Published in final edited form as:

Ther Apher Dial. 2019 April ; 23(2): 145–152. doi:10.1111/1744-9987.12761.

Individualized Cool Dialysate as an Effective Therapy for Intradialytic Hypotension and Hemodialysis Patients' Perception

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Abstract

Intradialytic hypotension (IDH) is the most common dialytic complication. Recurrent episodes of ischemia secondary to hemodynamic instability are associated with cardiomyopathy, increased risk of thrombosis of arteriovenous fistula, decreased quality of life, and increased mortality. Cool dialysate may be an effective approach to reducing intradialytic hypotension by promoting peripheral vasoconstriction. Most studies to date are small and do not employ individualized cool dialysates (ICD). The study consisted of standard and cool phases, with patients as their own controls. During the standard phase, participants underwent hemodialysis (HD) at their usual dialysate temperature at 37° C for six consecutive hemodialysis sessions. In the cool phase, the dialysate temperature was set at the core baseline temperature-0.5°C for six more sessions. We compared hemodynamic parameters during the standard and cool phases. A total of 93 participants were included. The number of IDH episodes during the standard and cool phases were 3.3 ± 2.8 and 2.0 ± 2.2 per patient respectively ($P < 0.001$). Other hemodynamic parameters including lowest intradialytic mean arterial pressure were significantly increased with ICD. We found that there was a high baseline rate of feeling cold among all participants and it increased after the implementation of ICD; however, the dropout rate was approximately 5%. ICD is an effective tool to decrease the frequency of IDH in the HD population and we provide a pragmatic, real-world approach to implement this technique.

Keywords

Cool dialysate; Hemodialysis; Intradialytic hypotension

Intradialytic hypotension (IDH) is the most common dialytic complication identified in 15–20% of all dialysis encounters in contrast to chronic persistent hypotension (pre-dialysis systolic blood pressure < 100 mmHg) which is present in 3–5% of dialysis patients (1–3). Most existing IDH definitions include one or more of the following components: (i)

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Conflict of Interest: Dr. Dena Rifkin and Dr. Danuta Trzebinska deny any conflict of interest.

intradialytic blood pressure criteria, usually a decrease in systolic blood pressure (SBP) by 20 mmHg or a decrease in mean arterial pressure (MAP) by 10 mmHg at any time during dialysis, (ii) need for interventions with a goal to restore effective arterial volume, and (iii) patient-reported symptoms, for example, dizziness, cramping, nausea etc. (4) Kuipers et al. investigated prevalence of IDH using definitions above in 124 patients during 3818 sessions and found it to be 78% using most liberal definition (intradialytic blood pressure only), 21% using patient reported symptoms only, 8.5% needing nursing intervention and 7.5% using all three criteria. (5)

Recurrent episodes of ischemia secondary to hemodynamic instability are associated with cardiomyopathy (6–8), brain white matter microstructure changes (9), and increased risk of thrombosis of arteriovenous fistula (10). Furthermore, it is associated with decreased quality of life (11) and it is an independent risk factor for mortality (12).

The high incidence of IDH remains despite use of bicarbonate dialysis, sodium and ultrafiltration modeling as well as midodrine, among other measures. In the early 1980's, Maggiore et al. first introduced the use of cool dialysate temperature as a way to decrease the incidence of IDH by promoting peripheral vasoconstriction (13,14). This technique has not yet been adopted as a standard of therapy and patients are generally dialyzed at 37° C which is considered to be a thermoneutral temperature, although this is debated (15). Multiple studies have assessed the use of cool dialysate as a therapy to decrease IDH (16–18) with however, the practical benefits and patient-associated outcomes of implementing this strategy in an individual dialysis unit have not been studied. Furthermore, there are few studies looking at the perspective of patients (19) or nephrologists on use of cool dialysate. It is unclear if the reluctance to apply this technique is due to lack of data, concerns about patients' symptoms from cool dialysate temperature, or simply clinical inertia. The goal of this study was to evaluate the benefit of implementation of an individualized cool dialysate on IDH in an outpatient dialysis clinic. In addition, we studied the level of acceptance of this technique by patients and physicians.

