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# Evaluation of reverse osmosis for improving quality of water utilized in hemodialysis devices (case study: Kerman University of Medical Sciences' hospitals)

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## ABSTRACT

The presence of some chemical compounds in water used in dialysis devices and the blood circulation system of patients causes many problems, such as acute toxicity, bone and brain diseases. Relevant standards must be observed when valuing these compounds in the water used in a dialysis device. In this study, the rate of total hardness and the concentrations of aluminum, lead, and zinc in dialysis water samples were determined. The concentrations of aluminum, lead, and zinc in the dialysis water at hospitals 1 and 3 and the concentrations of lead and zinc in dialysis water in hospital 2 corresponded with AAMI standards; the concentration of aluminum in the dialysis water at hospitals 1 and 3 also corresponded with EPH standards. Total hardness did not correspond with AAMI standard in any of the three studied hospitals. The promotion of a maintenance program in reverse osmosis devices and the timely replacement of films is important for improving the quality of water for use in dialysis systems.

*Keywords:* Dialysis; Reverse osmosis; Water; Kerman University of Medical Sciences' hospitals

## 1. Introduction

Chronic kidney deficiency is a progressive and irreversible disease which disrupts kidney functions. This disorder causes the disposal of specific solution materials by the kidney to decrease, and it forms deadly and unsafe conditions such as urine in body liquids. Dialysis is performed to prevent the formation of urine in the body. In this mode: blood solution materials were decreased by the dialysis device [1,2]. On average, one dialysis patient will be remedied three times per week for 4 h each time. In every hemodialysis session, they receive 150 L water plus dialysate, which contains necessary materials for the body [3,4], such as acid, salt, bicarbonates, and water. (Dialysate is over 99% water.) This is the reverse osmosis process [5,6]. The utilized dialysate consumes the greatest water volume [7]. Commercially concentrated liquid was produced in some quality and totally controlled: but, it is possible that utilized water have different quality using light water. It is accompanied by the potential transfer of toxic materials through dialysis to the patient's blood. Thus, the quality of the water consumed in dialysis is most important when preparing the dialysis solution [8,9]. In 98% of dialysis centers in the United States, water consumed in the dialysate was settled in filtration, softened, deionized, and finally treated with reverse osmosis. In the reverse osmosis process, water is passed among semipermeable membranes with high pressure, and over 99% of the solution ions are cleansed of microbial pollutants

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[10]. Pollutants in drinking water enter the blood mainly through the digestive system. During hemodialysis, however, pollutants in the dialysate are being directly entered into the blood. It is vital to consider microbial, chemical, and physical standards for dialysate. Chemicals and the microbial pollution of water could have serious and deadly results for patients [11]. Chemicals such as lead, zinc, aluminum, chlorine compounds, nitrate, and sulfate are toxic for hemodialysis patients. The important effects of these materials include osteomalacia, hemolytic anemia, nausea, and vomiting [6,8,12,13]. Compounds added to drinking water at refineries, such as aluminum, fluoride, and chloramines, have more effects on dialysis patients. In all centers that have dialysis devices, properly installed water treatments must exist so that the quality of the water used in dialysis meets the necessary standards [13,14]. In order to prevent the formation of unpleasant smells and films, silting inlet water to models of reverse osmosis mustn't have suspended solids and organic materials and surplus hardness. This important issue can be solved by installing water softening systems before the reverse osmosis system in areas that have relatively hard water [15]. A greater threat than the water in these devices is the chemical and microbial pollution occurring during transmit stock pile and the various steps of water treatment [16]. In Japan, Oie et al. performed microbial tests on dialysate samples [17]. In Belgium, Haese et al. studied cadmium, lead, zinc, and vanadium concentrations in the serum levels of some dialysis patients [11]. Tonelli et al. studied cadmium, lead, zinc, and vanadium concentrations in the water of dialysis devices in Italy [18]. Al-Naseri et al. studied the quality of inlet and outlet water in the reverse osmosis system of dialysis devices and compared their results with standards in Iraq [19]. Pirsaheb et al. studied the effectiveness of reverse osmosis for the removal of lead, cadmium, chromium, and zinc in water to be used in dialysis devices in Iran [20]. Aruonitidou et al. studied the concentrations of some metal elements, such as aluminum, iron, and nickel, in the outlet water quality of the reverse osmosis system of a hospital in Greece and compared their results with standards [21]. The American National Standards Institute of the USA formed the Association for Advancement of Medical Instrumentation (AAMI) [13]. This association has stated the minimum standard levels of toxic compounds for patient safety and nontoxic compound levels in hemodialysis water to prevent any imbalance in the dialysate compound (for example Ca, Mg, K, Na), and admissible levels of toxic elements in drinking water. Patient health is endangered by these compounds remaining in and passing through the outlet water of a reverse osmosis system in the dialysis devices [13]. The European Public Health Council in 1963 formed technical, legal, and administrative institutions such as the European Pharmacopeia (EPH) [22].

