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Review Article

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Green Hemodialysis: A Possible Way of Nature Friendly and Cost-Effective Kidney Replacement Therapy

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ABSTRACT

The most common kind of kidney replacement therapy worldwide is hemodialysis and in comparison to many other medical treatments, hemodialysis programs appear to have an expensive and producing plenty of waste.
Hemodialysis systems currently in use are water hungry, but it is possible to reduce it by adjusting the reverse osmosis system and saving the rejected water. The dialysate flow rate could be tailored to low normal limits according to the patient's need. Temperature effect on reverse osmosis system and flow rate must be taken into consideration. There would be no hesitation to use rejected water in different areas if the composition of it is clearly explained. Using a central dialysate system may reduce the amount of waste products, especially plastics, and the cost of dialysate transportation. It is possible to implement the idea of reduce, reuse, recycle, and repair throughout the hemodialysis for decreasing the carbon footprint and health expenditures.
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INTRODUCTION

Human populations having health advancements and life expectancy nearly doubled over the past century. However, these advancements have come at a significant environmental cost. By 2050, only 10% of the entire Earth will be free from the invasion of mankind's activity, down from less than 25% today.[1] Pollution is a global problem that threatens public health. Plastic waste from industrial facilities is permitted in amounts of 4.8-12.7 million tons per year, along with several million tons of harmful chemicals and other pollution leaking into the lakes and oceans.[2] Additionally, greenhouse gas emissions have increased 2 times since the late 20th century, increasing the environmental surface temperature by 1°C over the pre-industrial point. Unprecedented threats are being presented by global warming to both ecological systems and human health.[3] Importantly, healthcare systems require many resources and contribute significantly to greenhouse gas emissions, especially in wealthy nations. At the beginning of the 2000s, the Medicare contributed almost 1/10 of all US emissions, whereas in 2014-2015, it contributed only 7% of all Australian emissions.[4] In every hemodialysis (HD) session, nearly 2 kg of hazardous waste wasproduced which were mainly contaminated plastics and technological materials and require plenty of water and electricity usage. In UK medical sector emissions contributed lower in 2015 were significant attempts have been done to lessen carbon footprint at 4%. In comparison to many other medical treatments, HD programs appear to have excessively high expenditures' and waste production profile.[5,6]

The most common kind of kidney replacement therapy worldwide is HD. End-stage kidney disease (ESKD) affects almost 786 000 people in the US, with 71%

relying on dialysis. According to the 2020 Annual Data Report of the United States Renal Data System, Medicare spent more than $70 billion on beneficiaries with chronic kidney disease (CKD) in 2018 (excluding ESKD), accounting for 23.8% of all spending on beneficiaries in this age range. Patients with CKD aged ≥66 years spent more than twice as much per person each year ($23 691 vs. $10 842) as those without CKD. Medicare expenditures for individuals with ESKD were $49.2 billion in 2018.[7]

According to registries, 3 362 000 persons had dialysis globally in 2018, with 2 993 000 (89%) receiving HD and 369 000 (11%) receiving peritoneal dialysis.[8] As a matter of fact, the number of people who undergo dialysis around the world is expected to increase every year and reach close to 5 million people by 2025.[9] The magnitude of the environmental impact of this 1 medical intervention is evident when these figures are compared to the resources required and waste generated for each dialysis treatment.[10]

In Turkey, 15.7% of the population have CKD, and according to 2020 Turkish Society of Nephrology Registry Report, there are 57 920 chronic HD patients and 88% of these patients are treated with HD treatment for 3 sessions or more per week.[11] If we analyze the current HD patients, 903 552 sessions are held annually, and it is known that 120 L per session totally 1 084 262 m^3 of pure water is needed. The amount of water going to the sewerage is 2 times and calculated as approximately 2 500 000 m^3. The water going to the sewerage is a burden to the sewerage but is billed as wastewater, thus harming the Turkish National Economy. Our aim in this review was to take attention the huge magnitude of water use and waste production, so the wasted water would be determined according to the need, and the water that goes to the sewerage and is a burden on the economy would be saved, which means taking the country one step further.

