ (mmHg)	119 +/− 16	129 +/− 21 (n = 160)	0.01
Pre-HD mean arterial pressure (mmHg)	78 +/− 12	84 +/− 15 (n = 160)	0.04
Admission diagnosis			0.26
Cardiovascular	9 (30.0%)	44 (27.3%)	
Infectious	7 (23.3%)	40 (24.8%)	
Renal	1 (3.3%)	26 (16.2%)	
Other	13 (43.3%)	51 (31.7%)	
Respiratory Failure§	20 (66.7%)	88 (54.7%)	0.22
Medical ICU§ (vs. surgical)	19 (63.3%)	86 (53.4%)	0.32

Covariate	Sodium modeling (n = 30) †	Stable dialysate sodium (n = 161) †	P-value‡
Non-oliguric in the 24h prior to session§	10 (33.3%)	56 (34.8%)	0.88
Cooled dialysate§	3 (10.0%)	4 (2.5%)	0.04
Sequential UF-HD§	2 (6.7%)	10 (6.2%)	0.93
Albumin use§	3 (10.0%)	8 (5.0%)	0.28
Initial UF goal (L)	1 [0.5, 2]	1.5 [1, 2]	0.22
Baseline eGFR§ (mL/min/1.73 m^2)			
<60	5	51	
≥60	7	28	0.24
Missing	18	82	
Prescribed duration of dialysis (minutes)	180 [150, 180]	150 [120, 180]	0.14
Achieved duration of dialysis (minutes)	180 [150, 185]	135 [120, 180]	0.02
Blood Flow (mL/min)	300 [200, 300]	250 [200, 300]	0.02
Dialysate Calcium (mEq/L)	2.5 [2.5, 2.5]	2.5 [2.5, 2.5]	0.74

† Unless otherwise noted; normally distributed continuous variables are presented as mean +/− standard deviation; non-normal continuous variables are presented as median [quartile 1, quartile 3]; categorical variables are presented as count (percent).

‡ P-values were generated for categorical variables using the Chi-square test and calculated for continuous variables using the t-test or Wilcoxon rank-sum test depending on normality.

§ Variables included in the multivariable model.

Abbreviations: WBC, white blood count; BUN, blood urea nitrogen; SOFA, sequential organ failure assessment; CRRT, continuous renal replacement therapy; HD, hemodialysis; ICU, intensive care unit; UF, ultrafiltration; eGFR, estimated glomerular filtration rate.

Table 4

Per-patient outcomes based on dialysate sodium prescription (modeling versus stable sodium) prior to each individual's (n=191) initial intermittent dialysis session.

	Sodium Modeling (N=30)	Stable dialysate sodium (N=161)
Composite of in-hospital death or dialysis dependence at hospital discharge		
N (%) affected patients	16 (53.3%)	104 (64.6%)
Crude OR (95% CI)	0.63 (0.29–1.38) p=0.24	1 (ref)
Multivariable adjusted OR (95% CI) †	0.39 (0.15–1.02) p=0.06	1 (ref)
Propensity score adjusted OR (95% CI)‡	0.48 (0.20–1.15) p=0.10	1 (ref)
In-hospital death		
N (%) affected patients	6 (20.0%)	42 (26.1%)
Crude OR (95% CI)	0.71 (0.27–1.85) p=0.48	1 (ref)
Multivariable adjusted OR (95% CI) †	0.28 (0.07–1.17) p=0.08	1 (ref)
Propensity score adjusted OR (95% CI)‡	0.45 (0.15–1.35) p=0.15	1 (ref)
Dialysis dependence among patients who survived to hospital discharge		
N patients alive at discharge	24	119
N (%) patients with persistent HD need	10 (58.3%)	62 (47.9%)
Crude OR (95% CI)	0.66 (0.27–1.60) p=0.35	1 (ref)
Multivariable adjusted OR (95% CI)†	0.54 (0.17–1.68) p=0.29	1 (ref)
Propensity score adjusted OR (95% CI)‡	0.56 (0.21–1.48) p=0.24	1 (ref)

†Pre-HD systolic blood pressure, vasopressor use, age, sex, race (white vs nonwhite), diabetes, hypertension, systolic congestive heart failure, cirrhosis, albumin, BUN, respiratory support, ICU location (MICU versus SICU), sequential UF-HD, cooled dialysate, albumin given with dialysis, urine output in the 24 hours prior to the dialysis (oliguric versus non-oliguric), prior CRRT, total SOFA score, day of hospitalization, and baseline eGFR (<60 versus ≥60).

‡Adjusted for pre-HD systolic blood pressure, vasopressor use, and a propensity score based on likelihood of sodium modeling prescription using age, sex, race (white vs nonwhite), diabetes, hypertension, systolic congestive heart failure, cirrhosis, albumin, BUN, respiratory support, ICU location (MICU versus SICU), sequential UF-HD, cooled dialysate, albumin given with dialysis, urine output in the 24 hours prior to the dialysis (oliguric versus non-oliguric), prior CRRT, total SOFA score, day of hospitalization, and baseline eGFR (<60 versus ≥60).