CMAJ OPEN

Research

Estimating patient-borne water and electricity costs in home hemodialysis: a simulation

Matthew Nickel BEng, Wes Rideout, Nikhil Shah MD, Frances Reintjes RN, Justin Z. Chen MD, Robert Burrell PhD, Robert P. Pauly MD

Abstract

Background: Home hemodialysis is associated with lower costs to the health care system compared with conventional facility-based hemodialysis because of lower staffing and overhead costs, and by transferring the treatment cost of utilities (water and power) to the patient. The purpose of this study was to determine the utility costs of home hemodialysis and create a formula such that patients and renal programs can estimate the annual patient-borne costs involved with this type of treatment.

Methods: Seven common combinations of treatment duration and dialysate flows were replicated 5 times using various combinations of home hemodialysis and reverse osmosis machines. Real-time utility (electricity and water) consumption was monitored during these simulations. A generic formula was developed to allow patients and programs to calculate a more precise estimate of utility costs based on individual combinations of dialysis intensity, frequency and utility costs unique to any patient.

Results: Using typical 2014 utility costs for Edmonton, the most expensive prescription was for nocturnal home hemodialysis (8 h at 300 mL/min, 6 d/wk), which resulted in a utility cost of $1269 per year; the least expensive prescription was for conventional home hemodialysis (4 h at 500 mL/min, 3 d/wk), which cost $420 per year. Water consumption makes up most of this expense, with electricity accounting for only 12% of the cost.

Interpretation: We show that a substantial cost burden is transferred to the patient on home hemodialysis, which would otherwise be borne by the renal program.

Conventional intermittent in-centre hemodialysis is the most used modality of renal replacement therapy in North America. However, there is increasing interest in the use of alternative strategies, such as peritoneal dialysis and home hemodialysis. Home hemodialysis is recognized as resulting in improved quality of life, indices of mineral metabolism, cardiac health and even overall survival compared with conventional in-centre hemodialysis.[1–5] This modality also results in cost savings to the health care system when compared with in-centre intermittent hemodialysis.[6–8] Existing economic analyses have looked at the costs of providing this therapy solely from the payer perspective. Although there is considerable variability in analytic approaches and their results, it is generally accepted that home hemodialysis is associated with fewer human resources and lower facility management expenses.[6–14] However, when patients self-dialyze at home, some expenses (such as the utility costs of running the dialysis equipment) are transferred to the patient. The aim of this study was to measure utility consumption (water and electricity) required to perform various prescriptions of home hemodialysis, and estimate the associated costs.

Methods

This study was conducted in the home hemodialysis program of the Northern Alberta Renal Program in Edmonton. We performed simulations of 7 different home dialysis prescriptions (i.e., 7 combinations of dialysis treatment duration and dialysate flow): 6 hours at 300 mL/min, 8 hours at 300 mL/min, 4 hours at 500 mL/min, 6 hours at 500 mL/min, 2 hours at 800 mL/min, 3 hours at 800 mL/min and 4 hours at 800 mL/min. Treatment frequencies were determined on the basis of a 31-day month. For each prescription, we performed a set of 5 repeats using 5 different combinations of 5 hemodialysis machines (Bellco Formula Domus; Bellco Canada, Mississauga, Ont.) and 5 reverse osmosis machines (Gambro WRO 300; Gambro Canada, Richmond Hill, Ont.). Each set was conducted at 20°C to approximate ambient water temperature entering the hemodialysis machine from the reverse osmosis machine. An additional simulation of each prescription using a single combination of hemodialysis machine and reverse osmosis machine was conducted at 8°C to simulate a cold water source requiring additional preheating by the

Competing interests: None declared.

This article has been peer reviewed.