The UN published a Global Assessment Report in May 2019 that was hailed as the most thorough examination of life on Earth ever carried out.[12] This study delivered a dire caution: "The ecosystems' health, on which humans and other genus depend, is declining more quickly than forever." The core underpinnings of the economy, livelihood, eating security, well-being, and life quality are all being undermined by us globally.[12] It was made plain that, although remediation is conceivable, it will necessitate drastic, immediate change on all fronts, from local to global.[13] In this situation, it is crucial to prevent ecological catastrophe. The areas of medicine with the largest environmental impact should take the lead in efforts to lessen that impact. The nephrology society has a responsibility to create wide-ranging and cutting-edge environmental programs because dialysis appears to have one of the biggest environmental footprints of all.

MAIN POINTS

- Rejected water of reverse osmosis is an excellent and must be used either recycling (although membrane life shortens) in the hemodialysis treatment sterilizing units, toilets cleaning, or all gardening purposes.
- Less than one-third of the non-infectious garbage was possibly recyclable, and even polysulfone dialyzers must be regained by logical solutions to prevent being wasted. Do not forget 4 R: "Reduce, Reuse, Recycle, and Repair."
- Central dialysate system is economical and lessens the carbon footprints so all the countries must stimulate the local authorities to allow this system.
- In the near future, sorbent dialysate must be studied.

Hemodialysis systems currently in use are water hungry. Low-efficiency reverse osmosis (RO) systems are almost exclusively used as water filtering systems for HD treatment. This system rejects 60%-70% of water supply from mains, tanks, bores, or well. Hemodialysis treatment needs 0.5 L/min dialysate flow which is composed of a ratio of 35:1 with a chemical concentration. In order to fit that amount, 1.5 L/min water supply must be produced from the RO system.[14] According to the length of treatment (4 h/session), the efficiency of the RO system (60%-70%), inter-treatment sterilization and rinsing stages, and total feed, 500 L or more of water will be drawn for each session of treatment.[15]

REDUCING DIALYSATE FLOW RATE

Renkin[14] developed the first theoretical arguments in the late 1950s connecting hemodialyzer cleaning power to dialysis fluid and blood flow rates. An association between the blood and solute transport curves flow-rate or dialysate at a steady flow-rate. Clearance augments when dialysate flow increases, but only to some instant, the price of dialysate water won't be balanced by the advantages of greater effectiveness or dumpier length of treatment. Sigdell and Tersteegen,[15] proposed that theoretical investigation the realistic upper bound of dialysis flow is twice as fast as blood flow; above for tiny molecules, the improvement in solute transport is limited. Polaschegg and Peter[16] suggested "dialysate flow = 1.5 × Blood flow" as a workable compromise because the cleaning of intermediate or big solutes are, however, minimum dependence on the flow. This strategy works well for automatic control as well.[17]

In older patients with low metabolic demands, the balance may currently indicate toward a lower dialysate flow, where the most favorable dialysis is likely balanced with personal needs.[18,19] An adequate gradient of solutes could be achieved throughout the HD session at considerably lower flow rates, particularly on short daily HD sessions, several of the recent tiny home HD machines recirculate low-flow dialysate.[20] These experiences also imply that, for the elderly HD patients with low metabolic needs, ineffectively functioning vascular accesses and bad nutritional condition; reducing their dialysate flow may not cause negative end results.

High dialysate flow rate (800 mL/min) should be reconsidered where there is no benefit to the patient and should be replaced with automatic flow rate regulators to maintain 1.2 times the blood flow rate of the dialysis fluid.[21]

REVERSE OSMOSIS SYSTEM

Reverse Osmosis System Choice

Oversized RO systems can reject RO water and waste a lot of treated water.[22] Additionally, a large RO membrane demands a high output and a high reject flow.[23] As a result, when constructing water treatment equipment, these aspects must be considered.

