

Novel Use of Premixed Dialysate Bags during Water Supply Interruption in Acute Hospital Setting

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Abstract

Patients on dialysis are exposed to large amounts of water during conventional intermittent hemodialysis; hence, there are strict regulations regarding the quality of water used to prepare dialysate. Occasionally, water systems fail due to natural disasters or structural supply issues, such as water-main breaks or unplanned changes in municipal or facility water quality. It is critical to regularly monitor and immediately recognize such a failure and take steps to avoid exposing the patients to contaminants. In addition to the recognition of the problem, the ability to pivot and continue to provide safe treatment to inpatients who are dependent on dialysis is essential, both from an ultrafiltration and a clearance standpoint. At our hospital, an unforeseen water disruption occurred and we were able to continue to provide KRT with premade, bagged dialysate to mitigate the effect on our patients on dialysis. This is a novel method using available machines and dialysate, which we normally stock for continuous KRT, for short dialysis sessions. The methodology is similar to that which has been widely used for short daily home hemodialysis with low dialysate flow rate. Because this situation occurred in the midst of the SARS-CoV-2 pandemic, we had to be mindful of dialysate volumes and staffing time. Here, we present our investigation into the cause of the water-system failure and how we quickly implemented the alternative dialysis method. Short dialysis with low-flow dialysate will not deliver the same Kt/V per session as standard dialysis; however, this method was successfully implemented and tailored with adjustments for patients requiring higher clearance for specific indications, such as severe hyperkalemia.

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Introduction

With standard dialysis, dialysate flow rate (DFR) typically ranges from 600 to 800 ml/min. During a 3.5-hour session, a patient is exposed to 126–168 L of dialysate. Therefore, strict regulations have been developed by the Association for the Advancement of Medical Instrumentation and the International Standards Organization for chemical and microbiologic standards for the water used to prepare dialysate (1,2). On a day in early summer 2020, toward the end of the first shift of our hospital-based inpatient unit, we were alerted that the alarms of several of our portable reverse-osmosis (RO) machines were triggered. The first alarm went off in a machine that was being cleaned away from the unit and was not in clinical use, but, shortly thereafter, the alarms of all seven RO machines in the seven-chair inpatient unit, and those being used for bedside procedures, were triggered due to increased conductivity in the water. As per institutional policy, all conventional intermittent hemodialysis (IHD) was stopped within minutes of the initial alarms due to concerns for water contamination. All patients had their vital signs checked and all were found to be hemodynamically stable and afebrile. All patients were monitored over the rest of the morning, and no patients had complications from their treatments.

Within minutes, we began an investigation to determine the cause of the water disruption. Because the

disruption could not be quickly resolved and other patients were due for dialysis later that day and for the first shift the following day, all patients were converted to short hemodialysis using premixed, bagged dialysate with slow dialysate flow using our available NxStage equipment and supplies. We describe our water investigation and implementation of the alternative dialysis method.

Materials and Methods

In our institution, we have not had a dedicated water room for nearly 10 years. Instead, all traditional IHD is performed with portable RO systems. A Gambro Phoenix Dialysis Machine is connected to a Mar Cor WRO 300 Reverse Osmosis Purifier (3). The water source is a water box that has a backflow preventer and blending valve for the hot and cold city water. The water coming from the water box passes through a sediment filter and two carbon filters before reaching the RO unit.

Within minutes of the alarms sounding and stopping the RO units, we tested the dialysis feed-water conductivity in several locations. All conductivity readings were made on a Mesa Laboratories 90XL Dially-Guard Technician Meter (Mesa Laboratories, Lakewood, CO) (4).

After checking the conductivity of the blended feed water, we conducted separate tests of the individual hot- and cold-water intakes. We tested each of the

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intakes from the water boxes for hardness, chlorine levels, and temperature.

In addition to attempting to determine the source of the water issues, there were ten patients scheduled for hemodialysis later that day and one patient in the emergency room who required hemodialysis. The majority of pending patients had reasonable laboratory values, including several with mildly elevated potassium levels. The patient in the emergency room, who had a history of ESKD, was found to have a potassium level of 8.1 mEq/L after missing a week of hemodialysis. Thus, at least one patient would require emergent treatment.

