A simulation study of patient-borne water and electrical costs in home hemodialysis: Off-loading the expense onto patients

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Abstract

Background: There is increasing interest in the use of home hemodialysis (HHD) as an alternative renal replacement therapy to facility-based conventional hemodialysis. HHD can result in better physiological parameters, quality of life, and overall survival for patients with end stage renal disease (ESRD). While HHD is associated with lower costs to the healthcare system due to lower staffing and overhead costs, it transfers the treatment cost of utilities (water and power) to the patient. The purpose of this study was to determine the utility costs of HHD and create a model such that patients and renal programs can predict the annual patient-borne dialysis utility 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 HHD and reverse osmosis machines. Real time electrical and water consumption was monitored during these dialysis simulations. **Results:** Using typical 2014 utility costs for Edmonton, Alberta, the most expensive prescription was for nocturnal HHD (8 hours, 6 days/week; Qd 300mL/min), which resulted in a utility cost of $1263/year, while the least expensive prescription was for conventional HHD (4 hours, 3 days/week; Qd 500mL/min) costing $422/year. A generic formula is presented to allow patients/programs to calculate a more precise estimate of utility costs based on individual combinations of dialysis intensity, frequency and utility costs unique to any individual patient. **Interpretation:** We demonstrate a significant cost burden of hemodialysis is transferred to the patient on HHD, which would otherwise be borne by the renal program.

KEY WORDS:

Home hemodialysis, water, electricity, utilities, cost, economics, expenses

Introduction

Conventional intermittent in-centre hemodialysis is the most utilized modality of renal replacement therapy in North America. However, there is increasing interest in the usage of alternative strategies such as peritoneal dialysis and home hemodialysis (HHD). HHD is recognized as resulting in better quality of life, indices of mineral metabolism, cardiac health and even overall survival compared to conventional in-centre hemodialysis [1-5]. This modality also results in cost savings to the healthcare system when compared to in-centre intermittent hemodialysis [6-8]. Previously published analyses have looked at the costs of providing this therapy from the payer perspective. Although there is considerable variability in analytic approaches and their results, it is generally accepted that HHD is associated with lower human resource and facility management expenditures [2,5,7]. However, when patients self-dialyze at home, some expenses (such as utility costs of running the dialysis equipment) are transferred to the patient, and to date, no one has attempted to explicitly delineate these patient-borne costs. The aim of this study was to measure utility consumption (water and electrical) required to perform various prescriptions of HHD, and estimate the associated expenditure.

Methods

This study was conducted in the HHD program of the Northern Alberta Renal Program in Edmonton, Canada. We performed simulations of 7 different home dialysis prescriptions (ie. 7 combinations of dialysis treatment duration and dialysate flow – Qd): 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. For each prescription we performed a set of five repeats using five different combinations of five hemodialysis machines (Bellco Formula Domus; Bellco Canada, Mississauga, Canada) and five reverse osmosis (RO) machines (Gambro WRO 300; Gambro Canada, Richmond Hill, Canada). Each set was conducted at 20 °C. An additional simulation of each prescription using a single combination of hemodialysis machine and RO machine was conducted at 8 °C to simulate a cold water source requiring additional pre-heating by the hemodialysis machine prior to generating dialysate. All simulations included a 60-minute pre-treatment period during which the hemodialysis and RO machines undergo automated system checks, as well as an approximately 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 out program prescribes after every three treatments) and on the RO machine (which our program prescribes once weekly).

Water consumption was measured using a Seametrics FT400-SERIES in-line flow meter proximal to the RO machine, with Seametrics DL76 Data Logger (Seametrics Inc., Kent, USA); data was 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, USA) for each of the RO and dialysis machines.

The cost of water and electricity was calculated using local utility cost estimates in Edmonton, Alberta using average 2014 rates from one of multiple available water and electricity providers in Alberta. Data are presented in 2014 Canadian dollars. The costing of utilities also assumed a fixed rate monthly cost for both water and electricity which may be less accurate in jurisdictions where utility rates are variable depending on consumption (eg. the rate is different for the first *x* cubic meters of water and changes to a different rate for the next *y* cubic meters of water).

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

Formula 1

$$Cost\ of\ Dialysis = n\left(U_w C_w + U_p C_p\right)$$

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 per treatment. U_w and U_p are reported in litres (L) and kilowatt-hours (kWh) respectively, while C_w and C_p are quoted in dollars per L and dollars per kWh respectively.

