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ORIGINAL ARTICLE

Pilot study to reduce interdialytic weight gain by provision of low-sodium, home-delivered meals in hemodialysis patients

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Abstract

Introduction: Patients with kidney failure undergoing maintenance hemodialysis (HD) therapy are routinely counseled to reduce dietary sodium intake to ameliorate sodium retention, volume overload, and hypertension. However, low-sodium diet trials in HD are sparse and indicate that dietary education and behavioral counseling are ineffective in reducing sodium intake. This study aimed to determine whether 4 weeks of low-sodium, home-delivered meals in HD patients reduces interdialytic weight gain (IDWG). Secondary outcomes included changes in dietary sodium intake, thirst, xerostomia, blood pressure, volume overload, and muscle sodium concentration.

Methods: Twenty HD patients (55 ± 12 years, body mass index [BMI] 40.7 ± 16.6 kg/m^2) were enrolled in this study. Participants followed a usual (control) diet for the first 4 weeks followed by 4 weeks of three low-sodium, home-delivered meals per day. We measured IDWG, hydration status (bioimpedance), standardized blood pressure (BP), food intake (3-day dietary recall), and muscle sodium (magnetic resonance imaging) at baseline (0 M), after the 4-week period of usual diet (1 M), and after the meal intervention (2 M).

Findings: The low-sodium meal intervention significantly reduced IDWG when compared to the control period (−0.82 ± 0.14 kg; 95% confidence interval, −0.55 to −1.08 kg; $P < 0.001$). There were also 1 month (1 M) to 2 month (2 M) reductions in dietary sodium intake (−1687 ± 297 mg; $P < 0.001$); thirst score (−4.4 ± 1.3; $P = 0.003$), xerostomia score (−6.7 ± 1.9; $P = 0.002$), SBP (−18.0 ± 3.6 mmHg; $P < 0.001$), DBP (−5.9 ± 2.0 mmHg; $P = 0.008$), and plasma phosphorus −1.55 ± 0.21 mg/dL; $P = 0.005$), as well as a 0 M to 2 M reduction in absolute volume overload (−1.08 ± 0.33 L; $P = 0.025$). However, there were no significant changes in serum or tissue sodium (all $P > 0.05$).

Discussion: Low-sodium, home-meal delivery appears to be an effective method for improving volume control and blood pressure in HD patients. Future studies with larger sample sizes are needed to examine the long-term effects of home-delivered meals on these outcomes and to assess cost-effectiveness.

Keywords: Hemodialysis, sodium, meal delivery, interdialytic weight gain, blood pressure, volume overload

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INTRODUCTION

Patients with kidney failure undergoing maintenance hemodialysis (HD) therapy have excessive cardiovascular comorbidities that contribute to a poor quality of life,

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higher mortality, and excessive health care costs.[1] Chronic volume overload is a primary driver of the cardiovascular comorbidities in HD, including hypertension, left ventricular hypertrophy, and heart failure.[2] The prevalence of volume overload and hypertension in HD patients may approach between 40% and 90%, respectively, depending on the populations studied and definitions used.[2–5] Acute volume overload manifests in HD patients because kidney failure results in interdialytic weight gain (IDWG) that is secondary to excess fluid consumption.[6] In patients with excessive IDWG, not all of the excess fluid can be removed by ultrafiltration during dialysis due to side effects such as cramping and intradialytic hypotension,[7,8] leading to chronic volume overload.[9] To mitigate these effects, dialysis sessions may be shortened or skipped, saline treatments may be provided, or ultrafiltration rates reduced, each of which may further exacerbate volume overload.[7,10]

One strategy to prevent and treat volume overload and hypertension is to reduce dietary sodium intake, which should reduce thirst as well as subsequent fluid intake and retention.[11] Indeed, sodium restriction is a component of HD dietary guidelines to prevent adverse cardiovascular outcomes.[12] Unfortunately, most HD patients still consume excessive dietary sodium and nutritional education, and counseling to reduce sodium intake is largely ineffective.[13] These findings may be attributed to a high-sodium food environment and a variety of barriers to dietary and behavioral changes.[14–17] A multitude of other HD dietary restrictions (e.g., phosphorus and potassium) further complicates dietary adherence.[18,19]

Recent studies have shown that sodium can be stored in soft tissues, such as skin and muscle, and that elevated tissue sodium is associated with hypertension and left ventricular hypertrophy.[20,21] Tissue sodium dysregulation, characterized by deficient lymphatic expansion, vasoconstriction, and excretion, is evident in aging, diabetes, and chronic kidney disease.[20–24] Prior research has shown that tissue sodium levels are transiently reduced during dialysis,[24] but no study to date has investigated if reducing dietary sodium intake reduces tissue sodium accumulation in HD patients. Two recent interventions in heart failure suggest that providing home-delivered, commercial meals is a well-tolerated method to reduce dietary sodium intake,[25,26] and similar meals have been formulated for the renal diet. This approach could also allow HD patients to meet recommendations for intake of sodium, potassium, phosphorous, and protein.