Our acute unit uses NxStage System One (NxStage Medical, Lawrence, MA) for continuous venovenous hemodialysis and, as such, our staff is familiar with its setup for continuous use in the intensive care unit (ICU). Although this machine can be used for intermittent home-hemodialysis treatments, this is not something we had experience with in our inpatient acute care unit. Our institution stocks prepackaged dialysis-solution bags, including bicarbonate-based (4 or 2 mEq/L potassium) solutions and 2 mEq/L potassium lactate-based solutions. The machine used for continuous RRT does not have the same preset values as the NxStage machine typically used in the home for short daily hemodialysis. For example, the home setup requires the input of the ratio of spent DFR (dialysate plus ultrafiltrate) to blood flow rate (BFR) (Q_{ds}/Q_b =flow fraction or FF). The higher the FF, the lower the efficiency of the dialysis will be (*i.e.*, effluent will have a lower saturation with urea), hence it must be input during setup of the home machine to ensure the Kt/V will fall within the desired range. The FF combined with the total dialysate volume and ultrafiltration (UF) volume determine the treatment time as a dependent value. The machine, when set up for ICU use, does not require entry of FF or total UF, but rather the desired hourly DFR and fluid removal rate is inputted. On the basis of physician (O.F.K.) experience with the NxStage machine for home hemodialysis, we decided to convert the patients' orders for the acute setting to IHD using the NxStage machine (5). The factors considered in prescription conversion were patients' weight, access type, net UF goal (on the basis of volume status), and metabolic needs (as determined by reviewing blood chemistries). Because the water disruption persisted for >24 hours, we used the same techniques the following day as well.

When prescribing a short dialysis session on the NxStage machine, the nephrologist has to prescribe the total dialysate volume required, total UF (net UF plus both the prime and rinse-back volumes), BFR (in milliliters per minute), DFR (in liters per hour), treatment duration, and dialysate base (lactate or bicarbonate and potassium content). Hourly DFR is the total dialysate volume divided by treatment time. The hourly UF rate is the total UF divided by treatment time. A timer was set to finish treatment at the desired time. Generally, lactate dialysate is well tolerated, excluding patients with reduced lactate metabolism, such as patients with liver failure or those with lactic acidosis. Lactate-based solutions are routinely used in the home-hemodialysis setting with the NxStage system, because bicarbonate-containing bags are not available for home use. A sample order set is shown in Table 1.

On this machine, BFR is set high relative to DFR. Urea saturation is >90% when BFR is about three times DFR

(6–9). Our goal was to keep dialysis treatment time at about 3–3.5 hours when possible (similar to acute conventional-dialysis sessions). Using a home-dialysis model, a rough calculation for minimum dialysate volume is that which will result in single-pool Kt/V of at least 0.5 (for adequate weekly treatment with six sessions per week using this machine). For example, in a patient who weighs 70 kg, total body water (TBW) would be roughly 35 L. Total effluent (dialysate plus UF) should be nearly 20 L for single-pool Kt/V of approximately 0.5. Because the efficiency of dialysis declines with lower BFR/DFR ratio and hourly DFR is limited on this machine, it is not possible to do a short treatment and achieve Kt/V of 1.2. The maximum DFR of our inpatient machines is 12 L/h (some NxStage home-hemodialysis models go as high as 18 L/h). As with all dialysis, BFRs are dependent on vascular access, and our patients with AKI and ESKD have a mix of temporary and permanent central venous catheters and arteriovenous (AV) grafts and fistulas.

In scheduling treatments, we were aware of patients' predialysis laboratory values and, because we anticipated this water issue to be relatively short term but to last for >1 day, we attempted to ensure all patients who were due for treatment received it. We planned on repeat treatments the following day for those who required it. For patients with higher specific clearance needs, higher dialysate volumes were ordered. Given these considerations, we tailored dialysate volume around half TBW for those without specific higher needs.

