Cost-Utility of Dialysis in Canada: Hemodialysis, Peritoneal Dialysis, and Nondialysis Treatment of Kidney Failure

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Rationale & Objective: The kidney failure population is growing, necessitating the expansion of dialysis programs. These programs are costly and require a substantial amount of health care resources. Tools that accurately forecast resource use can aid efficient allocation. The objective of this study is to describe the development of an economic simulation model that incorporates treatment history and detailed modality transitions for patients with kidney disease using real-world data to estimate associated costs, utility, and survival by initiating modality.

Study Design: Cost-utility model with microsimulation.

Setting & Population: Adult incident maintenance dialysis patients in Canada who initiated facility-based hemodialysis (HD) or home peritoneal dialysis (PD) between 2004 and 2013.

Intervention: HD and PD.

Outcomes: Costs (related to dialysis, transplantation, infections, and hospitalizations), survival, utility, and dialysis modality mix over time.

Model, Perspective, & Timeframe: The model took the perspective of the health care payer. Patients were followed up for 10 years from initiation of dialysis. Our cost-utility analysis compared the intervention with receiving no treatment.

Results: During a 10-year time horizon, the cost-utility ratio for all patients initiating dialysis was $103,779 per quality-adjusted life-year (QALY) in comparison to no treatment. Patients who initiated with facility-based HD were treated at a cost-utility ratio of $104,880/QALY and patients who initiated with home PD were treated at a cost-utility ratio of $83,762/QALY. During this time horizon, the total mean cost and QALYs per patient were estimated at $350,774 ± $204,704 and 3.38 ± 2.05) QALYs respectively.

Limitations: The results do not include costs from the societal perspective. Rare patient trajectories were unable to be assessed.

Conclusions: This model demonstrates that patients who initiated dialysis with PD were treated more cost-effectively than those who initiated with HD during a 10-year time horizon.

Visual Abstract included

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The prevalence of kidney failure in Canada has doubled in the last 2 decades.[1] Kidney failure is ideally treated with a kidney transplant because this form of kidney replacement therapy (KRT) is typically associated with the longest life span and best quality of life at the lowest cost.[2]

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Transplantation is often not possible because the supply of organs is insufficient to meet demand and the aging kidney failure population carries a greater burden of comorbid risk, rendering many patients unsuitable.[3] As such, kidney failure is often treated with maintenance dialysis: either hemodialysis (HD) or peritoneal dialysis (PD). PD is a continuous therapy typically performed in the home setting and HD can be performed in a facility or at home.

Providing maintenance dialysis treatment is costly and consumes disproportionate resources relative to the size of the prevalent dialysis population and outcomes acheived.[4] Much of these costs are attributable to the direct provision of dialysis therapy, with notable cost differences between modalities and setting. HD provided at a tertiary care center or outpatient clinic is the most expensive, costing on average more than CaD $60,000 per patient per year when delivered thrice weekly (conventional) and even higher when delivered in shorter sessions daily or longer sessions nocturnally (intensive). In contrast, self-care HD or PD performed in the home costs significantly less, between CaD $35,000 and $45,000 per year.[5] In addition, patients receiving dialysis may undergo multiple vascular access procedures and experience complications, including increased risk for infections, cardiovascular events, and hospitalizations, increasing the total cost of providing treatment for kidney failure.[6]

Although most patients who undergo dialysis will receive only a single modality, up to 40% will switch modalities or setting during the course of their treatment.[7,8] For example, patients initiating with facility-based HD may transition to home modalities or receive a kidney transplant, reducing costs. Transplant recipients may subsequently experience allograft failure and revert to facility-based HD, increasing costs. As such, tools to accurately plan resource use that incorporate modality switches and setting changes are needed to aid efficient planning, particularly in the face of a growing kidney failure population and expanding dialysis programs.

PLAIN-LANGUAGE SUMMARY

Dialysis programs are costly and require a substantial amount of health care resources; thus, it is important to develop tools that can accurately forecast associated costs, quality of life, and survival for different types of dialysis. In this study, we developed an economic simulation model using treatment history from Canadian patients receiving facility-based hemodialysis or home peritoneal dialysis. We evaluated the cost-effectiveness of each treatment by dividing health payer cost by quality-adjusted life years. This model demonstrated that patients who initiated dialysis with peritoneal dialysis were treated more cost-effectively than those who initiated with hemodialysis during a 10-year time horizon.

The primary aim of this study is the construction of an economic simulation model incorporating detailed modality transitions that incorporate treatment history for dialysis patients using real-world data in Canada.