The primary purpose of this study was to determine the efficacy of home-delivered, low-sodium, dialysis-friendly (low-potassium and low-phosphorus) meals to reduce IDWG. We hypothesized that 4 weeks of these meals would reduce IDWG when compared to 4 weeks of a usual diet. In secondary analyses, we also assessed the effects of the home-delivered meals on dietary sodium intake, thirst, xerostomia (dry mouth), systolic and diastolic blood pressure, markers of chronic volume overload, and muscle sodium levels.

MATERIALS AND METHODS

Study population, design, and measurements

Patients were recruited from a single HD clinic in central Illinois. Inclusion criteria included HD treatment ≥3 days/week, dialysis vintage ≥3 months, and age >18 years. Exclusion criteria included (i) bioelectrical impedance exclusions (pacemakers and leg amputations); (ii) MRI exclusions (such as ferric metal implants, devices, claustrophobia); (iii) on a sodium restricted diet approximately <1,500 mg per day; and (iv) a diagnosed gastrointestinal disorder. The study was a sequentially designed trial of 8 weeks duration. Written informed consent was obtained prior to baseline testing. The study was approved by the University of Illinois Institutional Review Board (IRB 17530) and registered at clinicaltrials.gov (NCT03189758). All procedures performed were in accordance with the ethical standards of the 1964 Helsinki Declaration and its later amendments.

The commercial vendor PurFoods, LLC (Des Moines, IA, USA), prepared and shipped 21 microwaveable meals per week (equivalent of 3 meals/d) to participant's homes during the intervention period (Data Supplement 1). These meals were standardized to <700 mg sodium each (<2,000 mg total sodium per day) and were also low in potassium and phosphorus (Data Supplement 2). To further prevent short-term protein energy deficits, participants were supplemented with 15 g Vidafuel protein (in medicine cups or mixed with water) and a kidney-friendly snack (e.g., chips and crisps ~80 kcal and 120 mg sodium) per day during the meal intervention period (Data Supplement 3, https://www.vida-fuel.com).

The overall study timeline is depicted in Figure 1. Patients underwent testing on a mid-weekday dialysis day or non-dialysis day (for sodium magnetic resonance imaging) at baseline (0 M), after 4 weeks (1 M), and 8 weeks (2 M), which was kept consistent at each timepoint. Following baseline testing, patients followed their usual diet for 4 weeks (control period; CON), followed by 4 weeks on the low-sodium diet (intervention period, INT). The CON and INT periods occurred sequentially

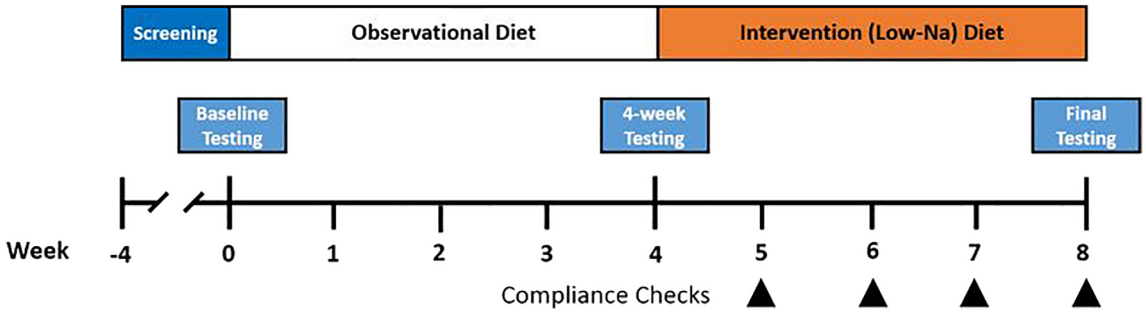

Figure 1 Study timeline. The study trial was sequential in design. After participant screening and baseline testing (0 M), subjects underwent 4 weeks of usual (observational) diet. Participants then underwent 4-week testing (1 M) followed by 4 weeks of low-sodium (intervention) diet and subsequent final testing (2 M). [Color figure can be viewed at wileyonlinelibrary.com]

due to the potential impact of the low-sodium meal intervention on dietary habits or taste preferences. During CON, no additional counseling, meals, or dietary supplements were provided. After these 4 weeks, patients began the INT period when they consumed the home-delivered meals. During INT, research staff visited the enrolled subjects at each dialysis session on a weekly basis to monitor, record, and positively reinforce home-delivered meal adherence. During INT, the research staff also provided minor supplemental nutrition education on how to adhere to a low-sodium diet, mainly providing lists of low-sodium foods and snacks to supplement the provided meals (Data Supplement 4). All dietary advice and assessments were conducted by the research team and were approved or supervised by the clinic registered dietitians (RD).