Because our stock consisted of 5-L dialysate bags, it was best to round up the volume to a multiple of five to avoid wasting fluid. These events occurred during the severe acute respiratory syndrome coronavirus 2 pandemic, after a surge period, therefore, we felt a conservative approach to pre-mixed dialysate bags was particularly important (10). Earlier in the calendar year, due to national shortages of bicarbonate-based dialysate, our institution began regularly stocking lactate-based solutions.

Results

Water Investigation

The water conductivity was 1093 microsiemens (μS) and temperature was 25.5°C (78°F) (Figure 1A) in our equipment maintenance room. Conductivity ranged between 370 and 1,600 μS in several of the acute dialysis unit rooms and throughout the ICU rooms. Conductivity is the measure of the ability of a material or solution to conduct an electric current, and it correlates directly with the concentration of electrolytes in a solution. Historically, our hospital feed-water conductivity is roughly 300 μS and never higher than 320 μS .

Hard-water checks demonstrated that both the hot and cold water had a level of 120 ppm across several different water boxes throughout the institution (Figure 1B). Our usual readings for city-water hardness, for both cold and hot water, ranges from 50 to 120 ppm (test strip can only read up to 120 ppm).

Chlorine levels varied from 0 to 5 ppm across the water boxes, with increased levels found in much of the hot-water checks (Figure 1C). This higher-end value is well above our usual readings for chlorine level, which are 0.1 ppm for the

Table 1. Sample order set for short hemodialysis with low dialysate flow rate

| Treatment Parameter | Suggested Value |
|---|--|
| Treatment duration (h) | 3 h or more depending on metabolic needs and UF requirements |
| Dialysate potassium (mEq/L) | 1 or 2 mEq/L (4 mEq/L if patient is significantly hypokalemic) |
| Lactate or bicarbonate base | |
| Total dialysate volume (L) ^a | 0.5–1 × TBW |
| Hourly dialysate flow rate (L/h) | |
| Net ultrafiltration goal (L) ^a | On the basis of volume status assessment |
| Hourly UF=($[\text{net UF goal} + \text{prime} + \text{rinse back}] / \text{treatment duration}$) | |
| Blood flow rate (ml/min) | As catheter or AV access permits |

If there is no need to conserve fluid, aim for dialysate volume of about half body weight (or TBW). This will result in a longer treatment time. We typically add MAP parameter (*e.g.*, maintain MAP >65 mm Hg). It is recommended to keep flow fraction around 30%–35% if conserving fluid. UF, ultrafiltration; TBW, total body water; AV, arteriovenous; MAP, mean arterial pressure.

^aThese parameters are necessary to determine hourly rates and for staff to set up the machine, but are not keyed into the machine.

cold water and 0.5 ppm for the hot water. The Environmental Protection Agency drinking-water standard allows for a maximum level of free chlorine of 4 mg/L (or 4 ppm) (11).

Finally, it was noted that the temperature of the water in all of the dialysis water boxes feeding the RO units was elevated to roughly 76°F (24.4°C), in accordance with the readings from the conductivity check (Figure 1D). Our water boxes all have hot- and cold-water blending valves and, in the summer, water temperature is set at 60°F, so that even as the external water temperature rises, the feed-water temperature should not go above 70–75°F.

Over the course of the next 48 hours, we worked closely with infection control and hospital-plant operations to determine the source of impurities and to determine the ideal methodology to fix the issues. Through our investigation, it was determined that, due to a local heat wave in Chicago, the plant-operations team attempted to increase the cooling capacity of the hospital air-conditioning system. Contractors added water to the cooling system, which ultimately pushed some of the condensing water into the domestic water pipes, contaminating the water supply to the dialysis water boxes.

Over the course of the same 48 hours, in addition to monitoring repeated bacterial cultures and endotoxin levels, which all turned out to be negative, we continually flushed the system and the domestic water supply was cleaned. Currently, the plant-operations team are investigating alternate options to increase future cooling capacity, including modifications to the plumbing system to minimize the effect on the dialysis water supply.