Temperature Effect

The feed water's composition and temperature have an impact on the RO system's efficiency.[24] Product flow through the membrane is inversely influenced by temperature: approximately 70% of the feed water might be rejected and high temperatures increase product flow, while low temperatures decrease it. The adoption of a dual-pass RO system, in which the rejected water travels through the RO procedure before being thrown away to trash, can lessen this[24] Advanced RO systems are also typically more effective and send a reduced amount of water to the sewer.[25,26] Because of worries that used dialysis fluid could contaminate the environment with bacteria or viruses, reuse of utilized dialysis fluid is still at the starting level. In their examination of the possibility of reusing such water, Tarrass et al[27] found that the USA's rejected water and dialysis fluid output both amount to around 27 GL, which is enough to gather the annual demands of a conurbation with a population of 175 000.

Water Flow Control

A mechanism installed on the delivery ring to automatically change the water stream to meet concrete use is referred to as a flow regulation device. As a result, the RO system uses less water and sends less waste to the sewage. The fluid requirements of machines in HD are not constant and change as the machine cycles.[28]

In order to control the water flow rate in accordance with the water consumption by machines, flow regulators like a regulator (directly working or pilot driven) can be utilized.[28] As a consequence, the RO unit decreases water waste by appropriately controlling water construction.[22]

The advantages of employing this technology in lowering waste from RO systems were mentioned by Printz.[22] Using a service with 20 machines, 2 sessions of 4 hours each, 6 days a week, and operating at 50% of capacity 3 times a week, the discard RO water can be estimated to be 1372.8 m^3 per year. However, employing a motorized triple-way valve reduced the discard RO water to 917.28 m^3 per year, resulting in directly water reserves of 455.52 m^3 per year.[22]

Composition of Rejected Water

People frequently misunderstand the idea of RO system reject water. Currently, leaving water from the pre-dialysis water purification procedure is frequently mistaken. Generally discarded or considered to be water that has come into contact with patients and is polluted by their waste. Effluent dialysate comprises end-products of the treatment procedures (post-dialyzer and post-patient.)

Reverse osmosis system reject water is produced by the purification procedure before patient contact. Once this distinction is realized, RO system reject water "can be used for nearly any requirement that arises locally."

John W.M. Agar showed how quality of the RO rejected water actually, it was innocent water. Up to now, all over the world, this water was removed to the sewer. Like mineral water, RO system reject water is good enough to use any purposes could be even used for drinking (Table 1), but convincing local authorities of its potability may require local testing.[29]

In their study, 2 36 000-L holding tanks were erected on an eighth-floor rooftop in our 8-station hospital's in-center setting. From there, under gravity feed, RO system reject water was piped to the hospital's centralized sterilizing department to supply steam for its autoclave systems (Figure 1).

Additionally, inflow plumbing connections to certain toilets for waste flushing as well as to nearby janitor stations for use in floor washing were established.[31-33] Water that is still available is used for landscaping. Within 30 months, the investment paid for itself in full, and from that point on, hospital water costs started to fall sharply. Two additional industry-donated tanks at their 16-station suburban satellite center store RO system reject water for free collection by schools, athletic fields, and local parks and gardens.

Connor et al[34] described their system in the UK using RO lost water for more than 10 years. The water lost by RO is diverted to a recovery tank. From here, it is pumped into the gray water tank on the roof and sent to the toilets. Float buttons direct the water lost with RO if the gray water tank is full, and these diverter caps direct the water lost from the RO system during monthly chemical disinfection. It is reported that more than €12 000 is saved and 0.76 tons less carbon is consumed per unit.

Effluent Dialysate Reuse

Moroccan Tarrass et al discussed that waste dialysate can be used for irrigation in arid countries with water shortage.[23] In this case, the dialysate is likewise cured using ultrafiltration and RO techniques; this is cheaper than desalination of seawater.