PATIENTS AND METHODS

Study design

We conducted a prospective, single center, nonrandomized two-phase study at an academic hemodialysis unit from May 2016 to June 2016. Our study was conducted as a quality improvement project in order to decrease the incidence of IDH in a unit where the standard dialysate temperature was 37°C. We included all adult patients receiving three-times weekly in-center hemodialysis. We excluded patients who refused to be dialyzed at a cooler temperature, those who had a change in dry weight goal or antihypertensive regimen during the study period, those who did not undergo consecutive treatment at the hemodialysis unit due to hospitalization, patients who relocated to a different hemodialysis unit, transitioned to another form of renal replacement therapy or died during the study period.

The study period consisted of standard and cool phases. Patients were informed about the change of dialysate temperature a priori. A week prior to the standard phase, we determined the core baseline temperature (CBT) as an average of oral temperature prior to three

consecutive sessions of HD and we recorded episodes of IDH to determine the baseline frequency for each participant. During the standard phase, we recorded hemodynamic parameters during and after dialysis for six consecutive HD sessions. In the cool phase, the dialysate temperature was set to CBT minus 0.5°C, as suggested by Jefferies et al. (20), and hemodynamic parameters were measured for six more consecutive HD sessions. Parameters during the standard and cool phases were compared with each patient serving as his or her own comparator. All patients underwent bicarbonate-based dialysis on volumetric dialysis machines (Fresenius 2008 K, Fresenius Medical Care, Bad Homburg, Germany). Dialysate sodium was fixed at 140 meq/L, and calcium concentration was 2.25 or 2.5 meq/L in both phases of the study. Oscillometric blood pressure measurements on the nonvascular access arm were taken immediately before HD, then every 30 min during the HD treatment, and finally at the end of HD treatment. Baseline sitting blood pressure at the start and end of dialysis as well as lowest intradialytic blood pressure were determined from six consecutive HD sessions during standard and cool phases. Patients were considered to have IDH if they had a decrease in SBP by 20 mmHg or a decrease in MAP by 10 mmHg at any time during the session even in the absence of symptoms. Blood pressure at the end of dialysis did not count toward IDH. For each dialysis session, the net fluid removal was calculated by nursing staff according to the individual ideal prescribed dry weight. Changes in prescription were instituted at the discretion of the rounding nephrologist per usual care, without any per-protocol changes during the intervention. Average ultrafiltration (UF) was determined from six consecutive HD sessions during standard and cool phases. Kt/V and albumin were recorded and analyzed during standard and cool phases.

Baseline characteristics were obtained from the electronic medical records including date of birth (age), gender, race/ethnicity, co-morbidities (hypertension, diabetes), end-stage renal disease (ESRD) etiology and dialysis vintage. Change in antihypertensive medications was determined by the review of prescriptions in electronic medical record. We assessed blood urea nitrogen measurements for kinetic analysis obtained before and during the intervention. We used variable-volume single-pool urea kinetic model to calculate Kt/V according to the best logarithmic formula of Daugirdas (21). We assessed patients' perception of symptoms using a questionnaire provided during standard phase and at the end of cool phase (Appendix I). As part of the questionnaire, we asked patients to grade their degree of fatigue immediately after HD, fatigue the day after dialysis, and their frequency of intradialytic cramps, dizziness, and cold sensation. The questionnaires were distributed to the participants by the HD nurses. Due to the significant Hispanic population in our HD unit, a Spanish version of the questionnaire was available upon request. We evaluated the nephrologists' perception about the efficacy and tolerability of ICD with a different questionnaire provided during standard phase (Appendix II).

The primary objective of this clinical study was to evaluate the effects of implementation of an ICD protocol on the frequency of IDH episodes in an outpatient dialysis population. There were four secondary objectives of this study. First, to compare the lowest intradialytic and post-dialytic blood pressure in both phases. Second, to assess the impact of ICD on adequacy of dialysis as measured by the Kt/V. Third and fourth, to assess the level of acceptance of ICD by patients and physicians, respectively.