The current study aimed to evaluate reverse osmosis devices and compare them with AAMI and EPH standards in a case study of hemodialysis devices in hospitals affiliated with the Kerman University of Medical Science.

## 2. Material and methods

This sectional study was performed at the Research Center of Environmental Health Engineering in Kerman University of Medical Science every three months in 2017. Twenty-four samples of inlet and outlet water were selected from 3 reverse osmosis systems in all three studied hospitals. The features of these devices are given in Table 1.

Features of reverse osmosis systems and dialysis devices of hospitals related to Kerman University of Medical Sciences.

Samples were taken from water entering the reverse osmosis system that purifies drinking water in the Kerman plumbing network. Dialysis devices included in the study were the BMA made in Germany and the Surdial-X made in Japan. The 1600 L/h reverse osmosis device utilized in water treatments for dialysis had 11.5–12 bar pressure and polyamide membranes. Before arriving at the reverse osmosis device, water in the city water network was softened by three resin capsules. Twenty-four samples of inlet and outlet water were taken from three reverse osmosis devices that provided water for dialysis devices. Chemical analysis and sampling was done according to methods described in the standard methods book for water and wastewater testing [23]. The pH of the samples was kept below 2 by adding nitric acid. After sampling, The Varian AA240 FS atomic absorption device (made in Australia) was used to determine the concentration of aluminum, lead, and zinc. To measure the metal concentrations, the stoke of aluminum, lead and zinc were prepared at a concentration of 1000 µg/mL. For testing after turning on the atomic absorption device, the light conditions of the device were set at 309.2 nm for aluminum, 213.9 nm for zinc, and 283.3 nm for lead. Titration was performed to determine the total hardness concentration. Statistics analysis was performed on the data by descriptive statistics.

## 3. Results and discussion

Since the quality of dialysis fluid plays an important role in patient safety and welfare, it should be viewed as a medicinal product, and every effort should be made to ensure a high-quality fluid. The water purification systems in some hemodialysis centers, especially reverse osmosis, lead to a sufficient decrease in the contaminant parameters. The results of the current study showed that the chemical quality of drinking water is not acceptable as dialysis water because of the presence of some chemicals in higher concentrations than recommended by standards for dialysis water. Based on the results, the concentrations of lead, aluminum and zinc in the outlet water of reverse osmosis (RO) devices exceeded the maximum levels suggested by the AAMI, and the purification systems could not significantly reduce

Table 1
Number of dialysis beds and devices in Kerman University of Medical Sciences' hospitals

| Hospital name | Hospital number | Number of dialysis beds | Number of dialysis devices |
|---|---|---|---|
| Shafa | 1 | 18 | 18 |
| Afzalipour | 2 | 5 | 6 |
| Javad-alaemeh | 3 | 24 | 24 |

these chemicals in some centers. In other words, the chemical quality of water coming out of the RO in all centers was not completely suitable as dialysis water (Table 2). Furthermore, the concentrations of lead, aluminum, and zinc of the dialysis water in some centers did not comply with AAMI guidelines (Table 3). These results indicate that the water purification systems in some centers could not sufficiently reduce the concentrations of these chemicals. Generally, RO-based treatment systems produce dialysis water of optimal chemical quality. However, the efficacy of the systems depends on maintenance and operation. Therefore, special attention must be paid to the suitability of materials and chemicals used in dialysis treatment systems.