Short Low-Dialysate-Flow Dialysis

There were 11 treatments scheduled for the afternoon of the day of the water disruption, and six treatments scheduled for the morning shift of the following day, 17 sessions in total. In terms of vascular access, seven patients had an AV fistula, two patients had an AV graft, and eight patients had a central venous catheter. BFR was about 400 ml/min in patients with AV access, and as high as 350 ml/min in those with catheters. Patients' weights ranged from 48 to 122 kg. Five of the patients were relatively new to dialysis, having started dialysis on the current admission, and nonoliguric. Net UF averaged 1.6 L (with a range of 0–3 L). The dialysate volumes prescribed ranged from 12.5 to 40 L. In one case of

a patient initiating dialysis for AKI on top of CKD, planned for three consecutive sessions, the prescribing nephrologist chose to initiate at lower dialysate volumes. For established patients with ESKD, the dialysate volume averaged 0.65 of their TBW, whereas it averaged 0.44 of TBW for patients new to dialysis (as noted, one patient new to dialysis had two treatments 2 days in a row on the NxStage machine). The average duration of treatments was 3 hours 11 minutes (range from 2.5 hours, for one patient new to dialysis, to 6 hours). No patient experienced any adverse complication related to their treatments.

We did not measure single-pool Kt/V or urea reduction ratio for any treatments. Measurement of Kt/V in the setting of inpatient dialysis, and more specifically AKI, is quite rare (12). For 11 patients, pre-NxStage hemodialysis (predialysis) and the next morning (postdialysis+1) chemistry values were available. The average predialysis BUN was 42 mg/dl, and the average postdialysis+1 BUN was 32 mg/dl; predialysis potassium was 4.7 mEq/L, and postdialysis+1 potassium was 4.2 mEq/L. Of these 11 patients, five had predialysis phosphorus levels >5 mg/dl, with a mean predialysis value of 5.9 mg/dl and a postdialysis+1 mean value of 5 mg/dl. Treatment FF averaged 35%.

The aforementioned patient with the predialysis potassium of 8.1 mEq/L was prescribed a dialysate volume of 40 L, and treatment time was extended to 6 hours, because of the degree of hyperkalemia and because the lowest potassium dialysate concentration available in our stock was 2.0 mEq/L (for home use, 1mEq/L potassium lactate dialysate is available). His FF was 30%. At 4 hours 9 minutes after completion of hemodialysis, he had a potassium level of 4.9 mEq/L; at 8 hours after completion of hemodialysis, his potassium level was 5.4 meq/L.

Discussion

Our experience highlights several issues for nephrologists. Vigilance around water quality is of the utmost importance. Although our water issues were predominantly iatrogenic, water impurity demands prompt attention and a standardized, rapid response. All treatments must be stopped immediately, with patient safety being the top priority. If the water supply is compromised, whether due to conductivity issues, infectious complications, or even due to

