Reusing and recycling dialysis reverse osmosis system reject water

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Water is at the very core of the dialytic process—both water quantity and water quality—the two being interdependent. Meanwhile, both are under increasing global stress.[1] Coincident with this, despite the uncertainties around accurate data from emerging nations, worldwide incident and prevalent dialysis numbers are burgeoning, especially as nations such as China and India begin to swell the dialysis population. Finally, water stresses appear most evident in the very regions where dialysis demand is set to exponentially increase.

Current hemodialysis (HD) systems are water-hungry. Global HD is currently almost exclusively provided by single-pass, proportioning dialysis systems paired with low-efficiency reverse osmosis (RO) system water filtration that rejects 60–70% of the presented mains, tank, bore, or well water at the RO system membrane. As about 0.5 liters per minute of dialysis-grade water must be generated for 35:1 proportioning with a chemical concentrate to create dialysis fluid, a total of about 1.5 liters per minute is required to be drawn from the supportive water source. Depending on treatment duration (mean 4 hours per session), RO system efficiency (60–70%), and intertreatment sterilize and rinse phases, the total feed water draw per treatment will approach 500 liters.

Although on the face of it, peritoneal dialysis (PD) is less water-wasteful, with 6–12 liters per day of sterile, ultrapure dialysate being required, depending on manual bag exchange frequency and/or prescribed automated volumes, manufacturer specifications for the total water draw required to *create* each liter of peritoneal dialysate are currently protected by commercial confidentiality. However, and not unlike in HD, several liters of feed water are also likely to be needed to generate every final liter of PD fluid.

Even if funding, availability, or national circumstance truncates HD frequency and duration, or if PD volumes and exchanges are similarly restricted, the demand for water for dialysis must inevitably compete with community and industrial demands—especially where water is scarce.

Smarter ways must be found—and found quickly. A fundamental reassessment is needed across the whole dialysis spectrum of our macro-resource management and conservation practices. This should include water, power, and dialysis waste management. However, as this topic is vast and is described in detail elsewhere,[2] for this brief discussion, water will be the focus.

Several back-to-the-future systems that focus on sorbent regeneration of used dialysate[3]—similar to the REDY dialysis system used in the 1970–1990 era—are now in the pipeline. All seek to miniaturize dialysis systems to portability by minimizing water requirements by eliminating complex water preparation by RO system, or by avoiding other cumbersome on-line dialysate generation options. However, all such projects remain in the research and development phase, still have significant operational hurdles to overcome, are at best some years away from commercial application, and are cost-uncertain. Finally, even if all these obstacles can be overcome, it would probably take a sorbent system further significant time to gain widespread practical use.

Meantime, the focus must be on conservation. Here, there is an enormous scope for commonsense progress. As this 'Sans Frontières' section reflects, there *are* no boundaries to the development of sensible, achievable conservation principles and practices. Yet, to date, these have been given little thought by dialysis providers as they have concentrated on process provision, and not resource consumption.

Question: Is the water rejected by an RO system still 'good' water? Unequivocal answer: Yes, it is—indeed, it is excellent water. Yet, almost universally, this water is discarded to drain. Modern RO system water treatment first applies carbon filtration, microfiltration, and softening to remove chloramines, benzene, solvents, trihalomethane compounds, volatile organics, and many other chemicals, as well as suspended particulate matter from 50 mm down to 0.5 mm in size. Importantly, this purifying and decontaminating multifiltration process is applied to

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the feed mains water—the same water that we currently happily drink, use for steam manufacture in hospital sterilizing departments, and mop floors with. Although the pre-RO system purification processes that are applied to mains water will not remove all potential inorganic and organic contaminants, the filtered water finally presented to the RO system for final filtration with or without deionization is certainly no more contaminated with these substances than the mains water that we all daily consume—and, indeed, is less so. Thus the argument that we should not use RO system reject water simply doesn't make sense. The final RO system step simply ensures that any remaining salts and ions that are still in the water at this point are flushed away. A detailed analysis of the residual chemical content of RO system water was performed in 2004 by our local water authority and is shown in Table 1. This analysis has been of great assistance in overcoming local regulatory barriers to RO system water reuse.