Waste Production

In the healthcare industry there are 3 main waste disposal streams: general garbage, infectious waste, and waste for

Table 1. Water Chemicals in Mains Water In-Feed and RO System Reject Water Outflow

	HD1	RO RW1	HD2	RO RW2	US EPA Standard
Aluminum, mg/L	0.01	0.01	0.01	0.01	<0.05
Arsenic, mg/L	0.001	0.001	0.001	0.001	<0.01
Cadmium, mg/L	0.0002	0.0002	0.0002	0.0002	<0.005
Copper, mg/L	0.021	0.009	1.3	0.01	<1.3
Iron, mg/L	0.05	0.02	0.02	0.02	<0.3
Lead, mg/L	0.002	0.001	0.003	0.002	<0.015
Manganese, mg/L	0.001	0.001	0.001	0.002	<0.05
Mercury, mg/L	0.0001	0.0001	0.0001	0.0001	<0.002
Zinc, mg/L	0.014	0.002	0.055	0.008	5
Calcium, mg/L	8.4	0.1	8.4	0.1	No std
Magnesium, mg/L	5.3	0.1	5.3	0.1	No std
Sodium, mg/L	34	140	33	68	<200
Total hardness, mg/L	43	0.1	43	0.1	No std
Chloride, mg/L	60	150	61	74	<250
Nitrate, mg/L	0.01	0.01	0.01	0.01	<10
Nitrite, mg/L	0.01	0.01	0.01	0.023	<1
Sulfate, mg/L	9.4	23	9.5	11	<250
Dichloramine, mg/L	0.1	0.1	0.1	0.1	<0.8
Conductivity, mS/cm	280	680	280	340	<2500
Fluoride, mg/L	0.06	0.15	0.07	0.08	<4
Free chlorine, mg/L	0.1	0.1	0.1	0.1	<4
Monochloramine, mg/L	0.1	0.1	0.1	0.1	<4
pH	7.3	7.5	7.3	7.3	7.5 ± 1.0
Dissolved solids, mg/L	110	320	190	200	<500
Trichloramine, mg/L	0.1	0.1	0.1	0.1	Uncertain
Turbidity, NTU	0.2	0.1	0.1	0.4	<5
Escherechia coli, MPN/100 mL	-	0	-	0	0
Pseudomonas, org/100 mL	-	<1.0	-	<1.0	1.0
Total coliforms, MPN/100 mL	-	0	-	0	0

Samples taken from hospital in-center unit (mains HD1 and RO RW1) and suburban satellite unit (mains HD2 and RO RW2), compared with US Environmental Protection Agency (EPA) standards for drinking water.[30]
HD1, 8-station hospital in-center dialysis unit; HD2, 16-station suburban satellite dialysis facility; MPN, most probable number; No std, no standard set; NTU, nephelometric turbidity units; org, organisms; (assays performed by Barwon Water, 2004) RO RW1, reject water outflow port: centralized in-center unit reverse osmosis system; RO RW2, reject water outflow port: centralized satellite unit reverse osmosis system.[29]

recycling. Hazardous waste must be either chemically sterilized or burned in order to reduce the danger of infection before being disposed of in a landfill, which has significant financial and environmental costs. General garbage is dumped into landfills without being treated, yet pollutants and chemicals, for example, phthalates included in various medical plastic materials can diffuse into the soil and groundwater and cause environmental and living organisms hazardous risks.[35] A greenhouse gas methane released by organic garbage in landfills is more than 20 times more causative agent than carbon dioxide leading to the warming of the earth.[36] When compared to producing a product from virgin materials, optimal recycling uses fewer resources,[37] but recycling of them differs by country due to the cost. There is a lack of comprehensive information on the kinds and quantities of trash produced by hemodialysis. A UK-based HD center reported the generation of every hemodialysis treatment, 2.5 kg of infectious rush was generated, more than 30% of that was synthetic.[38] Although several different materials and plastic types were present in the garbage, polyvinyl chloride was the greatest prevalent (0.65 kg or 26% of the total). The container's including individual products, the total weight increased by 0.075 kg. cardboard was used, and it was recycled.