Three dietary record-assisted recalls were collected in-person at the dialysis facility, including 1 dialysis weekday, 1 nondialysis weekday, and 1 nondialysis weekend day at each testing time-point generally following the United States Department of Agriculture 5-pass method.[27] Dietary recalls (24-48 h) were unscheduled and conducted within the 2-week period prior to each testing timepoint if patients were unwilling or unable to record dietary intake. Dietary data were analyzed using Nutrition Data System for Research (University of Minnesota Nutrition Coordinating Center, MN, USA).

Clinical data were obtained from participants treatment records one-month prior to and during the study period, including IDWG, ultrafiltration (UF) rate and volume, pre-dialysis weight, estimated dry weight (EDW), predialysis BP, monthly laboratory values, dialysate composition, and medications. Monthly and individual weekly IDWG and UF averages were calculated as the average of the 4 weeks (12 HD treatments) preceding each study time-point or as 3 treatments per week, respectively. Blood samples (10 mL) were obtained at each time-point within 5 min of starting HD (preheparin) for immediate analysis of plasma sodium, potassium, and phosphorus using colorimetric enzymatic assays (Renal function panel, Piccolo-Xpress, Abaxis, Union City, CA. USA).

Hydration status, a marker of volume overload, was measured using a bioimpedance spectroscopy device (ImpediMed SFB7, Carlsbad, CA, USA) that estimates total body water as well as intracellular fluid and extracellular fluid. Both absolute volume overload (volume overload = $1.136 \times$ extracellular fluid $-0.430 \times$ intracellular fluid $-0.114 \times$ body weight) and percent volume overload (percent volume overload = volume overload/extracellular fluid $\times 100$) is calculated from bioimpedance spectroscopy parameters.[28] Bioimpedance spectroscopy measurements were performed while seated until at least three consecutive and consistent results, differing less than 10%, were obtained. Standardized (e.g., sitting in a quiet room for 5 min) duplicate BP measurements were taken using an automated cuff (Mobil-O-Graph, IEM, Stolberg, Germany) until the two readouts differed by less than 10 mmHg and then were averaged. Thirst intensity and xerostomia were evaluated with a 7-item dialysis thirst inventory and an 11-item xerostomia inventory survey.[29] The dialysis thirst inventory ranges from 7 (no thirst) to 35 (very thirsty), and the xerostomia inventory ranges from 11 (no dry mouth) to 55 (extremely dry mouth), respectively.[29]

Muscle sodium concentration in the right lower leg (calf) was measured on a nondialysis day using a Siemens Prisma 3T MRI scanner with two custom birdcage coils with matching geometry tuned to ^{1}H- and ^{23}Na-MRI frequencies. T1-weighted proton imaging was run with the following parameters: a field of view (FOV) of 280 mm^2, an in-plane resolution of 256×256 mm^2, 16 slices at a

thickness of 5 mm, repetition time (TR) = 7.5 ms, echo time (TE) = 3.69 ms, 5° flip angle, and 8 averages. The T1 structural scan provided the anatomical image that allowed the definition of muscle region of interest. Sodium MRI was performed using the flexible twisted projection imaging sequence (flexTPI)[30] (TR = 200 ms, TE = 0.5 ms, 70° flip angle, FOV = 280 × 280 × 280 mm, an effective matrix size of 44 × 44 × 44, radial fraction of 0.25, maximum gradient of 4 mT/m, maximum slew rate of 150 mT/m/ms, 3 averages, and total scan time of about 15 min). The tissue sodium data were reconstructed on a 64 × 64 × 64 matrix using an iterative reconstruction approach[31] implemented in MATLAB (R2019a; MathWorks, Natick, MA, USA).

Quantification of muscle sodium concentration was performed by using region of interest and trend analyses modified from previously published ^{23}Na-MRI studies.[20,22,24] In brief, a linear trend function for estimating muscle sodium level was fitted based on the concentrations and ^{23}Na-signal intensities of three calibration standards that contained sodium chloride aqueous solutions at 10, 30, and 50 mM. Region of interest analysis was performed in ImageJ (NIH, version 1.52a) by placing region of interests on calibration standards and muscles of interest, including medial gastrocnemius, lateral gastrocnemius, tibialis anterior, soleus, and the whole leg. The research personnel responsible for quantification of muscle sodium concentrations was blinded for subject identification.