Most dialysis service RO systems still flush away upwards of 60% of the already highly purified

Table 1 | Assay results for water contaminants in mains water in-feed and RO system reject water outflow

Analyte	Units	Mains HD1	RO RW1	Mains 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	8.3	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	μS/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	pH units	7.3	7.5	7.3	7.5	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
E. 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.[9]

Abbreviations: HD1, eight-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; 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.

Assays performed by Barwon Water, 2004.

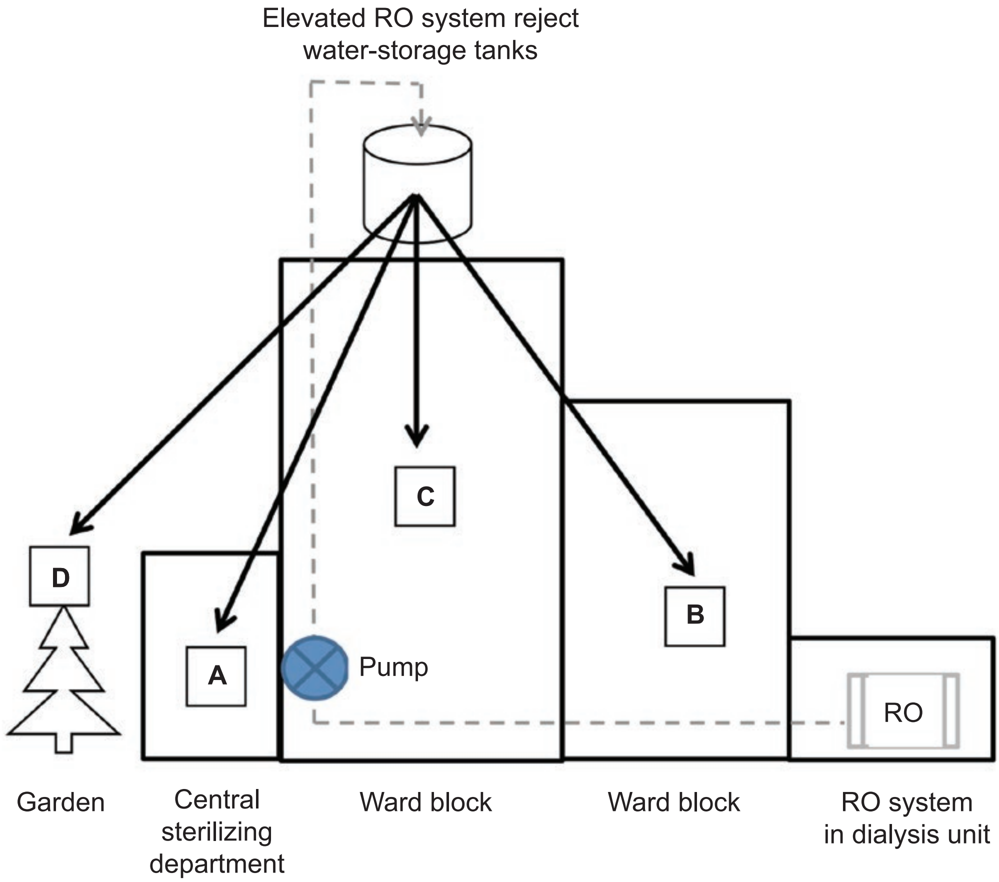

Figure 1 | Hospital-based dialysis unit reuse system for RO system reject water. RO system reject water is pumped to rooftop storage tanks, from where gravity feed is used to provide reject water for reuse in (A) steam generation for central sterilizing department autoclaves; (B) selected ward and other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

water that is presented to them. But conventional practice still dictates that this 'reject water'—which contains only small final traces of salts and ions and lies well within all biochemical and bacteriological standards for potable water set by the Association for the Advancement of Medical Instrumentation and the US Environmental Protection Agency[4]—is discarded to drain. Although regulatory hurdles may be encountered at a local jurisdictional level where potentially outmoded regulation may be present that prohibits or limits the use of RO system reject water, it is my view that these prejudices are commonly based on misconception and misunderstanding, not on factual contraindication. Nevertheless, these barriers may need to be identified and overcome with each local authority.