Correspondence to: Robert Pauly, robert.pauly@ualberta.ca

***CMAJ Open* 2017. DOI:10.9778/cmajo.20160108**

hemodialysis machine before generating dialysate. All simulations included a 60-minute pretreatment period during which the hemodialysis and reverse osmosis machines undergo automated system checks, as well as a roughly 45-minute post-treatment heat disinfection cycle. Additional tests were conducted to simulate the chemical disinfection procedure performed on a hemodialysis machine in the home (which our program prescribes after every 3 treatments) and on the reverse osmosis machine (which our program prescribes once weekly).

Water consumption was measured using a Seametrics FT400-SERIES in-line flow metre proximal to the reverse osmosis machine, with Seametrics DL76 Data Logger (Seametrics Inc., Kent, Washington); data were analyzed using FlowInspector version 2 software provided by Seametrics. Power consumption was measured using a Kill-A-Watt P4400 electricity usage monitor (P3 International, New York) for each of the reverse osmosis and dialysis machines.

The costs of water and electricity were calculated using local utility cost estimates in Edmonton, using average 2014 rates from one of multiple available water and electricity providers in Alberta; both- water and electricity are metered in Edmonton. Data are presented in 2014 Canadian dollars. The costing of utilities also assumed a fixed monthly rate for both water and electricity.

A monthly generic formula for the cost of performing hemodialysis was calculated as follows:

Equation 1: Cost of dialysis = $n(U_w C_w + U_p C_p)$

where n is the number of dialysis treatments per month, U_w and U_p are the mean water and electrical power usage, respectively, per treatment for a given prescription, and C_w and C_p are the cost of water and electrical power, respectively, per treatment. U_w and U_p are reported in cubic metres (m^3) and kilowatt-hours (kWh), respectively; C_w and C_p are quoted in Canadian dollars per cubic metre and Canadian dollars per kilowatt-hour, respectively.

The total monthly utility cost of home hemodialysis must also include the expense of the chemical disinfecting cycle of the dialysis and reverse osmosis machines. The monthly frequency of these disinfection cycles is variable, and the protocols for these procedures are independent of dialysis prescription. The monthly cost of disinfection is estimated as the cost of disinfection of the hemodialysis machine plus the cost of disinfection of the reverse osmosis machine, using the following equation:

Equation 2: Cost of disinfection = $[n_d(U_{dw} C_w + U_{dp} C_p)] + [n_r(U_{rw} C_w + U_{rp} C_p)]$

where n_d and n_r are the number of times per month the dialysis and reverse osmosis machines undergo a chemical disinfection cycle, U_{dw} and U_{dp} are the mean water and electrical power usage during the disinfection cycle of the hemodialysis machine, and U_{rw} and U_{rp} are the mean water and electrical power usage during the disinfection cycle of the reverse osmosis machine. Because the disinfection cycles are standard regardless of dialysis prescription U_{dw}, U_{dp}, U_{rw}, and U_{rp} can be determined as constants. We determined that water consumption for the chemical disinfection cycle of the hemodialysis and reverse osmosis machines was 0.1106 ± 0.002 m^3 (n = 5) and 0.0676 ± 0.0020 m^3 (n = 4), respectively. Electricity consumption was 0.56 ± 0.07 kWh and 0.15 ± 0.01 kWh for hemodialysis and reverse osmosis machines, respectively. Thus, the total cost of disinfection using the Bellco/Gambro home hemodialysis ensemble can be rewritten as follows:

Equation 3: Cost of disinfection = $[n_d(0.1106 C_w + 0.56 C_p)] + [n_r(0.0676 C_w + 0.15 C_p)]$

Combining equations 1 and 3 allows one to calculate the total monthly and annual out-of-pocket cost borne by patients who perform home hemodialysis as the cost of dialysis plus the cost of disinfecting the hemodialysis machine plus the cost of disinfecting the reverse osmosis machine (Figure 1).