Central Dialysate System

The usage of centralized water preparation systems, which have been around since the late 1970s and have become especially widespread in Japan,[40-43] which integrate water purification which is used for both HD and hemofiltration, is on the rise. The elimination of synthetic bags is obviously advantageous for cutting waste as well as water usage, and this somewhat offsets the higher costs of HDF. Up to 180 L of water may be needed to produce 1 kg of plastic. Regardless of whether it is used in HD or HDF, a 2-L empty dialysate bag approximately weighs 150 g, and the water footprint varies depending on the type of synthetic material.

Up to 50 patients may receive acid concentration (solution A) simultaneously from the centralized water preparation system. Constant mixing or "servo-control" established on sequential conductivity testing, proportioning is computer-assisted. Each patient's monitor combines the basic concentrate (solution B). The preference is typically for powder concentrate because it is less expensive to ship and needs small depots.[40] But for backup purposes, a main mixing device has to include a surplus control arrangement with numerous conductivity screens, central managing units, power battery, flow meters, and mixing drives.

The Cartridge contains raw material, all in dry form, for the production of 750 L dialysis acid concentrate.

In Türkiye, according to "Water Treatment System Directive," concentrated HD solutions are automatically diluted with

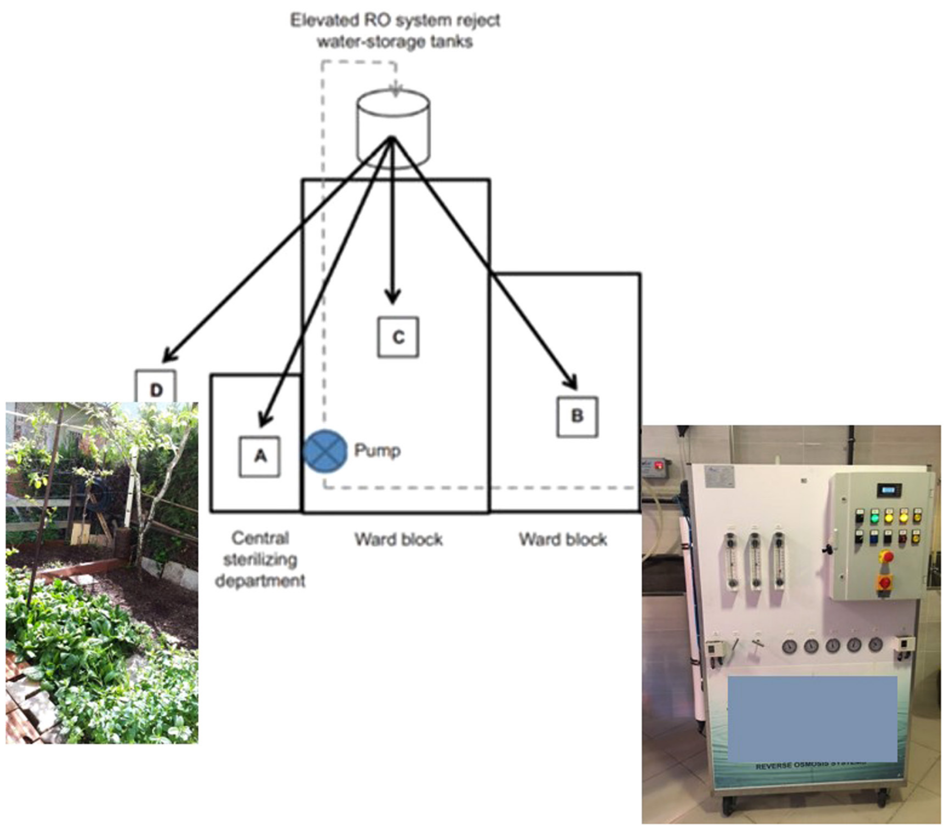

Figure 1. a-d. Hospital-based dialysis unit reuse system for RO system reject water. RO system reject water is pumped to rooftop storage tanks, from where gravity feed is used to provide reject water for reuse in (A) steam generation for central sterilizing department autoclaves; (B) selected ward and other area toilet flushers; (C) janitor stations and window cleaning; and (D) gardens, lawns, and landscaping.