Statistical analysis

For descriptive purposes, we divided the study population into two groups defined by IDH during the baseline period. We described demographic and clinical characteristics of the study population using means (SDs) and percentages, and compared using either *t*-tests for continuous variables and Chi-square or Fisher's exact test, as appropriate, for categorical variables.

We used paired *t*-tests to analyze the change in all hemodynamic variables between the standard and the cool dialysate phases. We performed linear regression to examine the effect of age, gender, dialysis vintage, diabetes mellitus, midodrine, and baseline pre-HD blood pressure on the frequency of IDH in the two phases. We also conducted a sensitivity analyses wherein participants were considered to have IDH at baseline if they had more than one episode of IDH to assure that the main results were consistent. We also evaluated the response to the questionnaire among those who had two or more episodes of IDH.

We did statistical analysis on IBM SPSS Statistics Version 23.0. We considered *P* values less than 0.05 (two-tailed) as statistically significant. This study was approved by the Institutional Review Board of the University of California San Diego.

RESULTS

Of the 124 prevalent patients in our dialysis unit, 98 were included in the study. We excluded twenty-six patients for the following reasons: dry weight or antihypertensive medication change during the study period ($n = 12$), hospitalization ($n = 4$), language barriers ($n = 3$), visiting patients ($n = 3$), death ($n = 2$), transition to peritoneal dialysis ($n = 1$), relocation ($n = 1$). Five patients (5.1%) dropped out of the study during the cool dialysate phase requesting to be dialyzed at their prior temperature. Final analysis consisted of 93 participants (Fig. 1).

Of the 93 participants, average age was 56.5 ± 14.6 years, 52.7% were Hispanic, 18.3% White, and 17.2% African American. The average dialysis vintage was 4.7 ± 5.0 years. 89.2% had hypertension and 54.8% had diabetes mellitus. The majority of patients (82.3%) had IDH at least once during the standard phase (Table 1). Baseline use of midodrine and average UF were not different in the two groups.

Primary outcome

During the baseline phase of the study, mean pre dialysis core temperature for all patients was $36.4 \pm 0.2^\circ \text{C}$. The average dialysate temperature was 36.9 ± 0.3 and $35.9 \pm 0.2^\circ \text{C}$ during standard and cool phases respectively ($P < 0.001$). During standard phase, none of the patients were dialyzed against a dialysate 0.5°C below their CBT. Implementation of ICD was associated with a significant decrease in the number of IDH episodes from 3.3 ± 2.8 to 2.0 ± 2.2 ($P < 0.001$). (Fig. 2a). Among those with baseline IDH, the frequency of IDH episodes decreased from 3.9 ± 2.62 to 2.2 ± 2.3 ($P < 0.001$) (Fig. 2b). Among those few patients without baseline IDH who developed it during the study, there was no change in frequency of IDH (Fig. 2b).

We conducted sensitivity analyses where we considered patients to have IDH at baseline if they had more than one episode of IDH at baseline. In patients with baseline IDH, the frequency of IDH episodes decreased from 4.6 ± 2.4 to 2.5 ± 3.2 ($P < 0.001$). Among patients without baseline IDH, ICD implementation was associated with a significant decrease in the number of IDH episodes from 3.2 ± 2.8 to 2.0 ± 2.2 overall ($P < 0.001$).

Age, gender, dialysis vintage, diabetes mellitus, use of midodrine, and baseline pre-HD blood pressure had no impact on frequency of IDH while implementing ICD (all $P > 0.1$).

