Novel use of pre-mixed dialysate bags during water supply interruption in acute hospital setting

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Abstract:

Dialysis patients are exposed to large amounts of water during conventional intermittent hemodialysis (IHD) hence strict regulations exist for 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 dialysis dependent inpatients is essential both from ultrafiltration and clearance standpoint. At our hospital, an unforeseen water disruption occurred and we were able to continue to provide renal replacement therapy with pre-made bagged dialysate to mitigate the impact on our dialysis patients. This is a novel method in utilizing available machines and dialysate, which we normally stock for continuous renal replacement therapy, 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. As this situation occurred in the midst of the Sars CoV2 pandemic we had to be mindful of dialysate volumes as well as staffing time. Here we present our investigation into the cause of 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 it was successful as implemented and tailored with adjustments for patients requiring higher clearance for specific indication such as severe hyperkalemia.
Introduction

With standard dialysis dialysate flow rate typically ranges from 600-800ml/min. During a 3.5hr session a patient is exposed to 126-168 liters of dialysate. Therefore, strict regulations have been developed by the Association for the Advancement of Medical Instrumentation (AAMI) and the International Standards Organization (ISO) for chemical and microbiological standards for the water used to prepare dialysate\(^1,2\). On a day in early summer 2020, towards the end of the first shift of our hospital-based inpatient unit, we were alerted that several of our portable reverse osmosis (RO) machines started alarming. While the first alarm occurred in a machine that was being cleaned off the unit and not in clinical use, shortly thereafter all seven ROs in the seven-chair inpatient unit as well as those being used for bedside procedures began alarming due to increased conductivity in the water. As per institutional policy all conventional IHD was stopped within minutes of the initial alarms due to concerns for water contamination. All patients had their vital signs checked and were all 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 investigation was begun to determine the cause of the water disruption. As the disruption could not be quickly resolved and other patients were due for dialysis later in the day and for the first shift the following day, all were converted to short hemodialysis using pre mixed bagged dialysate with slow dialysate flow using 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 which has a back-flow
preventer and blending valve for the hot and cold city water. The water coming from the water box
passes through a sediment filter and 2 carbon filters prior to reaching the RO.

Within minutes of the alarms and stopping the ROs we tested the dialysis feed water conductivity in
several locations. All conductivity readings were made on a Mesa Labs 90XL Dialy-guard Technician
meter (Lakewood, CO, USA).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 intakes from the water boxes for hardness and
chlorine level as well as temperature.

In addition to attempting to determine the source of the water issues, there were 10 other patients
scheduled for hemodialysis later that day as well as one emergency room patient. The majority of
pending patients had reasonable laboratory values, including several with mildly elevated potassium
levels. The emergency room patient, with a history of end-stage-kidney-disease was found to have a
potassium of 8.1meq/L after missing a week of hemodialysis. Thus, at least one patient would require
emergent treatment.

Our acute unit utilizes NxStage System One (NxStage Medical, Lawrence, MA, USA) for continuous veno-
venous hemodialysis (CVVHD) and as such our staff is familiar with its set-up for continuous use in the
intensive care unit (ICU). While 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 (4meq/L or 2meq/L
potassium) solutions and 2meq/L potassium lactate-based solutions. The machine used for continuous
renal replacement therapy does not have the same pre-set 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 dialysate flow rate (dialysate plus ultrafiltrate) to blood flow rate (Qds/Qb=flow fraction or FF).
The higher the flow fraction, the lower will be the efficiency of the dialysis (ie effluent will have a lower saturation with urea), hence it must be input at setup of the home machine to ensure Kt/V will fall within desired range. The FF combined with the total dialysate volume and ultrafiltration volume determine treatment time as a dependent value. The machine, as set for ICU use, does not require entry of FF nor total UF, rather desired hourly dialysate flow rate and fluid removal rate is inputted. Based on physician experience with NxStage machine for home hemodialysis (OFK) we decided to convert the patients’ orders for the acute setting to IHD using the NxStage machine. Factors considered in prescription conversion were patients’ weight, access type, net ultrafiltration goal (based on volume status) and metabolic needs (as determined by blood chemistries review). As the water disruption persisted for over 24 hours, we used the same techniques the following day as well.

When prescribing a short dialysis session on NxStage machine the nephrologist has to prescribe the total dialysate volume required, total ultrafiltration (UF) (net UF plus both the prime and rinse back volumes), blood flow rate (BFR in ml/min), dialysate flow rate (DFR in L/hr), treatment duration and dialysate base (lactate or bicarbonate and K content). Hourly DFR is total dialysate volume divided by treatment time. Hourly UF rate will be 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 liver failure patients or those with lactic acidosis. Lactate based solutions are routinely used in the home-hemodialysis setting with NxStage system, as 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 3 times DFR. Our goal was to keep dialysis treatment time at about 3 to 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 (sp) Kt/V of at least 0.5 (granted, for 6 treatments per week using this machine). For example, in a patient who weighs 70Kg, total body water (TBW) would
be roughly 35L. Total effluent (dialysate plus UF) should be nearly 20 liters for single pool Kt/V of approximately 0.5. As the efficiency of dialysis declines with lower BFR to 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. Maximum DFR of our inpatient machines is 12L per hour (some Nxstage HHD models for home use go as high as 18L per hour). As with all dialysis, blood flow rates are dependent on vascular access with our AKI and ESKD patients having a mix of temporary and permanent central venous catheters as well as arterio-venous grafts and fistulas.

In scheduling treatments we were aware of patients’ pre-dialysis lab values and while we anticipated this water issue to be relatively short term but last for more than 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.