COVID-19 pandemic study modifications

The COVID-19 pandemic required early suspension of in-person research activities. Clinical data were substituted from the dialysis clinic medical records for subjects in these instances. For example, three sitting predialysis BPs were averaged the week of each testing point and substituted for standardized BP, monthly laboratory values closest to each study time-point were utilized, and dietary recalls were conducted through phone interviews with three subjects. There were no statistical differences in primary or secondary outcomes when these data points were removed from the analysis.

Statistical analysis

All monthly and weekly outcomes were assessed by repeated measures analysis of variance (RM-ANOVA) followed by post hoc analysis. A P value <0.05 was considered significant. Nonparametric corrections and Friedman tests were conducted when appropriate. The eight study weeks were then collapsed into 4 weeks split by group (CON or INT) to conduct additional between-subject comparisons of IDWG and UF. We then ran generalized estimating equations (GEE) to analyze fixed weekly and treatment effects, as well as interaction effects, for both IDWG and UF (SPSS GENLIN procedure). The dialysis thirst inventory and xerostomia inventory survey scores were analyzed with a paired t-test. All statistical analyses and figures were conducted or generated using a combination of SPSS version 26.0 (IBM SPSS Inc., Chicago, IL, USA) and GraphPad Prism version 8.0 (GraphPad Software, San Diego, CA, USA).

RESULTS

The baseline demographic characteristics of the study population are shown in Table 1. A total of 20 subjects completed the study and the consort diagram is depicted in Figure 2. Six subjects did not complete 1 M and/or 2 M testing and the last three enrolled subjects did not undergo any in-person testing due to the COVID-19 pandemic. Table 2 summarizes the dietary results and study outcomes at each time-point. Baseline dietary sodium intake remained constant after 4 weeks of usual diet (0 M to 1 M difference: 54 ± 224 mg/d, P = 0.812). However, participants significantly reduced their sodium intake after home-delivered, low-sodium meal provision (2 M), when compared to both 0 M (0 M to 2 M difference: −1687 ± 297 mg/d, $P < 0.001$) and 1 M (1 M to 2 M difference: −1633 ± 282 mg/d, $P < 0.001$). There were no changes in calories, protein, or potassium consumed at any time-point (all $P > 0.05$, Table 2). However, there was an increase in carbohydrate consumed as well as decreases in fat and phosphorus consumed at 2 M (all $P < 0.05$, Table 2). Overall, participants reported eating an average of 66 ± 15 meals out of 84 meals provided, which translated to approximately 2.4 ± 0.5 meals per day eaten for overall average adherence rate of 79%. An average of 2.3 ± 0.7 of those meals were consumed on weekends and an average of 2.4 ± 0.8 were consumed on weekdays. The four most common feedback themes provided by the participants were "helped with not cooking and shopping" (80%), "liked the different meal options and taste" (75%), "helped with thirst, fluid intake, and/or fluid gain" (40%), and "helped with busy work or life schedule" (30%). Common reasons given for not eating the meals included lack of storage, lack of appetite, and lack of preference for certain individual menu items.

IDWG was significantly reduced from both 1 M to 2 M (−0.82 ± 0.13 kg, $P < 0.001$) and 0 M to 2 M (−0.59 ± 0.14 kg, P = 0.001), which was characterized

Table 1 Subject demographics

Variable	Value
N	n = 20
Age, y	55 (12)
BMI, kg/m^2	40.7 (16.6)
Women, n (%)	9 (45%)
Black/African American, n (%)	13 (65%)
Diabetes, n (%)	14 (70%)
Cardiovascular disease, n (%)	10 (50%)
MWF day dialysis, n (%)	7 (35%)
First/second/third shift dialysis, n	7/11/2
BP medications, mean	2.9 (1.7)
Dialysis vintage, y	4.5 (3.2)

All values reported as mean (SD) unless otherwise indicated.
BMI = body mass index; BP = blood pressure; MWF = Monday–Wednesday–Friday.