Secondary outcomes

The lowest intradialytic SBP increased from 106.3 ± 21.2 mmHg in standard phase to 111.7 ± 20 mmHg in cool phase ($P = 0.04$) (Table 2). The lowest intradialytic diastolic blood pressure (DBP) increased from 63.0 ± 13.8 to 66.7 ± 12.8 mmHg ($P = 0.04$). The lowest MAP increased from 77.4 ± 15.6 to 81.7 ± 14 mmHg ($P = 0.03$). Post dialysis SBP increased from 132.6 ± 21.2 to 140.9 ± 20.9 ($P = 0.005$), DBP increased from 72.9 ± 13.2 to 76.2 ± 13.4 ($P = 0.07$) and MAP increased from 92.9 ± 13.8 to 97.8 ± 13.4 ($P = 0.007$). The mean increase in systolic and diastolic blood pressures at the end of dialysis were 8.3 ± 27.7 ($P = 0.03$) and 3.3 ± 17.2 ($P = 0.07$), respectively.

The Kt/V was not different between the two phases ($P = 0.78$). The average difference in net ultrafiltration between both phases was of 0.03 ± 0.63 L and it was not significantly different ($P = 0.68$).

The participants' response rate to the questionnaire was 100%. There was no significant difference in energy level immediately after dialysis ($P = 0.20$), energy level the following day ($P = 0.07$), dizziness ($P = 0.07$) and cramps ($P = 0.54$) between the standard and cool phases of the study. There was, however a significant difference in feeling cold between the two phases of the study ($P = 0.04$), with more participants reporting feeling cold during the cool phase (Table 3). We performed a sensitivity analysis evaluating the response to questionnaire only among those with more than two episodes of intra-dialytic hypotension (Table 4). In this analysis, cramps decreased with the use of ICD, but none of the parameters reached statistical significance.

Of the 11 rounding nephrologists (100% response rate), 90.9% reported that the use of a cool dialy- sate was an effective technique to decrease IDH. However, only 54.5% of the nephrologists reported using it frequently (70–99% of the time) and 45.4% stated the main reason why they did not utilize this technique was concern for patient discomfort.

DISCUSSION

In our study, we found that ICD reduced the incidence of IDH by over 40% overall and by 44% among those with IDH at baseline. Results were similar in our sensitivity analyses using a stricter definition of baseline IDH. Additionally, SBP, DBP, and MAP at the end of dialysis were higher in cool phase. Improved hemodynamic parameters at the end of dialysis might improve efficiency of patient transition between consecutive dialysis shifts.

We found that the prevalence of IDH is very common in our population (over 80% of patients). This high prevalence can be at least partially explained by a liberal definition of IDH using blood pressure criteria alone (decrease in SBP by 20 mmHg or a decrease in MAP by 10 mmHg at any time during dialysis). We did not include the presence of symptoms or need for nursing intervention for several reasons. Asymptomatic IDH by itself is clinically significant and has been found to have deleterious effects (22,23). In addition we wanted to make this study easy to implement and be able to extract data electronically without manual review of treatment records for over 90 patients looking for potential symptoms. There are numerous other studies which used a similar definition of IDH. (8,18,24)

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Our findings are similar to those in a recent metaanalysis by Mustafa et al. which demonstrated that cool dialysate may reduce the rate of IDH and increase intradialytic MAP (25). Many studies in that meta-analysis were small, short, and used a fixed dialysate temperature. In contrast, our study sample is larger, of longer duration and demonstrates real-world implementation of ICD.

We also found that ICD did not affect the adequacy of dialysis, as measured by the Kt/V, despite the theoretical concern that lower dialysate temperature may lead to peripheral solute sequestration due to greater vasoconstriction. This finding was consistent with the study by Yu et al. (15) which revealed no change in urea reduction ratios at 37.5 and 35.0°C. Similar findings were also obtained by Kaufman et al. (26), who found no difference in Kt/V in patients with mean dialysate temperature of 35.7 ± 0.02 vs. 37.1 ± 0.02 °C.

In our study, ICD had no impact on achieved ultrafiltration rate. However, achieving a different dry weight while implementing ICD protocol was not an objective of this study. We felt that varying the dry weight during the intervention would make study results difficult to interpret. The study by Ayoub and Finlanson did find an increase in ultrafiltration rate (19), which is potentially another benefit of using ICD.