The measured values for aluminum, lead, and zinc concentrations and total hardness in the inlet and outlet water from the reverse osmosis system of dialysis devices and their standard deviations are shown in Table 2.

As can be seen in Table 2, the concentration of lead in hospital no. 1, the aluminum, lead, and zinc concentrations in hospital no. 2, and the lead and zinc concentrations in hospital no. 3 were increased in the outlet water of the reverse osmosis device. Total hardness concentration was decreased in the inlet water of the reverse osmosis device. The results of the comparison of zinc, lead, and aluminum concentrations in the outlet water of the reverse osmosis system for dialysis devices and EPH and AAMI standards are shown in Table 3.

Due to concentration gradient event and osmotic pressure that led to the accumulation of metals in the pores of the system's semipermeable membranes, they are used thereafter. When raw water is being pumped by the pump to the membrane, metals can potentially be passed to the other side of the membrane, which causes metals to accumulate on the membrane inside the outlet water of the reverse osmosis system. This indicates the high longevity of the membrane, and as a result, the system membrane must be changed.

As seen in Table 3, hospital number 1 had an aluminum concentration lower than EPH and AAMI standards, a lead concentration that was higher than EPH and AAMI standards, and a zinc concentration that was higher than EPH standards, but lower than AAMI standards. In hospital number 2, the aluminum concentration was higher than EPH and AAMI standards, and lead and zinc had concentrations that were lower and higher, respectively, than EPH and AAMI standards. In hospital number 3, the aluminum concentration was lower than both EPH and AAMI standards, lead was higher than EPH and AAMI standards, and the zinc concentration was lower than EPH standards and higher than AAMI standards. Moreover, in the reverse osmosis outlet water, all three hospitals had a total hardness concentration that was higher than AAMI standards. The highest rate of reverse osmosis system utility in the dialysis devices in number 1 hospital will have related to aluminum removal and lead in the number 3 hospital only related to aluminum removal. Mainly, the aluminum concentration in hospital number 2, the lead concentration in all three hospitals, and the zinc concentration in hospitals number 2 and 3 were not only decreased by the reverse osmosis system of the dialysis device, but was also increased in the outlet water of the reverse osmosis system. The inlet water quality of the dialysis device in hospitals number 1 and 3 in respect to all three metals and to lead and zinc in hospital number 2 corresponded with the AAMI standards. However, this statement is not true in hospital number 2; only aluminum corresponded with the EPH standard in hospitals number 1 and 3. With increasing some of metals after reverse osmosis system, this system could show proper effectiveness to transmit metals concentration to AAMI standard but it isn't proper effectiveness than Eph standard. Sanadgol et al. eval-

Table 3
Results of comparison of aluminum, lead, and zinc concentrations and total hardness in the outlet water of reverse osmosis system for dialysis devices and with EPH and AAMI standards

| Concentration | Hospital number<br>1 | <br>2 | <br>3 | EPH standard (mg/L) | AAMI standard (mg/L) |
|---|---|---|---|---|---|
| Aluminum (µg/L) | 0 | 44.48 | 0 | 0.01 | 0.01 |
| Lead (µg/L) | 5.7 | 4.88 | 5.93 | 0 | 0.005 |
| Zinc (µg/L) | 25.4 | 27.4 | 23.7 | 0 | 0.1 |
| Total hardness (mg/L $CaCO_3$) | 40 | 40 | 43 | – | 35 |