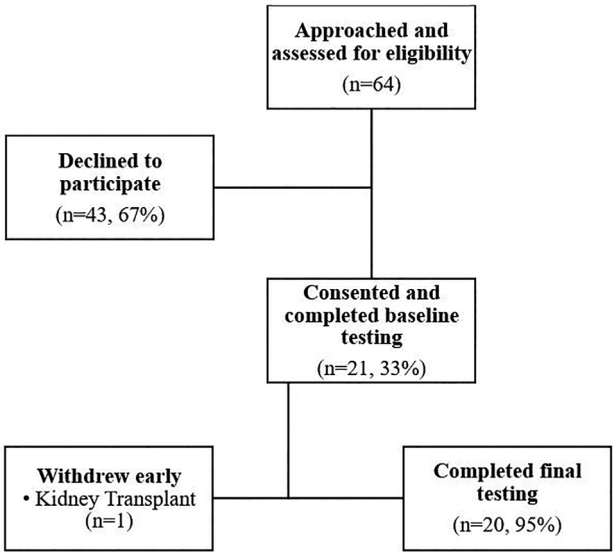

Figure 2 Study consort diagram. Participants were recruited and enrolled between August 2019 and May 2020. The most common reasons for declining to participate were "not interested" and "prefer to eat own food." Our original enrollment target was a convenience sample of n = 32 to exceed a sample size determination (n = 14) based on matching the small effect size of an internal pilot study[40] ($\alpha = 0.05$, $\beta = 0.20$, $E = 0.30$, $\Delta S = 0.40$). For comparison, a previous similar study[33] was powered (n = 24, $\alpha = 0.05$, $\beta = 0.20$, $\Delta S = 1.0$) to detect a 0.81 kilogram difference (Δ) in IDWG. IDWG, interdialytic weight gain.

by individual reductions (1 M-2 M) in most participants (Figure 3). IDWG and UF over the entire duration of the study is depicted in Figure 4. As expected, IDWG was higher on the long interdialytic period (3 days) on the weekends (2.6 ± 1.7) compared to the shorter interdialytic period (2 days) during the week (2.2 ± 1.8). RM-ANOVA revealed that the overall weekly IDWG was decreased over the course of the 8 week study ($P < 0.001$), primarily driven by post hoc pairwise differences in weekly IDWG when comparing the average IDWG during the 4-week control period to the average during the 4 intervention weeks (all $P < 0.05$; Figure 4A). In addition, there were no differences in IDWG within the 4 control period weeks (week 1–4) or within the 4 intervention period weeks (week 5–8) (Figure 4A). The GEE analysis showed that there was a significant treatment effect (-0.82 ± 0.14 kg; 95% confidence interval, -0.55 to -1.08 kg; $P < 0.001$), but not time (week, $P = 0.883$) or interaction (treatment × week, $P = 0.473$) effects on weekly IDWG (Figure 4B).

Both overall monthly EDW ($P < 0.039$) and predialysis weight ($P < 0.019$) were decreased throughout the 2 months of the study period (Table 2). For EDW, there was a significant reduction from 0 M to 2 M (-1.47 ± 0.60 kg, $P = 0.025$). For predialysis weight, there was a significant reduction from 1 M to 2 M (-1.85 ± 0.77 kg, $P = 0.026$) and 0 M to 2 M (-2.09 ± 0.82 kg, $P = 0.020$). Monthly UF changed in a similar pattern to that of IDWG ($P = 0.005$; Table 2), but with a significant post hoc reduction from 1 M to 2 M (-0.48 ± 0.10 L, $P = 0.001$). When UF was split into the 8 weekly averages, there were significant overall reductions in weekly UF throughout the 8 studied weeks ($P < 0.05$), but no post hoc between-week differences ($P > 0.05$; Figure 4A). According to the GEE analysis, there was a treatment effect (-0.43 ± 0.13 L; 95% confidence interval, -0.17 to -0.67 L; $P < 0.001$), but no time (week, $P = 0.703$) or interaction (treatment × week, $P = 0.796$) effects on weekly UF (Figure 4C).

Both systolic and diastolic BP remained unchanged from 0 M to 1 M, but were both reduced from 1 M to 2 M (SBP -18.0 ± 3.6 mmHg, $P < 0.001$; DBP: -5.9 ± 2.0 mmHg, $P = 0.008$; Table 2). One subject had an antihypertensive medication dosage increased from 0 M to 1 M (metoprolol tartrate) coinciding with a systolic BP decrease of -10 mmHg from 0 M to 1 M. Another subject had carvedilol dosage decreased and lisinopril and clonidine discontinued from 1 M to 2 M, coinciding with a systolic BP increase of 3 mmHg from 1 M to 2 M. There were no changes in dialysate composition, including dialysate sodium concentration (136.8 ± 1.6 mEq/L), at any study time-point (data not shown).

In the subset of patients (N = 11) with complete bioimpedance data, participants had significant reductions in total body water and extracellular fluid at 2 M