Patient comfort during dialysis treatment is a priority given the time spent receiving HD. We found that there was a high baseline rate of feeling cold among all participants and it increased after the implementation of ICD. The use of ICD was, however, generally well tolerated with only 5% drop out rate. We hypothesized that better hemodynamic stability during and after dialysis improves patient energy level. Unfortunately, we did not find a statistically significant difference in energy level using the ICD protocol. Despite the patient's relatively adequate tolerability of ICD, we found a high level of nephrologist's concern for patient comfort. This finding emphasizes the need to engage patients in treatment decisions and receive feedback on any changes in hemodialysis prescriptions.

Our study has several strengths. First, we decreased the dialysate temperature in a systematic and individualized fashion. The dialysate temperature was specific for each patient based on their CBT. Second, our study was not limited to symptomatic IDH based on protective effects of a cooled dialysate in major organs such as the heart and brain (14–16). Third, we evaluated the participant's perception before and after the intervention to identify any potential barriers to use of this therapy. Finally, we evaluated nephrologists' view on the use of ICD for its effectiveness and acceptance by patients. There are several limitations to this study. First, this was a single center, nonrandomized or blinded design. Patient knowledge of implementing ICD may have biased the reported sensation of feeling cold during intervention phase. Lastly, some patients dropped out of the intervention which indicates that not all patients tolerate ICD and should be offered alternative dialysate temperature.

CONCLUSIONS

In summary, our study shows that individualized cool dialysate (ICD) is an effective and easy to implement technique that is underutilized in decreasing intradialytic hypotension (IDH). We demonstrate that on a unit level, ICD can be broadly implemented using a straightforward protocol.

Acknowledgments:

We are grateful to all the patients and hemodialysis nursing staff who participated in this project, especially Wendy Lester MSN, RN, CNN Administrative Nurse Manager of UC San Diego Dialysis Unit and Peter Wang from IT services.

Dr. Alexander Bullen was supported by a Ruth L. Kirschstein training grant from the National Institute of Diabetes and Digestive and Kidney Diseases (NIDDK; T32DK104717).

APPENDIX I: PARTICIPANTS' QUESTIONNAIRE

1. How have your energy levels been in the past two (2) weeks?
 - Weak
 - Adequate for my usual activities
 - Energetic
2. How often have you cramped during dialysis in the past two (2) weeks?
 - Often
 - Some of the time
 - Rarely
3. How often have you felt lightheaded after dialysis in the past two (2) weeks?
 - Often
 - Some of the time
 - Rarely
4. How have you felt the day after dialysis in the past two (2) weeks?

- I am unable to perform my usual activities
 - Some problems performing usual activities
 - No problems performing my usual activities
5. How have you felt during dialysis in the past two (2) weeks?
- Cold
 - “Normal”
 - Warm

APPENDIX II: NEPHROLOGISTS' QUESTIONNAIRE

- a. Do you believe that lower dialysate temperature is an effective technique to decrease IDH?
- Yes
 - No
 - Not sure
- b. How often would you say you decrease the dialysate temperature in patients with IDH?
- Always-100%,
 - Frequently-70–99%,
 - Occasionally-30–69%,
 - Rarely-Less than 30%,
 - Never- 0%
- c. Why do you think you do not decrease the dialysate temperature more often?
- Not necessary
 - Patient might feel uncomfortable
 - Not a very effective technique
 - Other

REFERENCES

1. K/DOQI clinical practice guidelines for cardiovascular disease in dialysis patients. *Am J Kidney Dis* 2005;45 (4 Suppl 3):S1–153.
2. Rubin LJ, Gutman RA. Hypotension during Hemodialysis. *Kidney*, 1978;11:21–24.
3. Degoulet P, Reach I, Di Giulio S et al. Epidemiology of dialysis induced hypotension. *Proc Eur Dial Transplant Assoc* 1981;18:133–8. [PubMed: 7329960]
4. Assimon MM, Flythe JE. Definitions of intradialytic hypotension. *Semin Dial* 2017;30:464–72. [PubMed: 28691195]