Table 2
Concentration of aluminum, lead, and zinc in the reverse osmosis system for inlet and outlet water before arriving to the dialysis devices

| | Aluminum | | Lead | | Zinc | | Total hardness | |
|---|---|---|---|---|---|---|---|---|
| | Hospital number | Concentration (µg/L) | Standard deviation | Concentration (µg/L) | Standard deviation | Concentration (µg/L) | Standard deviation | Concentration (mg/L $CaCO_3$) |
| Inlet water to reverse osmosis | 1 | 7.4 | 0.02 | 4.40 | 0.03 | 33.7 | 0.08 | 220 |
| | 2 | 6.87 | 0.04 | 3.49 | 0.38 | 17.6 | 0.59 | 240 |
| | 3 | 8.30 | 0.28 | 4.45 | 0.48 | 9.2 | 0.55 | 215 |
| Outlet water to reverse osmosis | 1 | ND | 0 | 5.7 | 0.11 | 25.4 | 0.21 | 40 |
| | 2 | 44.84 | 0.07 | 4.88 | 0.04 | 27.4 | 0.11 | 40 |
| | 3 | ND | 0 | 5.93 | 0.01 | 23.7 | 0.67 | 43 |

uated the water of the reverse osmosis system in a dialysis device in Zahedan hospitals for aluminum levels and compared them with AAMI standards. Their results showed that the aluminum concentration was increased by 16 µg/L before reverse osmosis and by 19.8 µg/L after reverse osmosis [24]. Arvanitidou et al. studied 85 water samples from an osmosis system in the dialysis device of a dialysis center in Greece and revealed that the average aluminum concentration was greater than the AAMI standard limit [21]. Asadi et al. studied a water reverse osmosis system in the dialysis device in hospitals in Qom, Iran. Their results indicated that the aluminum concentration (13%) and cadmium concentration (6%) were higher than the AAMI and EPH standards [25]. Vorbeck et al. conducted a study in Australia that showed that lead, zinc, and aluminum concentration values were higher than the AAMI standard limit in water samples of a dialysis device [26]. Marjani et al. studied the water of a reverse osmosis system in the dialysis device of Gorgan hospitals in Iran and revealed that aluminum concentrations were higher than the AAMI standard limit [27]. Tonelli et al. studied the water of a reverse osmosis system in a dialysis device in Italy. Their results indicated that cadmium, lead, and vanadium concentrations were higher than the AAMI standards [18]. Pirsaheb et al. evaluated a reverse osmosis system in a dialysis device for cadmium, chromium, and zinc removal from inlet water to dialysis devices. Their results indicated that cadmium and lead concentrations were higher than AAMI and EPH standards in the inlet water to the dialysis devices [20]. These results are in line with those of the current study.

Fig. 1 and Table 4 show the comparative evaluation of metals in the water before and after RO on dialysis devices.

The mentioned research corresponded with the results of increased metal concentrations in the present study due to concentration gradient event and osmotic pressure that led to the accumulation of metals in the pores of the system's semipermeable membrane of course, they are used thereafter. When raw water is pumped to the membrane, it is possible to pass metals to the other side of the membrane. As a result metals accumulate on the membrane inside the outlet water of the reverse osmosis system [25]. This indicates the high longevity of the membrane and, as a result, the system membrane must be changed. Because of the softening resin in the water before it arrives in the reverse osmosis device, the total hardness of the outlet water of the reverse osmosis system in all three hospitals was higher than the AAMI standard limit. Due to the total hardness of Kerman's potable water, placed in the limits relatively hard water and whatever solution solids were more in the water as same as it will exceed scale formation on membranes, the low efficiency of the reverse osmosis system can be attributed to low efficiency softening resins. If the softening resin is not reduced in a timely fashion, the concentration of hardness sediments will accumulate in water entering the reverse osmosis device, and it will obstruct the pores of the reverse osmosis membrane and finally reduce the efficiency of the reverse osmosis device.

