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RESEARCH LETTER

Updating the Data: The Resource Consumption of Modern-Day Hemodialysis Systems

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INTRODUCTION

Two decades ago, the kidney care community was first alerted to the extraordinarily high resource consumption of hemodialysis. Agar *et al.*[1] identified that ∼500 l of water were required for each 4-hour conventional treatment, with only one-third used for dialysis and two-thirds lost as reverse osmosis (RO) "reject" water. Subsequently, this group and others reported high power usage, waste generation, and carbon emissions from hemodialysis,[2-4,S4–S8] leading them to suggest that the overall recurrent per capita environmental impact of hemodialysis may well exceed all other medical therapies.[3]

Since these reports, and in parallel with rising global environmental concern, interest in "green nephrology" has grown.[4,5] However, when considering ways to address the resource impact of hemodialysis, the kidney care sector has continued to rely on 2000 to 2005 data garnered from hemodialysis and RO equipment manufactured in the last millennium.

A pressing need exists for hemodialysis resource usage data based on current-day practice and hemodialysis systems. Accordingly, this study aimed to measure and compare the water and energy requirements of hemodialysis equipment in use in 2 Australian satellite hemodialysis units under standard operating conditions. Power and water usage data were collected over 2 sequential 2-week periods from Essendon Fields (EF), a 15-chair hemodialysis facility, and Barwon Health North (BHN), a 12-chair hemodialysis facility. Full details of the methods are reported in Supplementary Methods.

RESULTS

Essendon Fields

On average, 11.75 of 15 available chairs were occupied over the monitoring period (range, 9–15), with an average of 143 treatments delivered per week. Average treatment time was 4.08 (SD, 0.02) hours.

RO Plant and Dialysis Machine Power Usage

Average daily power consumption by the RO plant was 64 kWh (SD, 8.5) (69kWh on operating days and 34kWh/day on the nonoperating day). Based on 143 treatments delivered per week, the estimated per-treatment energy consumption by the RO plant was 3.1 kWh (Supplementary Figure S1 and Supplementary Table S1).

The power consumption of the dialysis machines averaged 2.2 kWh (SD, 0.11) per treatment, giving an average total power consumption of 5.3 kWh per treatment (Supplementary Figure S1 and Supplementary Table S1).

RO Plant Water Usage

The total volume of incoming mains water to the RO plant averaged 7.1 m^3 (SD, 0.80) per day. Based on the average of 143 treatments recorded per week, the estimated water consumption was 357 l per treatment (Supplementary Figure S2 and Supplementary Table S1).

Data obtained from the EF RO's online monitoring system showed that an average of 3.26 m^3 of purified water was delivered from the distribution loop to the dialysis machines per day. With incoming mains water averaging 7.1 m^3 per day, this indicates 3.8 m^3, or 54% of the total, was discarded.

Barwon Health North

On average, 8 out of 12 available chairs were occupied each day (range, 5–12), with an average of 103 treatments delivered per week. Of these, 68% were hemodiafiltration and the remainder were hemodialysis. The average treatment time was 4.22 hours (SD, 0.03).

RO Plant and Dialysis Machine Power Usage

The BHN RO system has 2 operating modes: automatic (the usual mode of operation at BHN) and manual (see Supplementary Methods). For the first 10 days of the 2-week monitoring period, the RO plant was inadvertently run in manual mode. In this mode, the average daily RO plant power consumption was 129 kWh (SD, 3.5) (130 kWh on operating days and 121 kWh on the nonoperating day). Based on 103 treatments delivered per week, average per-treatment energy consumption was 8.7 kWh (Supplementary Figure S1 and Supplementary Table S1). After return to automatic mode, power consumption averaged 106 kWh per day (SD, 6.8), with 117 kWh consumed on operating days and 40 kWh on the nonoperating day. Average per-treatment energy consumption decreased to 7.2 kWh (Supplementary Figure S1 and Supplementary Table S1).

The power consumption of the dialysis machines averaged 3.1 kWh (SD, 1.2) per treatment. Total energy usage per treatment therefore averaged 11.8 kWh and 10.3 kWh for the manual and automatic modes, respectively (Supplementary Figure S1 and Supplementary Table S1).

RO Plant Water Usage

RO plant water usage in the manual mode averaged 11.1 m^3 (SD, 0.94) per day compared with 8.1 m^3 (SD, 1.1) in the automatic mode. Estimated per-treatment water consumption in the 2 modes were 754 l and 548 l, respectively (Supplementary Figure S2 and Supplementary Table S1).