pure water (RO water) by dialysis machines. In addition, water-soluble solid concentrates (granules, powder) can also be used. Health authorities must lead or at least allow the use of these new technologies as cheaper and minimum carbon footprint (no need to transport tons of acidic dialysate solutions mainly water transport in canisters and huge amounts of waste)

Central dialysate system requires double-pass RO producing ultrapure water in which ultrapure dialysate acts as intravenous replacement fluid. We would not need isotonic saline solutions at the beginning and at the end of HD procedures. This will save the money and lessen the carbon footprint (no need to packeting with plastic and transport). Even though each HD center could produce intravenous replacement solutions for exporting purposes if tremendously needed in natural disasters such as earthquake, worldwide diseases or wars if isotonic production is in shortage.

FUTURE WATER CONSERVATION METHODS

The usage of water may be significantly reduced by newer dialysis techniques like online dialysate generation and sorbent dialysate regeneration. One recently developed sorbent system has been demonstrated to minimize total water use for dialysis to 6 L/treatment.[44-46] Simple water conservation techniques used with conventional dialysis equipment are crucial as these innovations prove practical and/or become widely used.

The first issue is REDUCING the amount of waste products, which can be done at all levels. For example, fewer patients will begin dialysis if conservative and nutritional treatment is used wisely; fewer sessions will be needed if incremental dialysis strategies are used; less water will be wasted if dialysate flow is tailored to specific needs; and less contaminated waste will result from selecting HD waste materials. Through collaboration between doctors and manufacturers, other factors, such as lowering stocking and shortening the transport distance, would be done.

REUSE in nephrology is frequently thought to have a negative connotation because it is associated with the contentious dialyzer reuse. Nevertheless, some disposables used in dialysis that do not come in contact with blood, such bicarbonate, have a significant potential for reuse cartridges.

RECYCLING is another issue that is frequently disregarded. Plastic waste generated by dialysis is significant and at least a portion of clean plastic products could be recycled and

Figure 2. Waste products after hemodialysis.

frequently eludes the management of HD facilities. Additionally, hospital initiatives for the regular recycling of materials that could (and ought to) be recycled at home, such as non-medical plastic products, food, paper, and glass.

REPAIR is another concern that stands in stark compared to the current mindset that gadgets and supplies, including dialysis machines, should be thrown away in their entirety, significantly increasing the amount of thrown away electrical devices formed by HD. In addition to extending the lifespan of equipment, repair can form the cornerstone of a strategy.

Simple precautions such as dual flush wc, flow restriction of taps, water harvesting from roof drains should be applied in hospitals and dialysis centers besides HD prescriptions, new technology devices to reduce carbon footprint of the facility while also teaching patients how to use water wisely.[47]

Indeed reject water produced by RO system is potable that has already passed through purification steps as particulates, ions especially chlorine, chloramines and further potentially hazardous substance all are cleaned. The reject water never comes in contact with the patient or the dialyzer, and it poses no greater (in fact, much lower) risk of infection than tap water, as brilliantly proved by our Australian colleagues. Apart from a slight increase in conductivity, the World Health Organization's standards for drinking water are met. The resourceful Australian team came up with a number of uses for this wastewater. In their initial tests, they diverted the water into a collecting reservoir not directly letting it go down the sewer to meet the needs of other sections (the hospital's central sterilizing unit, wc, and gardens). Home HD treatment innocent rejected water may be used for cleaning such as toilets, laundries, and gardening purposes.

CONCLUSION

If it's compared to most other medical treatments, HD programs appear to have a more expensive and lead waste generation processes. Reverse osmosis system must be adjusted for the number of patients. Product water generation must be precisely controlled by new technology RO instead of constant production not related to the number of patients in the HD session. Cold temperature must be avoided since the product flow across the membrane is inversely correlated with temperature.

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