$$\text{Monthly treatment cost} = \text{Number of treatments per month} \times \left(\left(\text{Amount of water per treatment in m}^3{}^* \times \text{Cost of water per m}^3 \right) + \left(\text{Amount of power per treatment in kWh}^* \times \text{Cost of power per kWh} \right) \right)$$
$$+ \text{Number HD disinfects per month} \times \left(\left(0.1106\ \text{m}^3 \times \text{Cost of water per m}^3 \right) + \left(0.56\ \text{kWh} \times \text{Cost of power per kWh} \right) \right)$$
$$+ \text{Number RO disinfects per month} \times \left(\left(0.0676\ \text{m}^3 \times \text{Cost of water per m}^3 \right) + \left(0.15\ \text{kWh} \times \text{Cost of power per kWh} \right) \right)$$

*obtained from Table 1

Figure 1: Formula to calculate the out-of-pocket cost borne by patients who perform home hemodialysis.

In addition, we conducted a sensitivity analysis of estimated total utility costs using typical utility rates for October 2016 from a rural community in British Columbia's Lower Mainland (Chilliwack), Ottawa and Halifax, compared with utility costs from Edmonton in the same month.

Results

The total per treatment water and electricity consumption and associated costs for various dialysis prescriptions are outlined in Table 1. The costing assumes a flat rate of \$3.2438/m^3 for water and \$0.089/kWh for electricity. Note that between 74% and 87% of consumed water is waste water generated in the production of suitable dialysate or water discarded during the pre- and posttreatment phases of system checks and heat disinfection.

When simulations were conducted with a source water temperature of 8°C, the amount of water consumption remained unchanged (–1% ± 2%), but electrical power consumption per treatment increased by 34% (± 10%). The electricity consumed for the hemodialysis chemical disinfection when source water was 8°C was 50% more than when water entering the hemodialysis machine was 20°C; however, this was not considered in our calculations.

Table 2 summarizes expenses for 4 common dialysis prescriptions: (a) 8 hours at 300 mL/min with 6 treatments per week, (b) 8 hours at 300 mL/min with treatments every other night, (c) 2 hours at 800 mL/min with 6 treatments per week, and (d) 4 hours at 500 mL/min with 3 treatments per week. The greatest expense is associated with a frequent nocturnal hemodialysis prescription (i.e., \$1269.37); the least expense is incurred by a more conventional thrice-weekly hemodialysis prescription (\$420.49).

Utility costs vary across the country. Table 3 shows the total annual cost estimate for the most and least expensive dialysis prescriptions using October 2016 utility rates from a rural community in British Columbia, in addition to those from Edmonton, Ottawa and Halifax.

Table 1: Water and electricity consumption and cost per treatment for various combinations of treatment duration and dialysate flows (not including cost of intermittent chemical disinfection)

	Water				Electricity		
Duration	Per treatment dialysate desired, L	Per treatment water consumption, mean ± SD, m^3 at 20°C *n* = 5	% Dialysate desired to water consumed	Per treatment water cost*, \$	Per treatment electricity consumption, mean ± SD, kWh at 20°C *n* = 5	Per treatment electricity cost†, \$	Total cost per treatment, \$
6 h × 300 mL/min	108	0.8052 ± 0.0390	13	2.61	4.25 ± 0.46	0.38	2.99
8 h × 300 mL/min	144	1.0128 ± 0.0478	14	3.29	5.16 ± 0.48	0.46	3.74
4 h × 500 mL/min	120	0.6675 ± 0.0328	18	2.17	3.68 ± 0.22	0.33	2.49
6 h × 500 mL/min	180	0.8987 ± 0.0216	20	2.92	4.70 ± 0.28	0.42	3.33
2 h × 800 mL/min	96	0.4829 ± 0.0168	20	1.57	2.64 ± 0.23	0.23	1.80
3 h × 800 mL/min	144	0.6047 ± 0.0288	24	1.96	3.40 ± 0.26	0.30	2.26
4 h × 800 mL/min	192	0.7344 ± 0.0244	26	2.38	4.04 ± 0.38	0.36	2.74

Note: SD = standard deviation.
*Assumes a water cost of \$3.2438/m^3 and includes a 60-min pretreatment machine warm-up and operations check in addition to a 45-min posttreatment heat disinfection cycle.
†Assumes an electricity cost of \$0.089/kWh and includes a 60-min pretreatment machine warm-up and operations check in addition to a 45-min posttreatment heat disinfection cycle.