There is no rational reason why drain discard should occur. A back-of-an-envelope calculation of the volume of discarded reject water shows that about 1 liter per minute per patient × minutes of each treatment × treatments per week or per year × number of patients in a dialysis service is lost per year. This should prompt two sudden realizations: the sheer volume of wasted water, and the significant cost of that thoughtless waste.

Problem: The concept of RO system reject water is commonly badly misunderstood. Exit water from the pre-dialysis water filtration process is currently often either confused with direct patient waste, or regarded as patient-contacted, waste-contaminated water. Solution: Careful explanation is required to conceptually separate RO system reject water—water generated by the filtration process prior to patient exposure—from effluent dialysate that contains the products of the dialytic process post-dialyzer, and post-patient. Once this difference is clearly understood, RO system reject water can be used for almost any purpose that local needs require.

In 2003–2004, a prolonged, severe regional drought led the Geelong dialysis service to seek ways to minimize water losses, initially for our

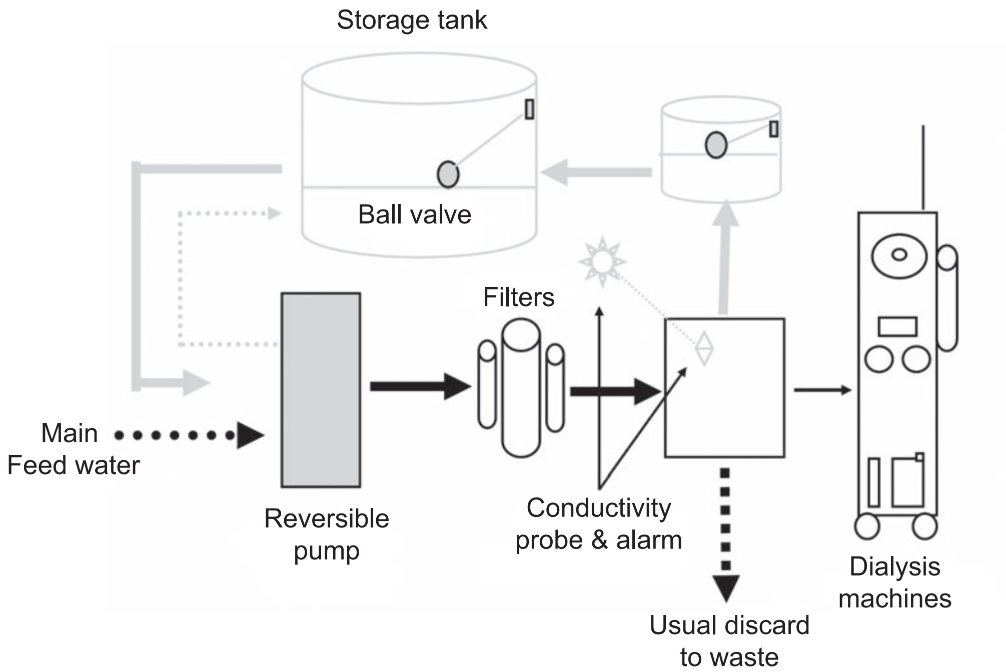

Figure 2 | Home dialysis recycling system for RO system reject water. Added components are shown in gray. A conductivity probe at the RO system permits recycling unless the recycled reject water conductivity rises too far. If so, this probe triggers an alarm, halts the dialysis, and awaits a manually operated return to mains water feed for the remainder of the treatment. In addition to reverting to mains feed, the reversible pump also allows mains water to dilute the storage tank for further recycling at the next treatment.

home HD patients. After confirmation of the potability of the RO system reject water that was being discarded to drain (Table 1), steps were taken on two fronts to address this.