Table 2 Changes in study outcomes

Variable	Time-point			*P* value
	0 M	1 M	2 M	
Clinical data				
Interdialytic weight gain, kg[a]	2.9 ± 1.2	3.1 ± 1.1	2.3 ± 1.1	<0.001
Ultrafiltration, L[b]	2.9 ± 1.1	3.1 ± 1.1	2.6 ± 1.0	0.005
Predialysis weight, kg	115.8 ± 41.2	115.6 ± 41.1	113.7 ± 40.3	0.019
Estimated dry weight, kg	112.4 ± 40.0	112.6 ± 40.1	111.2 ± 40.0	0.039
Systolic BP, mmHg[a]	161 ± 18	161 ± 24	143 ± 18	<0.001
Diastolic BP, mmHg[a]	91 ± 13	88 ± 11	82 ± 14	0.001
Dietary data				
Calories	1844 ± 620	1957 ± 706	1914 ± 181	0.662
Calories/kg	17.4 ± 6.7	18.8 ± 8.9	19.0 ± 7.1	0.282
Protein, g	72 ± 18	75 ± 19	69 ± 10	0.350
Protein/g/kg	0.67 ± 0.22	0.73 ± 0.31	0.68 ± 0.26	0.331
Carbs, g[a]	221 ± 98	230 ± 99	295 ± 44	<0.001
Fat, g[a]	76 ± 30	83 ± 34	53 ± 10	<0.001
Sodium, mg[a]	3506 ± 1303	3560 ± 1310	1873 ± 345	<0.001
Sodium, mg/calories[a]	1.94 ± 0.56	1.86 ± 0.42	0.97 ± 0.11	<0.001
Potassium, mg	1957 ± 553	2053 ± 582	2013 ± 235	0.731
Phosphorus, mg[a]	1022 ± 278	1083 ± 261	760 ± 99	<0.001
Volume parameters (N = 11)				
Total body water, L[b]	56.5 ± 15.3	58.3 ± 13.5	54.3 ± 11.8	0.040
Extracellular fluid, L[a]	25.2 ± 6.1	25.6 ± 6.2	23.8 ± 5.4[*]	0.007
Intracellular fluid, L	31.3 ± 9.5	32.7 ± 7.8	30.6 ± 7.0	0.148
Volume overload, L[c]	2.9 ± 4.9	2.9 ± 5.1	1.9 ± 4.6	0.041
Volume overload, %[c]	14.2 ± 21.3	11.0 ± 21.6	8.6 ± 21.0	0.036
Tissue sodium (N = 7)				
Lateral gastrocnemius Na, mM	22.6 ± 4.4	23.3 ± 4.3	21.5 ± 5.8	0.609
Medial gastrocnemius Na, mM	25.7 ± 5.8	26.2 ± 7.0	24.7 ± 10.3	0.870
Tibialis anterior Na, mM	22.9 ± 4.8	22.7 ± 3.9	21.5 ± 7.3	0.793
Soleus Na, mM	21.5 ± 4.0	22.1 ± 4.7	21.0 ± 5.9	0.794
Whole leg Na, mM	21.3 ± 3.3	21.9 ± 4.1	20.7 ± 5.9	0.699
Laboratory values				
Serum Na, mmol/L	141.0 ± 3.8	139.8 ± 3.4	140.1 ± 2.8	0.302
Serum phosphorus, mg/dL[a]	6.3 ± 1.4	6.9 ± 1.3	5.3 ± 1.3	<0.001
Serum potassium, mmol/L	4.9 ± 0.9	5.0 ± 0.6	4.7 ± 0.5	0.160
Thirst and xerostomia				
Dialysis thirst index, total score	—	19.2 ± 6.5	14.7 ± 5.4	0.003
Xerostomia index, total score	—	27.3 ± 10.9	20.6 ± 9.2	0.002

[a]2 M different from 0 M and 1 M (*P* value <0.05),
[b]2 M different from 1 M only (*P* value <0.05),
[c]2 M different from 0 M only (*P* value <0.05).
All values are reported as mean ± SD.
BP = blood pressure; Na = sodium.

($P < 0.05$, Table 2) but no changes in intracellular fluid ($P = 0.148$, Table 2). There were significant reductions in both absolute and percent volume overload at 2 M (both $P < 0.05$, Table 2), driven by 0 M to 2 M reductions (-1.08 ± 0.33 L, $P = 0.008$ and $-5.5 \pm 1.8\%$, $P = 0.010$, respectively). In the subset of patients (N = 7) with muscle sodium analyzed, there were no significant changes in muscle tissue sodium or plasma sodium at any time-point (all $P > 0.05$, Table 2). Participants had reductions in plasma phosphorus (1 M-2 M: -1.55 ± 0.21 mg/dL, $P = 0.005$ and 0 M-2 M: -1.00 ± 0.32 mg/dL, $P < 0.001$) but not in plasma potassium at 2 M (overall $P = 0.160$, Table 2). Participants significantly reduced both self-reported thirst