The total monthly utility cost of HHD must also include the expense of the chemical disinfecting cycle of the dialysis and RO machines. The monthly frequency of these disinfection cycles is also variable and estimated as follows:

$$\text{Cost of Disinfection} = \text{Cost of Disinfecting the HD Machine} + \text{Cost of Disinfecting the RO Machine}$$

Formula 2

$$\text{Cost of Disinfection} = \left[n_d\left(U_{dw}C_w + U_{dp}C_p\right)\right] + \left[n_r\left(U_{rw}C_w + U_{rp}C_p\right)\right]$$

where n_d and n_r are the number of times per month the dialysis and RO machines undergo a chemical disinfection cycle (eg. Dialox disinfection), U_{dw} and U_{dp} are the mean water and electrical power usage respectively during the disinfection cycle of the hemodialysis machine, and U_{rw} and U_{rp} are the mean water and electrical power usage respectively during the disinfection cycle of the RO machine. C_w and C_p are defined as above. Because the disinfection cycles are standard regardless of dialysis prescription, U_{dw}, U_{dp}, U_{rw} and U_{rp} can be determined as constants.

Results

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

All simulated dialysis prescriptions were conducted at 20 °C to approximate ambient water temperature entering the hemodialysis machine from the RO machine. However, using the same combination of dialysis and RO machines we conducted single simulations of all 7 prescriptions with a source water temperature of 8 °C to approximate a water source that would need significant pre-heating prior to generating dialysate. Under such conditions, the amount of water consumption remained unchanged (-1 ± 2%), but the electrical power consumption per treatment increased by 34 ± 10%.

Patients self-dialyzing at home are taught to chemically disinfect both the hemodialysis and the RO machines. The protocols for these procedures are independent of dialysis prescription. Water consumption for the chemical disinfection cycle of the hemodialysis and RO machines was 110.6 ± 6.2 L (n=5) and 67.6 ± 2.0 L (n=4) respectively. Electricity consumption was 0.56 ± 0.07 kWh and 0.15 ± 0.01 kWh for hemodialysis and RO machines respectively. Using these results as constants in Formula 2, the total cost of disinfection using the Bellco/Gambro HHD ensemble can be re-written as:

Formula 3

$$Cost\ of\ Disinfection = \left[n_d\left(110.6C_w + 0.56C_p\right)\right] + \left[n_r\left(67.6C_w + 0.15C_p\right)\right]$$

Note, the electricity consumed for the hemodialysis chemical disinfection when source water was 8 °C was 50% more than when water entering the hemodialysis was 20 °C; this has not been considered in Formula 3. Combining Formula 1 and Formula 3 allows one to calculate the total monthly and annual out-of-pocket cost borne by patients performing HHD. Table 2 summarizes these 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 hour at 800 ml/min with 6 treatments per week, and (d) 4 hours at 500 ml/min with 3 treatments per week. Treatment frequencies were determined on the basis of a 31-day month. The greatest expense is associated with a frequent nocturnal hemodialysis prescription (ie. $1263.27) while the least expense is incurred by a more conventional thrice-weekly hemodialysis prescription ($422.12).

Interpretation

While a number of economic analyses have been published for HHD, all take the perspective of the health system and ignore expenses incurred by the patient [6, 8-14]. To our knowledge, this is the first study to systematically estimate patient-borne water and electricity costs when patients perform HHD independently at home. The annual utility cost of HHD in this study range from $422 to $1263 and, not surprisingly, the most expensive form of dialysis is a prescription used for 8-hour six-times-weekly nocturnal home hemodialysis and the least expensive is for a prescription of conventional 4-hour thrice-weekly hemodialysis.

Because patients performing HHD would otherwise be dialyzing in facility-based dialysis 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 treat HHD patients in-centre. To some extent, the patient-incurred expense of paying for water and power for HHD is offset by being spared the time and expense associated with travel to and from facility-based hemodialysis on three days a week. However, especially for patients whose travel costs are minimal the imbalance between savings (eg. from bus, taxi, parking, vehicle depreciation, etc.) versus the expenses (eg. water and electricity costs) raises the question of equity among dialysis patients. In fact, several jurisdictions in Canada have recently proposed reimbursing patients for their monthly utility expenses. Others provide patients with letters they can submit with their income tax documents to claim the utility expense as a health care related medical deduction [15]. In some cases, the treatment-associated expense of HHD may even be a legitimate barrier to the uptake of HHD, especially for those patients on a fixed income. Indeed, some jurisdictions (most notably the state of Victoria, Australia) already provide an annual cash payment to patients to incentivize HHD and offset precisely the sort of expenses such as additional utility costs.