5. Kuipers J, Oosterhuis JK, Krijnen WP et al. Prevalence of intradialytic hypotension, clinical symptoms and nursing interventions--a three-months, prospective study of 3818 haemodialysis sessions. *BMC Nephrol* 2016;17:21. [PubMed: 26922795]
6. Aoki J, Ikari Y, Nakajima H et al. Clinical and pathologic characteristics of dilated cardiomyopathy in hemodialysis patients. *Kidney Int* 2005;67:333–40. [PubMed: 15610259]
7. Odudu A, Eldehni MT, McCann GP, McIntyre CW. Randomized controlled trial of individualized dialysate cooling for cardiac protection in hemodialysis patients. *Clin J Am Soc Nephrol* 2015;10:1408–17. [PubMed: 25964310]
8. Selby NM, Burton JO, Chesterton LJ, McIntyre CW. Dialysis-induced regional left ventricular dysfunction is ameliorated by cooling the dialysate. *Clin J Am Soc Nephrol* 2006;1:1216–25. [PubMed: 17699351]
9. Eldehni MT, Odudu A, McIntyre CW. Randomized clinical trial of dialysate cooling and effects on brain white matter. *J Am Soc Nephrol* 2015;26:957–65. [PubMed: 25234925]
10. Chang TI, Paik J, Greene T et al. Intradialytic hypotension and vascular access thrombosis. *J Am Soc Nephrol* 2011;22:1526–33. [PubMed: 21803971]
11. Sentveld B, van den Brink M, Brulez HF, Potter van loon BJ, Weijmer MC, Siebert CE. The influence of blood volume-controlled ultrafiltration on hemodynamic stability and quality of life. *Hemodial Int* 2008;12:39–44. [PubMed: 18271839]
12. Shoji T, Tsubakihara Y, Fujii M, Imai E. Hemodialysis-associated hypotension as an independent risk factor for two-year mortality in hemodialysis patients. *Kidney Int* 2004;66:1212–20. [PubMed: 15327420]
13. Maggiore Q, Pizzarelli F, Zoccali C, Sica S, Nicolo F, Parlongo S. Effect of extracorporeal blood cooling on dialytic arterial hypotension. *Proc Eur Dial Transplant Assoc* 1981;18:597–602. [PubMed: 7329988]
14. Sherman RA, Faustino EF, Bernholz AS, Eisinger RP. Effect of variations in dialysate temperature on blood pressure during hemodialysis. *Am J Kidney Dis* 1984;4:66–8. [PubMed: 6377884]
15. Pergola PE, Habiba NM, Johnson JM. Body temperature regulation during hemodialysis in long-term patients: is it time to change dialysate temperature prescription? *Am J Kidney Dis* 2004;44:155–65. [PubMed: 15211448]
16. Lindholm T, Thysell H, Yamamoto Y, Forsberg B, Gullberg CA. Temperature and vascular stability in hemodialysis. *Nephron* 1985;39:130–3. [PubMed: 3974775]
17. Yu AW, Ing TS, Zabaneh RI, Daugirdas JT. Effect of dialysate temperature on central hemodynamics and urea kinetics. *Kidney Int* 1995;48:237–43. [PubMed: 7564084]
18. Cruz DN, Mahnensmith RL, Brickel HM, Perazella MAM. Warm and cool dialysate are effective therapies for symptomatic intradialytic hypotension. *Am J Kidney Dis* 1999;33:920–6. [PubMed: 10213650]
19. Ayoub A, Finlayson M. Effect of cool temperature dialysate on the quality and patients' perception of haemodialysis. *Nephrol Dial Transplant* 2004;19:190–4. [PubMed: 14671056]
20. Jefferies HJ, Burton JO, McIntyre CW. Individualised dialysate temperature improves intradialytic haemodynamics and abrogates haemodialysis-induced myocardial stunning, without compromising tolerability. *Blood Purif* 2011;32:63–8. [PubMed: 21346338]
21. Daugirdas JT. Second generation logarithmic estimates of single-pool variable volume Kt/V: an analysis of error. *J Am Soc Nephrol* 1993;4:1205–13. [PubMed: 8305648]
22. Hekmat R, Ahmadi M, Fatehi H, Dadpour B, Fazelenejad A. Correlation between asymptomatic intradialytic hypotension and regional left ventricular dysfunction in hemodialysis patients. *Iran J Kidney Dis* 2011;5:97–102. [PubMed: 21368387]
23. Bradshaw W, Bennett PN. Asymptomatic intradialytic hypotension: the need for pre-emptive intervention. *Nephrology Nurs J* 2015;42:479–85 quiz 486.
24. van der Sande FM, Wystrychowski G, Kooman JP et al. Control of core temperature and blood pressure stability during hemodialysis. *Clin J Am Soc Nephrol* 2009;4:93–8. [PubMed: 18842948]
25. Mustafa RA, Bdair F, Aki EA et al. Effect of lowering the dialysate temperature in chronic hemodialysis: a systematic review and meta-analysis. *Clin J Am Soc Nephrol* 2016;11:442–57. [PubMed: 26712807]