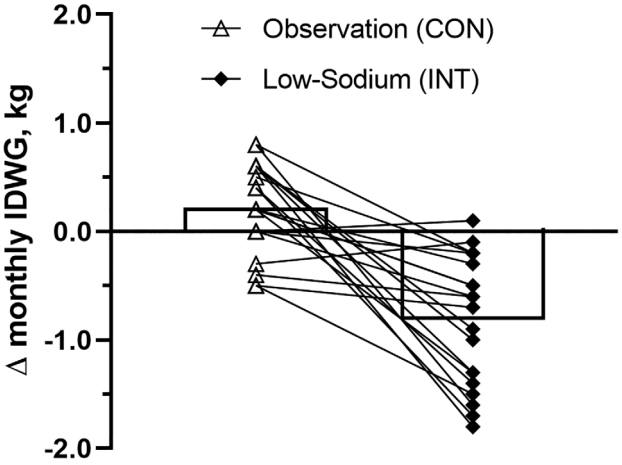

Figure 3 Individual changes in monthly IDWG. IDWG changes in the CON month were inconsistent and not significant. By contrast, most participants had IDWG reductions in the INT period compared with CON. CON, control period; IDWG, interdialytic weight gain; INT, intervention period.

score (-4.4 ± 1.3, $P = 0.003$) and xerostomia score (-6.7 ± 1.9, $P = 0.002$).

DISCUSSION

The primary finding in this study was that 4 weeks of home-delivered, low-sodium meals reduced IDWG when compared to the usual dietary habits of patients on HD. Other improvements included reductions in dietary sodium, thirst and xerostomia scores, SBP and DBP, volume overload, and plasma phosphorus; however, tissue sodium did not change after the 4-week, low-sodium meal intervention. The provided meals significantly reduced both sodium and phosphorus intake without reducing total calorie and protein intake. Another key finding was that participants had modest reductions in dialysis UF volumes during the meal provision period, indicating that not only were patients less hypervolemic, but they required less aggressive treatments to achieve this. Taken together, these data indicate that home-delivered meals may be a safe and effective way of improving the nutritional status and cardiovascular health in HD patients.

The average baseline sodium intake of our participants (> 2,300 mg per day, Table 2) was similar to or slightly lower than the amounts reported in other observational or interventional studies in HD patients.[32–39] Compared to a low sodium intervention by Rigby et al,[33] the magnitude of the reduction in sodium intake in our study was smaller, yet the reduction in IDWG was comparable. By contrast, our study had a greater reduction in sodium intake than reported by Maduell et al,[34] with a similar or greater reduction in IDWG. These studies were similar in sample size to ours, but our intervention period (4 weeks) was longer than some (1–2 weeks),[33,34] yet shorter than others (16 weeks-48 months).[32,35,37] However, these studies with longer intervention periods have not demonstrated successful reductions in both sodium consumption and IDWG.[13]

In a recent pilot study,[40] we aimed to reduce chronic volume overload in HD patients through a comprehensive approach modeled after the successful volume control protocol implemented in Izmir, Turkey.[2,11,41,42] After 6 months, we achieved modest reductions in markers of volume overload despite no detected change in dietary sodium intake.[40] Cultural differences in adherence likely contributed to the lower adherence and more modest results compared to the Izmir group, as high-sodium foods are present in both countries.[43] Furthermore, there are numerous barriers to low-sodium dietary adherence in the United States that have previously been reported.[14–17] The home-delivered meal approach used in the current study may be a more efficacious approach for reducing sodium intake, especially in patients with higher IDWG's, because it bypasses many of the barriers upon following a low-sodium diet or other renal diet restrictions. However, cost considerations should be taken into account for provision of these meals ($6.99 per renal meal; $587 per patient in this study).

Although there were no significant differences in tissue sodium levels at any time-point, there was a numerical increase during the observational period and a numerical decrease during the intervention period of approximately 4% to 8%. Our sample size was unfortunately limited by the exclusionary criteria for conducting MRI measurements in HD patients and interruptions in our research due to the 2020 COVID-19 pandemic. Our study was not powered (observed $1-\beta > 0.1$) to detect muscle sodium changes, as this was an exploratory outcome. Based on a post hoc power analysis, we would require a sample size of at least 76 subjects to detect a significant within-subject change in muscle sodium, given our observed effect size (Cohen's *d*) of 0.327. A hypothesis that may explain this modest effect of the meals on tissue sodium is that tissue sodium is not hypertonic, so it may be more reflective of extracellular volume expansion, and thus insensitive to change in much the same way as blood sodium concentrations.[44] However, this hypothesis requires further investigation, and future studies should investigate if longer term reductions in dietary sodium intake yield more robust changes in muscle sodium.