DISCUSSION

This study examined 2 different RO systems and types of hemodialysis machines in use in satellite hemodialysis facilities in Australia. We found substantial differences in per-treatment resource consumption between them as follows: average power usage was almost 2-fold higher and average water usage 1.5-fold higher at BHN than at EF, when the BHN RO plant was operating in the efficient automatic mode. When BNH's RO plant was operating in manual mode, energy and water consumption were even higher.

The differential power usage was largely due to a more efficient RO system at EF (Table 1). However, the BHN hemodialysis machines also used 41% more power compared with the EF machines due to their greater size and functionality.

Several factors explain the differences in per-treatment water usage. The EF RO system recirculates water sitting in the loop (~500 l) at RO system start up rather than discarding it, as occurs at BHN. Furthermore, the EF system is set to recirculate 60% of water rejected at the RO membrane compared to 50% at BHN. This is because a higher "water save" factor increases the likelihood of fouling of the RO membrane which can reduce its life expectancy. Because membrane replacement costs are more at BHN, a more conservative setting is applied.

In addition, BHN used hemodiafiltration for 68% of treatments. However, as per-treatment substitution volumes rarely exceed 25 l, we expect this would contribute <5% to total daily water consumption.

This study holds several key messages. First, the EF data indicate that there has been significant improvement in per-treatment resource consumption by hemodialysis systems compared to the earlier data

Table 1. Factors accounting for the differential RO plant power use at Essendon Fields and Barwon Health North

Factors	Essendon Fields	Barwon Health North
Disinfection methodology	- Disinfection automatically controlled to maintain a target A_O (a heat 'dose' sufficient to achieve a defined level of microbial inactivation, proportional to the water temperature and exposure time of the material requiring disinfection) - A_O optimized to suit facility requirements and conditions	- Disinfection achieved via water heating to a designated temperature - Hot water set to circulate almost continuously outside of treatment times
Water pump efficiency	- Variable-speed pumps utilized which optimize their speed to circulate only the amount of water required	- Fixed speed pumps utilized which run at maximum speed during treatment times
Length of pipework	- The RO plant and treatment room are located on the same floor	- The RO plant sits a floor above the treatment area, resulting in a longer distribution loop and larger heat loss
Plant size	- Appropriate for the number of HD chairs supplied with water	- Oversized to account for possible future expansion in HD chair numbers

HD, hemodialysis; RO, reverse osmosis.

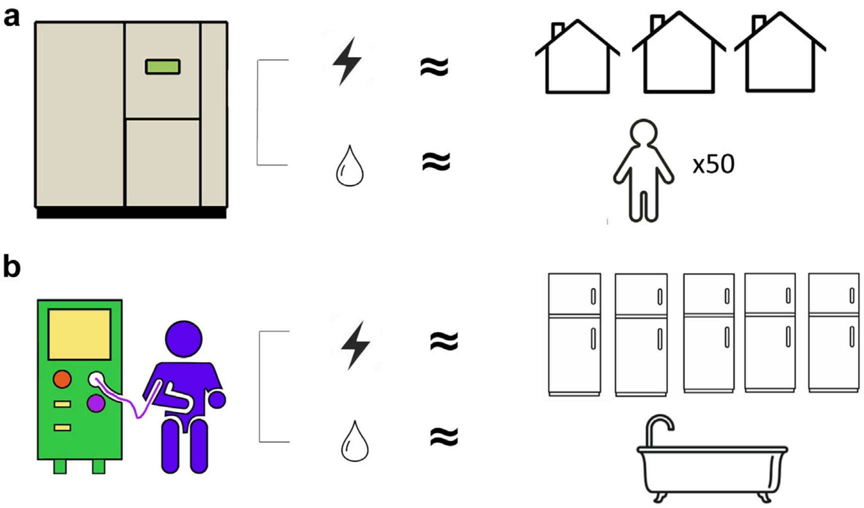

Figure 1. (a) The daily power usage by the reverse osmosis plant at Essendon Fields (64 kWh) is comparable to the daily usage of 3 average Australian households,[S8] whereas the daily water usage (7100 m^3) is comparable to the daily domestic usage of 50 average Australians.[S9] (b) The per-treatment power consumption at Essendon Fields (5.3 kWh) is comparable to the daily usage of 5 medium-sized refrigerators,[S10] whereas the per treatment water consumption (357 l) is comparable to the amount required to fill an average sized bathtub.[S11]