26. Kaufman AM, Morris AT, Lavarias VA et al. Effects of controlled blood cooling on hemodynamic stability and urea kinetics during high-efficiency hemodialysis. *J Am Soc Nephrol* 1998;9:877–83. [PubMed: 9596086]

FIG. 1.
Flow chart of participants.

FIG. 2.

(a) Average number of episodes of IDH during the standard and cool dialysate phases. (b) Average number of episodes of IDH during the standard and cool dialysate phases among those with and without baseline IDH.

TABLE 1.

Characteristics of patients at baseline

Characteristic	Without IDH	With IDH	<i>P</i> value
<i>N</i>	16	77	
Median age (range)—years	58(30–84)	56(25–93)	0.78
Sex—males (%)	43.8	51.9	0.56
Race—(%)			
White	18.8	18.2	0.96
African American	12.5	18.2	0.56
Hispanic	62.5	50.6	0.40
Asian	6.2	5.2	0.88
Other	0	7.8	
Cause of ESRD (%)			
Diabetic nephropathy	50	49.3	0.69
GN	12.5	18.2	0.56
HTN	6.2	5.2	0.88
Other	31.0	22.1	0.73
HTN- <i>n</i> (%)	15 (93.8)	68 (88.3)	0.13
DM- <i>n</i> (%)	8 (50)	43 (55.8)	0.67
CAD- <i>n</i> (%)	7(43.8)	30(39.0)	0.64
Hyperlipidemia- <i>n</i> (%)	12(75%)	37(48.1)	0.39
Length of time on maintenance HD in years- <i>n</i> (%)			<0.001
<5	10	60	
5–10	2	13	
>10	4	4	
Midodrine- <i>n</i> (%)	2 (12.5)	13(16.9)	0.67
Average UF	2.6 ± 0.3	2.4 ± 0.1	0.53
Average Kt/V	1.6 ± 0.05	1.7 ± 0.03	0.45
Average albumin	3.84 ± 0.1	4.0 ± 0.03	0.08
Baseline core pre-HD temperature	36.3 ± 0.04	36.4 ± 0.02	0.18
Baseline dialysate temperature	36.8 ± 0.1	36.9 ± 0.03	0.13
Baseline pre-HD SBP	149.9 ± 20.8	149.2 ± 23.2	0.90
Baseline pre-HD DBP	80.6 ± 16.9	79.6 ± 15.7	0.81
Baseline post-HD SBP	137.0 ± 17.4	131.8 ± 22.2	0.39
Baseline post-HD DBP	79.3 ± 13.5	71.6 ± 12.9	0.03

DBP, diastolic blood pressure; IDH, intradialytic hypotension; SBP, systolic blood pressure; UF, ultrafiltration.

TABLE 2.