Our stock of dialysate bags come in 5L, as such it is best to round up the volume to a multiple of 5 to avoid wasting fluid. As these events occurred during the SARS CoV-2 pandemic, following a surge period, we felt a conservative approach to premixed dialysate bags is particularly important 

Results:

A. Water investigation

Conductivity was 1,093 micro Siemens (µS) and temperature was 25.5°C (78°F) (figure 1A) in our equipment maintenance room. Conductivity ranged between 370 and 1,600µS in several of the acute dialysis unit rooms and throughout the intensive care unit (ICU) rooms. Conductivity is the measure of...
the ability of a material or solution to conduct an electric current, and correlates directly with 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 parts per million (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 120ppm (test strip can only read up to 120ppm).

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 of 0.1ppm for the cold water and 0.5ppm for the hot water. EPA drinking water standard allow for maximum free chlorine level of 4mg/L (or 4ppm)\textsuperscript{11}.

Finally, it was noted that the temperature of the water in all of the dialysis water boxes feeding the ROs 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, 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 determined the ideal methodology to fix the issues. Through our investigation it was determined that owing 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 which ultimately pushed some of the condensing water into the domestic water piping contaminating the water supply to the dialysis water boxes.
Over the course of the same 48 hours, in addition to sending 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 impact on the dialysis water supply.

B. Short low dialysate flow dialysis:

There were 11 treatments scheduled for the afternoon of the day of the water disruption and 6 treatments scheduled for the morning shift of the following day, total of 17 sessions. Vascular access was AV fistula for 7, graft for 2 and central venous catheter for 8 sessions. BFR was about 400 in patients with AV access and as high as 350ml/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 non-oliguric. Net UF averaged 1.6L (with a range of 0 to 3L). Dialysate volumes prescribed ranged from 12.5 to 40L. In one case of a patient initiating dialysis for AKI on top of some chronic kidney disease, the plan was for 3 consecutive sessions the prescribing nephrologist chose to initiate at lower dialysate volumes. For established ESRD patients dialysate volume averaged 0.65 of their total body water (TBW) whereas for patients new to dialysis it averaged 0.44 of TBW (as noted one new start had 2 treatments 2 days in a row on the NxStage machine). The average duration of treatments was 3hr11min (range from 2.5hr for one new start to 6hr). No patient experienced any adverse complication related to their treatments.

We did not measure sp Kt/V nor URR for any treatments. Measurement of Kt/V in the setting of inpatient dialysis and more specifically AKI is quite rare. For 11 patients pre NxStage HD (pre) and next morning (post+1) chemistry values were available. Average Pre-dialysis BUN was 42mg/dL and post+1
BUN average was 32mg/dl, pre-potassium 4.7, post+1 K 4.2meq/L. Of those 11 patients, 5 had pre-phos>5 with a mean pre-dialysis value of 5.9 and a post+1 mean of 5mg/dl. Treatment FF averaged 35%.

The aforementioned patient with the pre-dialysis potassium of 8.1 was prescribed a dialysate volume of 40 liters and treatment time was extended to 6 hours because of the degree of hyperkalemia and as the lowest potassium dialysate concentration available in our stock was 2.0meq/L (for home use 1K lactate dialysate is available). His FF was 30%. This resulted in a post dialysis K drawn at 4hr9min post dialysis completion of 4.9meq/L and one drawn 8hr post HD completion was 5.4meq/L.

Discussion

Our experience highlights several issues for nephrologists. Vigilance around water quality is of the utmost importance. While 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 conductivity issues, infectious complications or even due to a natural disaster, it is important to have a safe and effective short term back up 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, ultrafiltration 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:

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Author Contributions:

O Kohn: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Writing - original draft; Writing - review and editing

M Plascencia: Data curation; Investigation

Y Taylor: Data curation; Investigation

J Koyner: Conceptualization; Data curation; Formal analysis; Investigation; Writing - original draft; Writing - review and editing
## Table 1: Sample order set for short hemodialysis with low dialysate flow rate

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment duration (Hrs)</td>
<td>3 hr or more depending on metabolic needs and UF requirements</td>
</tr>
<tr>
<td>Dialysate potassium (meq/L)</td>
<td>1 or 2 (4 if patient is significantly hypokalemic)</td>
</tr>
<tr>
<td>Lactate or Bicarbonate base</td>
<td></td>
</tr>
<tr>
<td>Total dialysate volume (Liters)*</td>
<td>0.5-1 TBW</td>
</tr>
<tr>
<td>Hourly dialysate flow rate (L/H)</td>
<td></td>
</tr>
<tr>
<td>Net ultrafiltration goal (L)</td>
<td>based on volume status assessment</td>
</tr>
<tr>
<td>Hourly UF = ((net UF goal+prime+rinse-back)/treatment duration)</td>
<td></td>
</tr>
<tr>
<td>Blood flow rate (ml/min)</td>
<td>As catheter or AV access permits</td>
</tr>
</tbody>
</table>

*Parameters in Italics are necessary to determine hourly rates and for staff to set up the machine but are not keyed into the machine.

If no need to conserve fluid aim for dialysate volume of about half total body weight. This will result in longer treatment time. We typically add MAP parameter (example maintain MAP>65). It is recommended to keep FF around 30-35% if conserving fluid.
References:


Figure legend

Figure 1A- Mesa Labs 90XL Dialy-guard Technician Meter demonstrating elevated conductivity (1,093 µSiemens) that occurred within minutes of fresh water overwhelming the hospitals chilled water system. This elevated conductivity causes the reverse osmosis filters to shut down, alerting the dialysis staff to the issue with our water supply. Figure 1B- 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 over 120 parts per million or 7 grains per gallon. Figure 1C- Chlorine concentration reading in the hot water shortly after the first alarms. The initial measurements showed 5 parts per million. Figure 1D – The temperature gauge on one of the portable Mar Cor RO 300s 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 Figure 1A.