(Supplementary Table S2).[2,3] However, power and water usage remain high (Figure 1).[S9–S12]

The BHN data demonstrates the importance of ensuring the most efficient RO settings are applied. In addition, where RO systems are unable to modify the amount of water circulated in response to demand, it is important to ensure the RO system is sized to match the number of hemodialysis chairs, and that the number of treatments provided at any one time is maximized. Exemplifying this, if BHN were to have utilized all 12 available chairs each session, water consumption would have fallen from 548 l to 391 l per treatment when the RO was operating in the automatic mode, which is comparable to EF per-treatment consumption.

Furthermore, this study highlights the benefits of auditing power and water usage. Specifically, this can identify optimization opportunities; for instance, data obtained herein suggest there may be a role for improving loop insulation at BHN and/or reducing loop disinfection hours. Regular audits can also provide a resource usage baseline against which to measure future improvements. Notably, switchboard modifications and water meter installation were required for our study, at a cost. In our view, the installation of submetering equipment into new-built dialysis units should be mandatory.

Importantly, we estimate that the high observed power usage could be largely offset by the presence of 30 kW and 43 kW solar capacity at the 2 facilities, respectively. Based on current costs in Australia of $1000 per kW of solar capacity installed and 0.25c per kWh of electricity purchased, return on investment would be expected within approximately 3 years. There are currently few dialysis facilities in Australia that use locally generated solar power.[6] This should be rectified as a priority.

Similarly, few facilities report capturing RO reject water for reuse.[6] Given the simplicity of the methodology and the potential for water and cost savings,[S13–S16] feasibility and cost-benefit analyses should be undertaken by all hemodialysis services.

A final key message surrounds the need for greater transparency around resource usage by RO systems and dialysis machines. Currently, kidney care services have limited ability to understand and compare power and water efficiencies at the time of procurement. We propose that standard metrics be developed to permit comparisons between equipment produced by different manufacturers. It should be mandated that this information is provided by manufacturers, as is required of those selling equipment such as refrigerators and washing machines.

In conclusion, we confirm that the power and water requirements of modern hemodialysis equipment remains high. In the current era of escalating climate change and resource scarcity, this must be addressed as a matter of urgency. Considering that our study was limited to 2 hemodialysis and RO systems, we encourage other dialysis providers to undertake similar studies of alternative systems.

DISCLOSURE

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DATA AVAILABILITY STATEMENT

The data supporting the findings of this study can be provided by the authors in response to reasonable requests.

AUTHOR CONTRIBUTIONS

KAB contributed to conception and design of the work, analysis and interpretation of data for the work, drafting the work, revising it critically for important intellectual content, and final approval of the version to be published. JA contributed to conception and design of the work, interpretation of data for the work, revising the work for critically for important intellectual content, and final approval of the version to be published. SB contributed to acquisition and interpretation of data for the work, revising the work for critically for important intellectual content, and final approval of the version to be published. RK contributed to acquisition and interpretation of data for the work, revising the work for critically for important intellectual content, and final approval of the version to be published. SMc contributed to the analysis and interpretation of data for the work, revising the work for critically for important intellectual content, and final approval of the version to be published. SMo contributed to acquisition, analysis, and interpretation of data for the work, revising the work for critically for important intellectual content, and final approval of the version to be published. MS contributed to the conception and design of the work, interpretation of data for the work, revising the work for critically for important intellectual content and final approval of the version to be published. AW contributed to the conception and design of the work, acquisition and interpretation of data for the work, revising the work for critically for important intellectual content, and final approval of the version to be published.

SUPPLEMENTARY MATERIAL

Supplementary File (PDF)

Supplementary Methods.

Figure S1. Per-treatment power usage by the RO plants and dialysis machines at EF and BHN. BHN, Barwon Health North; EF, Essendon Fields; RO, reverse osmosis

Figure S2. Per-treatment water usage by the RO plants and dialysis machines at EF and BHN. BHN, Barwon Health North; EF, Essendon Fields; RO, reverse osmosis

Table S1. Per-treatment power and water usage at EF compared with BHN. BHN, Barwon Health North; EF, Essendon Fields

Table S2. Per-treatment power and water usage by modern-day hemodialysis systems compared with earlier data.

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