Table 2: Monthly and annual water and electricity costs associated with home hemodialysis for 4 common dialysis prescriptions (including treatment and routine chemical disinfection protocols*)

Prescription	Monthly water cost, \$	Annual water cost, \$	Monthly electricity cost, \$	Annual electricity cost, \$	Total annual cost, \$
4 h × 500 mL/min × 3/wk	30.53	366.31	4.51	54.17	420.49
2 h × 800 mL/min × 6/wk	46.47	557.59	6.85	82.20	639.78
8 h × 300 mL/min × 3.5/wk	52.02	624.20	7.20	86.34	710.54
8 h × 300 mL/min × 6/wk	92.88	1114.51	12.91	154.87	1269.37

*Based on a 31-day month and a chemical disinfection performed after every third treatment and once weekly for the reverse osmosis machine.

Table 3: Annual total utility costs associated with home hemodialysis in 4 diverse cities in Canada (including treatment and routine chemical disinfection protocols*)

Prescription	Rural Lower Mainland†, $	Edmonton†, $	Ottawa§, $	Halifax¶, $
4 h × 500 mL/min × 3/wk	216.04	412.79	555.58	370.49
8 h × 300 mL/min × 6/wk	643.39	1250.93	1670.21	1110.64

*Treatment frequency based on a 31-day month and a chemical disinfection performed after every third treatment and once weekly for the reverse osmosis machine. Costs are based on the highest-tier utility cost from each respective region in October 2016.
†$0.1243/kWh; $0.5057/m^3 consumption; $0.7374/m^3 waste water.
‡$0.04456/kWh; $2.6208/m^3 consumption; $0.7944/m^3 waste water.
§$0.1800/kWh; $1.8201/m^3 consumption; $1.8201 × 117%/m^3 waste water.
¶$0.1480/kWh; $0.8450/m^3 consumption; $1.6380/m^3 waste water.

Interpretation

Although a number of economic analyses have been published for home hemodialysis, it is common to take the perspective of the health system and ignore expenses incurred by the patient.[6,8–14] The annual utility cost of home hemodialysis in Edmonton in this study ranges from $420 to $1269. Not surprisingly, the most expensive form of dialysis is a prescription used for 8-hour 6-times-weekly nocturnal hemodialysis and the least expensive is for a prescription of conventional 4-hour thrice-weekly hemodialysis. However, we also show a substantial variability in the annual cost of water and electricity across the country, with a patient in a rural community in British Columbia paying less than half the amount a person in Ottawa may pay for the same prescription, based on vastly different local utility rates. Because of this variability, we present a formula that allows patients to calculate their anticipated utility expenses based on their local rates.

Because patients performing home hemodialysis would otherwise be dialyzing in facility-based units where the utility costs would be absorbed by the renal programs, this disadvantageous transfer of cost to the patient is a boon to renal care providers who benefit doubly because they also save on the staffing costs to provide treatment in-centre. To some extent, the patient-incurred expense of paying for water and power for home hemodialysis is offset by being spared the time and expense associated with travel to and from facility-based hemodialysis 3 days each week. However, particularly for patients whose travel costs are minimal, the imbalance between savings (e.g., from bus, taxi, parking, vehicle depreciation, etc.) compared with the expenses (e.g., water and electricity costs) raises the question of equity among dialysis patients.