Blood pressure data

BP (mmHg)	Standard phase	Cool phase	Mean difference	P value
Pre-HD				
SBP	146.4 ± 19.1	144.2 ± 18.9	2.3 ± 26.0	0.40
DBP	79.4 ± 17.9	77.5 ± 12.3	1.9 ± 19.8	0.35
MAP	101.8 ± 13.9	99.7 ± 12.9	2.1 ± 17.1	0.25
Lowest intradialytic pressure				
SBP	106.3 ± 21.2	111.7 ± 20.4	5.4 ± 25.6	0.04
DBP	63.0 ± 13.8	66.7 ± 12.8	3.7 ± 17.4	0.04
MAP	77.4 ± 15.6	81.7 ± 14.4	4.3 ± 19.2	0.03
Post-HD				
SBP	132.6 ± 21.2	140.9 ± 20.9	8.3 ± 27.7	0.005
DBP	72.9 ± 13.2	76.2 ± 13.4	3.3 ± 17.2	0.070
MAP	92.9 ± 13.8	97.8 ± 13.4	4.9 ± 17.3	0.007
Change in BP (post-pre-HD)				
SBP	-14.2 ± 30.1	-3.1 ± 26.7	-11.1 ± 35.8	0.004
DBP	-6.5 ± 21.9	-1.2 ± 17.1	-5.3 ± 25.5	0.049
MAP	-9.0 ± 20.8	-1.82 ± 17.5	-7.2 ± 24.0	0.005

DBP, diastolic blood pressure; MAP, mean arterial pressure; SBP, systolic blood pressure.

TABLE 3.

Participants' perception of cool dialysate

Question	Standard phase <i>n</i> (%)	Cool phase <i>n</i> (%)	<i>P</i> value Chi-square or Fisher' exact test
Energy level			0.20
Weak	16 (17.2)	27 (29.0)	
Adequate for my usual activities	60 (64.5)	43 (46.2)	
Energetic	17 (18.3)	23 (24.8)	
Cramps			0.54
Often	12 (12.9)	13 (14.0)	
Some of the time	30 (32.3)	23 (24.7)	
Rarely	51 (54.9)	57 (61.3)	
Dizziness			0.07
Often	5 (5.4)	12 (12.9)	
Some of the time	31 (33.3)	20 (21.5)	
Rarely	57 (61.3)	61 (65.6)	
Energy next day			0.07
I am unable to perform my usual activities	4 (4.3)	13 (14)	
Some problems performing usual activities	28 (30.1)	26 (28.0)	
No problems performing my usual activities	61 (65.6)	54(58.0)	
Temperature sensation			0.04
Cold	41 (44.1)	56 (60.2)	
Normal	43 (46.2)	34 (36.5)	
Warm	9 (9.7)	3 (3.3)	

TABLE 4.

Participants' perception of cool dialysate— Among those with two or more episodes of IDH

Question	Standard phase <i>n</i> (%)	Cool phase <i>n</i> (%)	<i>P</i> value Chi-square or Fisher' exact test
Energy level			0.32
Weak	5 (8.1)	6 (9.7)	
Adequate for my usual activities	49 (79.0)	42 (67.7)	
Energetic	8 (12.9)	14 (22.6)	
Cramps			0.08
Often	7 (11.3)	6 (9.7)	
Some of the time	27 (43.5)	16 (41.9)	
Rarely	28 (45.2)	40 (64.5)	
Dizziness			0.84
Often	5 (8.1)	5 (8.1)	
Some of the time	18 (29.0)	21 (33.9)	
Rarely	39 (62.9)	36 (58.1)	
Energy next day			0.56
I am unable to perform my usual activities	6 (9.7)	9 (14.5)	
Some problems performing usual activities	16 (25.8)	12 (19.4)	
No problems performing my usual activities	40 (64.5)	41 (66.1)	
Temperature sensation			0.60
Cold	11 (17.7)	16 (25.8)	
Normal	45 (72.6)	43 (69.4)	
Warm	6 (9.7)	5 (8.1)	