## 4. Conclusion

Promotion of a maintenance program in reverse osmosis devices, timely replacement of films, use of stage-two or -three RO or FO with the RO process, and reducing the period of use of an RO before dialysis are actions that can

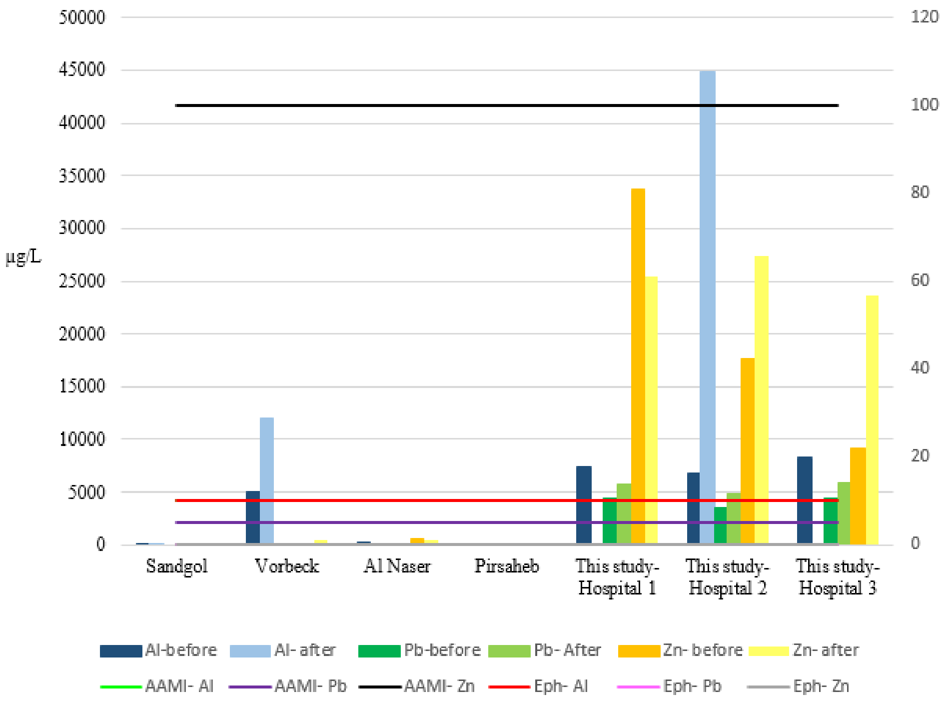

Fig. 1. Comparison of results of evaluation of metals in water before and after RO on dialysis devices and with EPH and AAMI standards.

Table 4
Comparison of results for evaluation of metals in water before and after RO on dialysis devices

| µg/L | Al-before | Al-after | Pb-before | Pb-after | Zn-before | Zn-after |
|---|---|---|---|---|---|---|
| Sanadgol (2004) | 16 | 19.8 | 0 | 0 | 0 | 0 |
| Vorbeck (1999) | 5000 | 12000 | 0 | 0 | 20 | 500 |
| Al-Naser (2013) | 270 | 150 | 10 | 9 | 495 | 500 |
| Pirsaheb (2014) | 0 | 0 | 18.53 | 18.81 | 112.67 | 43.39 |
| This study-Hospital 1 | 7400 | ND | 4400 | 5700 | 33700 | 25400 |
| This study-Hospital 2 | 6870 | 44840 | 3490 | 4880 | 17600 | 27400 |
| This study-Hospital 3 | 8300 | ND | 4450 | 5930 | 9200 | 23700 |

improve the quality of the outlet water from these devices to the input of the dialysis system. Inattention to this important issue and the arrival of metals and ions to the inlet water of dialysis devices and subsequently to the patient's blood circulation system will likely cause other diseases in the patient, such as acute toxicity, bone and brain disease. To attain EPH and AAMI standards, the replacement time of the reverse osmosis device membrane should be determined by doing monthly water tests before the whole obstruction of the membranes.

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