In some cases, the treatment-associated expense of home hemodialysis may even be a legitimate barrier to its uptake, particularly for patients on a fixed income. Several jurisdictions in Canada have recognized and attempted to address this disparity. The Manitoba Renal Agency, in collaboration with the provincial branch of the Kidney Foundation, have successfully lobbied for utility reimbursement for a portion of patients' monthly utility expenses (reimbursements originate from Manitoba Health, but are dispensed through the Kidney Foundation branch; Dr. Paul Komenda – personal communication). The Ottawa Renal Program provides patients with documentation they can submit to their municipality for a rebate on water charges up to a maximum of $500 per year (Dr. Deborah Zimmerman – personal communication).[15] Internationally, some programs (most notably in the state of Victoria, Australia) already provide annual cash payments to patients to incentivize home hemodialysis precisely to offset expenses such as additional utility costs.

Limitations

This study exclusively estimated the cost of water and power, and patient-borne costs associated with training for home hemodialysis are not included. Thus, the overall financial burden on patients starting and maintaining themselves on home hemodialysis is greater than is estimated simply by measuring the utility expenses. In addition, we did not consider additional equipment needed for water purification when the source water is from a well, or water delivery and storage costs when water must be transported and stored in a cistern (as may be the case for rural dwellers who have no suitable well water).

Utility rates are highly variable from region to region across Canada, and even within provinces. This makes it particularly important for individual patients to calculate their own water and electrical expenses associated with treatment based on their own utility rates. Like us, individual patients calculating these expenses will need to make some assumptions around their utility usage.

It is unknown whether the simulations presented here are generalizable to other home hemodialysis and reverse osmosis machines not manufactured by the vendors currently in use in our renal program. Although the Bellco/Gambro combination is relatively common among Canadian programs, it is not used exclusively; the variation in water and power consumption with other dialysis equipment is assumed to be similar but is not known with any degree of certainty. A system particularly worth noting is the NxStage hemodialysis system, which is a portable home hemodialysis device that was recently approved for use by Canadian renal programs. This system features hardware that is likely to have very different utility requirements than the conventional hemodialysis technology that still dominates the marketplace owing to its small footprint, portability and variable reliance on prepackaged consumables. The formula presented in this manuscript is not intended to apply to or estimate utility consumption for the NxStage interface.

Conclusion

We present per treatment, monthly and annual estimates of patient-borne water and electrical power costs based on simulations of commonly prescribed home hemodialysis regimens. Because these expenses are transferred to the patient, the current study addresses a much-overlooked perspective in the economics of home hemodialysis delivery.

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Affiliations: Department of Chemical and Materials Engineering (Nickel, Burrell), University of Alberta; Northern Alberta Renal Program (Rideout, Reintjes, Pauly), Alberta Health Services; Division of Nephrology, Department of Medicine (Shah, Pauly), University of Alberta; Department of Medicine (Chen), University of Alberta, Edmonton, Alta.

Contributors: Matthew Nickel and Wes Rideout performed the simulation studies. Matthew Nickel, Nikhil Shah and Justin Chen performed the calculations leading to the creation of the formula to calculate the cost of delivering home dialysis. Matthew Nickel, Wes Rideout, Frances Reintjes, Robert Burrell and Robert Pauly designed the study. Robert Burrell and Robert Pauly supervised the project. Matthew Nickel, Justin Chen and Robert Pauly wrote an initial draft of the manuscript. All of the authors contributed to the editing of the manuscript, approved the final version to be published and agreed to act as guarantors of the results.

Acknowledgements: The authors wish to acknowledge Anna Romano, Sashi Das, Maria and Michael Szeman, Karthik Tennankore and Dr. Deborah Zimmerman for providing their monthly electricity and water billing data. The authors also wish to thank to Dr. Deborah Zimmerman and Dr. Paul Komenda for sharing their experiences with patient reimbursement strategies from the Ottawa Renal Program and the Manitoba Renal Program, respectively.

Supplemental information: For reviewer comments and the original submission of this manuscript, please see www.cmajopen.ca/content/5/1/E61/suppl/DC1