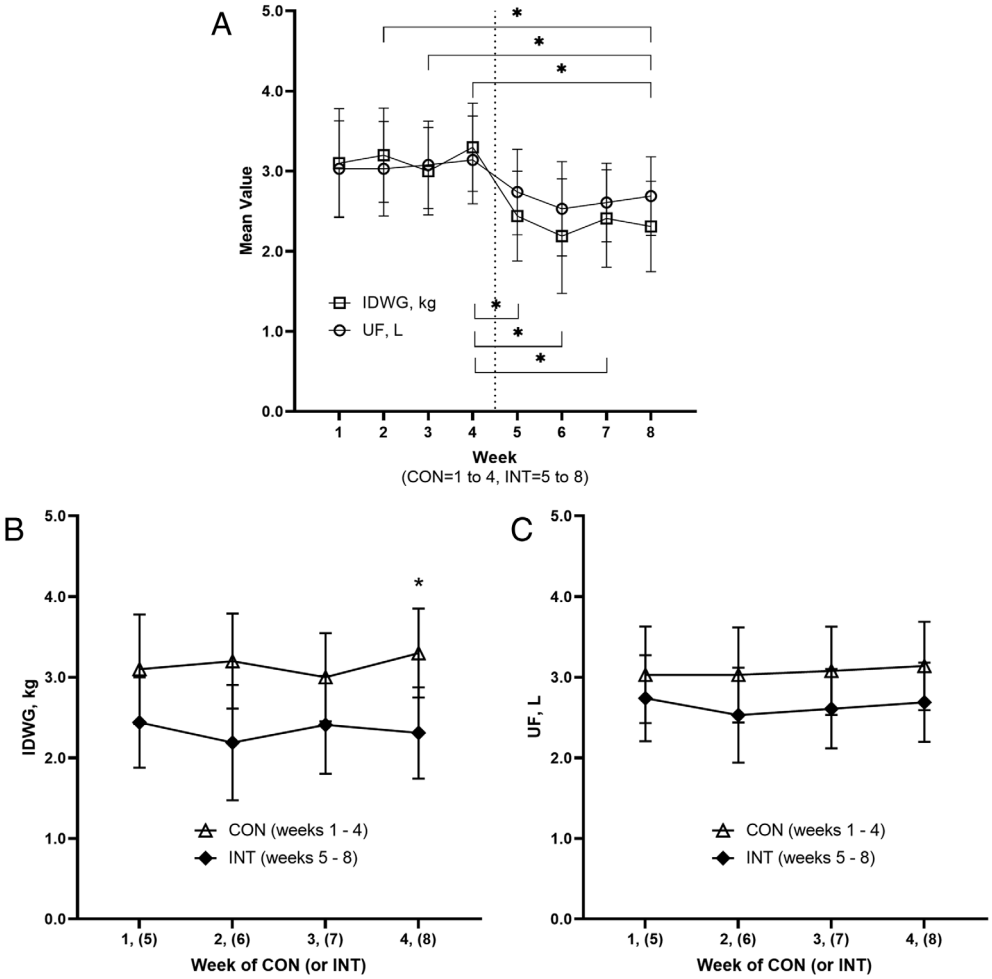

Figure 4 Weekly IDWG and UF volume by time and treatment. (A) Changes in IDWG and UF during the 8-week study period, assessed by separate RM-ANOVA, superimposed on the same graph to highlight similar temporal changes in these variables. For IDWG, there were significant reductions from within CON to INT. For weekly UF, there was an overall reduction over time, but no significant post hoc reductions observed. (B) IDWG split and superimposed by CON and INT. (C) UF split and superimposed by CON and INT. CON, control period; IDWG, interdialytic weight gain; INT, intervention period; GEE, generalized estimating equation; RM-ANOVA, repeated measures analysis of variance; UF, ultrafiltration. *post hoc *P* value of <0.05 for IDWG only.

There are several limitations to our study. First, this pilot trial was conducted as an unblinded, repeated measures, sequential design, as opposed to a randomized control trial or cross-over design. Second, we had relatively short-term study intervention period (~1 month) and a small sample size. Moreover, only about one-third of approached patients were willing to participate in our study, despite receiving free, home-delivered meals for 1 month. However, this was similar to the eligibility rate (30%) and final enrollment rate in a similar study by Sevick et al.[32] A similar intervention in heart failure patients demonstrated a 42% consent rate among eligible and approached individuals.[26] These modest recruitment rates may be reflective of a general resistance that many dialysis patients have toward participation in research. Future studies should include subjective analyses to determine if patients have concerns about the home-delivered meals or if they refused to participate for other reasons. Third, the self-reported dietary intake and meal adherence may have differed from reported intake due to meal fatigue or other factors. Fourth, we also lacked patient-reported outcomes and were not able to report total fluid consumption during the meal intervention period due to the omission of water content in the

customized intervention meals. Fifth, we did not control or standardize any dialysis prescription parameters in this study. Despite this, these parameters remained mostly unchanged during our intervention period.

CONCLUSION

In summary, home delivery of low-sodium, kidney-friendly meals is a feasible short-term approach to reduce sodium intake, thirst, xerostomia, IDWG, BP, plasma phosphorus, and volume overload in HD patients. Future studies should be conducted with larger sample sizes over longer durations to determine if these benefits persist and can translate to reduced hospitalizations, reduced mortality, and improved patient quality of life, and to determine if the approach is cost-effective.

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