In our eight-station hospital in-center setting, two 36,000-liter holding tanks (donated by local industry) were installed on an eighth-floor rooftop, from where, under gravity feed, RO system reject water was piped (Figure 1) to the hospital centralized sterilizing department to provide steam for its autoclave systems. In addition, inflow plumbing connections were installed to selected toilets for waste flushing and to adjacent janitor stations for use in floor cleaning.[5–7] Any remaining water is directed to landscaping. A full return on this investment was realized in about 30 months, with subsequent hospital water expenses decreasing significantly thereafter. At our 16-station suburban satellite center, two further industry-donated tanks store RO system reject water for free collection by schools, playing fields, and city parks and gardens.

In the home setting, tanking and piping for domestic laundry, window cleaning, horticultural, or agricultural purposes (for instance, animal watering) has become a routine home HD package that adds a one-time approximately Au$3000 to home installation costs. Again, while RO system reject water is potable standard water and is safe to drink—it is similar to mineral water—local testing may be needed to persuade and confirm potability to local authorities.

RO system reject water can also be recycled back through a closed loop system for re-presentation to the RO system, either with or without ongoing mains water mixing and/or dilution. RO system reject water recycling is described in more detail elsewhere.[4] However, as recycling will inevitably cause the conductivity at the RO membranes to slowly but progressively rise, a conductivity probe should be located within the RO system to detect whether the conductivity is approaching or exceeding membrane-safe limits. In case this should occur, the system can simply be engineered to either manually or automatically revert to mains feed for the remainder of the treatment. This system (Figure 2) has been successfully and continuously operated without incident in a number of home dialysis installations since 2007,[4] though regular bacteriological testing is advised. However, in the experience of this group, the need to revert to mains water feed mid-treatment has been rare.

Though most recycling experience to date has been described with individual home dialysis installations, there should be no contraindication to installing similar recycling circuits in multipatient facilities. However, the costs of a recycling retrofit may prove difficult to justify, and it may prove more prudent to plan for an RO system reject water recycling loop when establishing a new service.

Retrofitting for reject water reuse, however, is as simple as capture, store, pipe, plumb, and reuse. A recent preliminary feasibility study from Lyon, France, has reported that 1200 m^3/y of RO system reject water could be reused for all building sanitation purposes in a three-story building, with the modeled return on investment to retrofit the building being 5.8 years.[7] Following cost recovery, savings would then accrue, year on year, though local regulatory barriers have, to date, prevented full implementation.

For regions where water is scarce, the failure to conserve and reuse predialysis RO system reject water should now be regarded as wasteful and unacceptable. An excellent example of RO system reject water reuse has emerged from the remote community of Kiwirrkurra in the Australian outback.[8] Using an open tank for RO system reject water collection, several smaller transportable containers are siphon- or gravity-filled, then transported by tractor and forklift to raised platforms in local vegetable gardens where slow gravity-fed drip watering irrigates and nurtures native and other food vegetables for community use. This simple system was devised and built as a partnership between the community dialysis nurse and local indigenous workers, the latter accumulating sufficient weekly working hours to reach the mandatory requirements that qualify them for a government-subsidized wage. Water is saved, food is produced, and wages are assured—a win–win–win.

Simple but innovative systems such as the Kiwirrkurra program are applicable everywhere, and do not demand rocket science. But, in a global context, the potential for any or all dialysis services to give back in some small measure to the communities in which they operate should not be missed. As good global citizens, it is our responsibility to minimize waste wherever we can, and, while clearly the conservation and reuse of RO system reject water will contribute but a drop in the ocean of water that is currently thoughtlessly wasted, every drop helps. As the service providers of dialysis, we have ignored the environmental costs of dialysis for too long. We should be seeking ways to make a greater contribution to the health of the global environment and begin to pay back some of the capital we have squandered.

DISCLOSURE

The author declared no competing interests.

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