Perhaps a surprising and underappreciated result of these simulations is the recognition that only between 13% and 26% of water consumed during the hemodialysis treatment results in dialysate, while the rest is wastewater that is routinely discarded. Others have proposed to recycle this wastewater for other non-potable purposes such as flushing toilets or watering gardens [16].

Because the scope of this study was exclusively to estimate the cost of water and power, patient-borne costs associated with training for HHD (which may include room and board expenses or lost income while a person is training at a centre remote from home) are not included. Thus the overall financial burden on patients initiating and maintaining themselves on HHD is much greater than is estimated simply by measuring the utility expenses. But even if considering simply the cost of water, the estimates presented here do not include the additional equipment needed for water purification when the source water is from a well, or water delivery and storage costs when water must be trucked on location and stored in a cistern (as may be the case for rural dwellers who have no suitable well water). An additional limitation to the present study is the unknown generalizability of the simulations presented here to other HHD and RO machines not manufactured by the vendors currently in use in our renal program. While the Bellco/Gambro combination is relatively common among Canadian HHD programs, these are not used exclusively; the variation on water and power consumption with other dialysis equipment is assumed to be similar though not known with any degree of certainty.

In summary, we present per treatment, monthly and annual estimates of patient-borne water and electrical power costs based on simulations of commonly prescribed HHD prescriptions. Because these expenses are transferred to the patient, the current study addresses a much-overlooked perspective among in the economics of HHD delivery.

Disclosures

None

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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)

Duration and Qd	Water				Electricity		Total cost per treatment
	Per treatment dialysate desired (L)	Per treatment water consumption (L, 20 °C, n=5)*	% Dialysate desired to water consumed	Per treatment water cost**	Per treatment electricity consumption (kWh, 20 °C, n=5)*	Per treatment electricity cost***	
6 hr x 300 ml/min	108	805.2 ± 39.0	13%	$2.61	4.25 ± 0.46	$0.38	**$2.99**
8 hr x 300 ml/min	144	1012.8 ± 47.8	14%	$3.29	5.16 ± 0.48	$0.46	**$3.74**
4 hr x 500 ml/min	120	667.5 ± 32.8	18%	$2.17	3.68 ± 0.22	$0.33	**$2.49**
6 hr x 500 ml/min	180	898.7 ± 21.6	20%	$2.92	4.70 ± 0.28	$0.42	**$3.33**
2 hr x 800 ml/min	96	482.9 ± 16.8	20%	$1.57	2.64 ± 0.23	$0.23	**$1.80**
3 hr x 800 ml/min	144	604.7 ± 28.8	24%	$1.96	3.40 ± 0.26	$0.30	**$2.26**
4 hr x 800 ml/min	192	734.4 24.4	26%	$2.38	4.04 ± 0.38	$0.36	**$2.74**

* Mean
** Assuming water cost of $3.2438 per m^3 and includes a 60 min pre-treatment machine warm-up and operations check plus a 45 min post-treatment heat disinfection cycle
*** Assuming electricity cost of $0.089 per kWh and includes a 60 min pre-treatment machine warm-up and operations check plus a 45 min post-treatment heat disinfection cycle

Table 2 – Monthly and annualized water and electricity costs associated with HHD for common HHD prescriptions (including treatment and routine chemical disinfection protocols*)

Prescription	Monthly water costs	Annual water costs	Monthly electricity cost	Annual electricity cost	Total annual cost
4 hr x 500 ml/min x 3/wk	$30.63	$367.56	$4.55	$54.56	**$422.12**
2 hr x 800 ml/min x 6/wk	$45.91	$550.87	$6.72	$80.59	**$631.47**
8 hr x 300 ml/min x 3.5/wk	$51.99	$623.87	$7.21	$86.48	**$710.35**
8 hr x 300 ml/min x 6/wk	$92.35	$1108.15	$12.93	$155.11	**$1263.27**

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