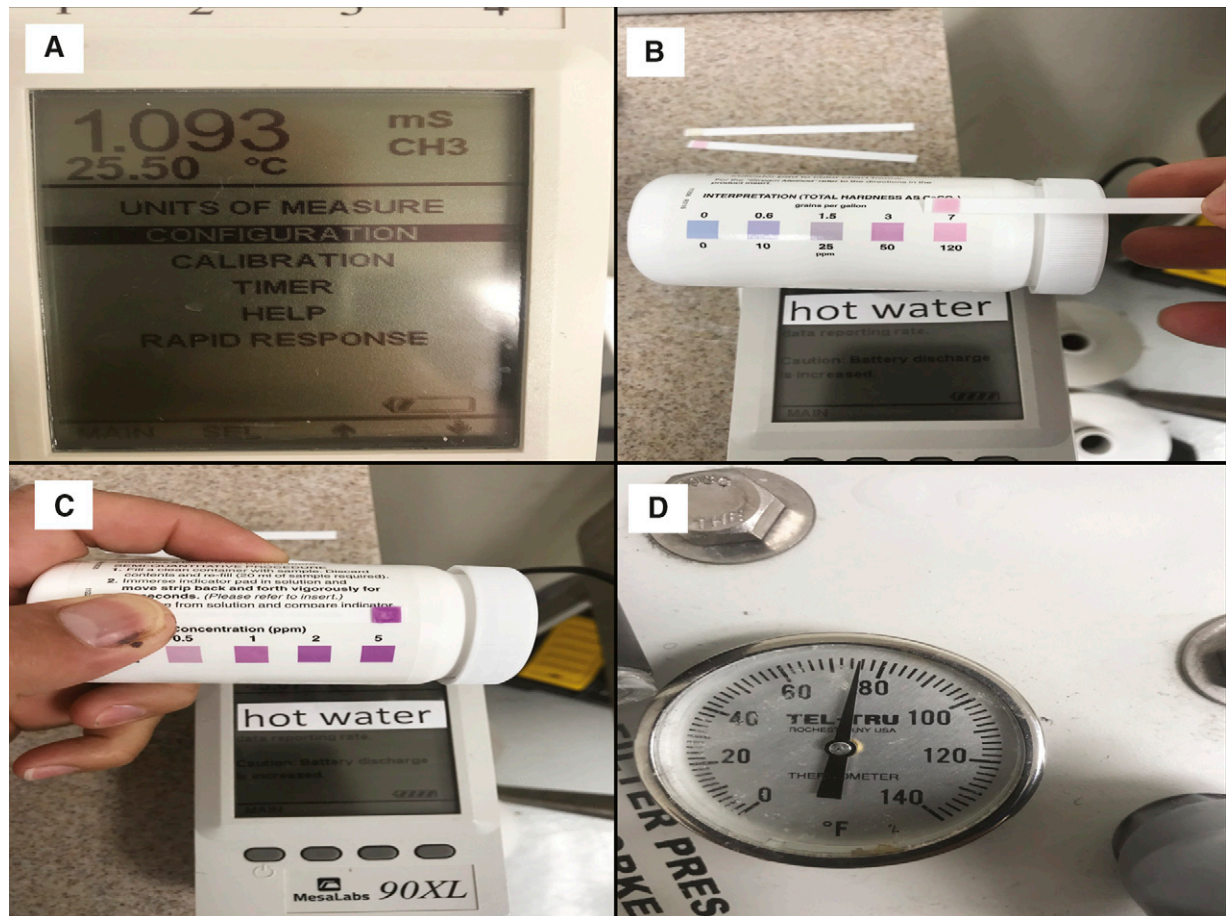


Figure 1. | Water testing images following multiple reverse osmosis unit alarms. (A) Mesa Laboratories 90XL Dialy-Guard Technician Meter demonstrating the elevated conductivity (1093 μ Siemens) that occurred within minutes of contaminated water overwhelming the hospitals chilled water system. This elevated conductivity causes the reverse-osmosis (RO) filters to shut down, alerting the dialysis staff to the issue with our water supply. (B) The hard-water testing strip reading for our hot water shortly after the initial RO alarm. There was elevation in the total hardness of the water with ≥ 120 ppm or 7 grains/gallon. (C) Chlorine concentration reading in the hot water shortly after the first alarms. The initial measurements showed 5 ppm. (D) The temperature gauge on one of the portable Mar Cor WRO 300 unit within the first 20 minutes of the alarm. It demonstrates an elevated water temperature of 76°F (24.4°C), which was similar to the 25.5°C seen in (A).

a natural disaster, it is important to have a safe and effective short-term backup plan. Our ability to pivot to a system with bagged dialysate allowed us to provide urgent and maintenance treatments for our inpatient population, without compromising patient safety, UF, and urgent clearance needs. Ideally, if fluid conservation is not paramount and staffing is available, higher dialysate volumes closer to the range of TBW should be used to increase urea clearance closer to that desired for thrice weekly treatments, keeping in mind that dialysis treatment time will be increased as well (13).

Disclosures

J.L. Koyner reports receiving grants and personal fees from Asute Medical; personal fees from Bioporto; and personal fees from SphingoTec, outside the submitted work. J.L. Koyner reports receiving personal fees from Baxter and grants from Nxstage Medical, during but unrelated to the conduct of this study. All remaining authors have nothing to disclose.

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Author Contributions

O.F. Kohn was responsible for methodology; O.F. Kohn and J.L. Koyner conceptualized the study, were responsible for formal analysis, wrote the original draft, and reviewed and edited the manuscript; and O.F. Kohn, J.L. Koyner, M. Plascencia, and Y. Taylor were responsible for data curation and investigation.

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