METHODS

Overview

We constructed a framework for a cost-utility model from the perspective of the Canadian single-payer universal health system for incident maintenance (at least 90 consecutive days receiving dialysis) dialysis patients 18 years or older. We used a decision analytic Markov model using microsimulation with TreeAge Pro (TreeAge Software, LLC) 2019 and adhered to generally accepted guidelines for economic evaluation in health care.[9,10] Model outcomes were expressed as costs, survival, utility (quality-adjusted life-years [QALYs]), and modality mix (proportion of dialysis type over time) of those who initiated HD or PD. Cost-utility ratios (expected cost of treatment divided by estimated QALYs) of therapies in comparison to no treatment were also generated. The baseline model provides estimates based on historical data for both these initial treatment modalities and can be modified to evaluate potential interventions in which treatment assumptions are modified in these populations. We considered outcomes up to a 10-year time horizon. Predicted modality mix was explored for the first 3 years following initiation of dialysis. Treatment states were modeled on a monthly basis to capture frequent transitions common in dialysis. When required, all costs were inflated to 2016 Canadian dollars using the Canadian consumer price index (Table S1).[11] All costs and utilities were discounted at 5%.[10] Approval for this project was granted by the University of Manitoba Health Research Ethics Board (Ethics # HS17565).

Data Sources and Model Inputs

The cohort was drawn from the Canadian Organ Replacement Register (CORR), which includes all incident maintenance dialysis starts, transitions, and kidney transplants in Canada and is managed by the Canadian Institute for Health Information (CIHI). Patients from the province of Quebec were excluded because privacy laws precluded the submission of deidentified data without first-person consent. We considered patients in this registry for the 10-year period between January 1, 2004, and December 31, 2013.[12,13] A patient's initial KRT modality in the model was assigned based on the distribution of initial KRT modalities in CORR. After entry into the model, each hypothetical patient could transition to another modality, receive a kidney transplant, or die. The transition probabilities for each modality, transplant, or death used in the model were derived from real-world transition probabilities from CORR. Baseline characteristics of the CORR cohort were described, including patient demographics and comorbid conditions. In addition, our model also accounted for infection-related hospitalization events, cardiovascular-related hospitalizations, and all-cause hospitalizations. Probability of infection requiring hospitalization was determined by linking the CIHI Discharge Abstract Database[14] to CORR with events defined using *International Statistical Classification of Diseases and Related Health Problems, Tenth Revision, Canada* codes (Table S2; Item S1). Rates of cardiovascular and all-cause hospitalization were taken from published studies in Canadian dialysis and transplant populations.[6,15] Training time required for patients receiving home dialysis was taken from a Canadian Agency for Drugs and Technology in Health (CADTH) Health Technology Assessment.[10] All rates were converted to monthly probabilities with calculations located in Item S2. Model inputs are summarized in Table 1 and a diagrammatic representation of the model is provided in Fig S1.

The model examined each incident maintenance dialysis patient's trajectory from initial modality until the end of treatment or mortality, capturing all intermediate transitions to incorporate treatment history in future transition probabilities. Patients were censored at recovery of kidney function, loss to follow-up, or end of the study period. We considered 6 possible treatment states, chosen for their potential differences in health outcomes and associated costs: conventional (thrice-weekly) facility-based HD, conventional home HD (HHD), intensive facility-based HD, intensive HHD, home PD, and transplantation. We included only patients who initiated dialysis with conventional facility-based HD or with PD because relatively few patients initiated with other treatment modalities (eg, HHD) and we were unable to derive robust transition probabilities due to insufficient sample size.

Because so few patients in CORR experienced 3 or more modality transitions before an end-of-treatment event, we truncated the model after 3 treatment states (eg, HD to PD to transplantation); after the third switch, a patient in the

Table 1. Model Inputs: Proportions and Transition Probabilities

Parameter	Baseline Point Estimate	Range or Distribution for Probabilistic Sensitivity Analysis	Source and Notes
Discount rate, costs	5%	Tested in univariate sensitivity analysis	Assumption
Discount rate, utilities	5%	Tested in univariate sensitivity analysis	Assumption
Utility, HD facility based	0.71	Normal (0.71, 0.04)	Wyld et al[19]
Utility, PD	0.71	Normal (0.71, 0.04)	Wyld et al[19]
Utility, HHD	0.71	Normal (0.71, 0.04)	Wyld et al[19]
Utility, transplant	0.82	Normal (0.82, 0.04)	Wyld et al[19]
Proportion of transplants that are deceased donor	0.6184	β (6,589, 4,066)	CORR
Proportion of patients with first treatment modality being HD	0.792	β (31,148, 8,170)	CORR
Monthly probability of a CV event requiring hospitalization in dialysis patients	0.028745	Poisson (0.35) distribution for annual rate	See calculation note below. Lafrance et al[6]
Monthly probability of a CV event requiring hospitalization in transplant recipients	0.003964	Poisson (0.047658) distribution for annual event rate	See calculation note below. Jiang et al[15]
Monthly probability of other (all-cause, excluding CV events and infections) hospitalization admission in dialysis patients	0.0645	Poisson (0.8) distribution for annual event rate	See calculation note below. Lafrance et al[6]
Monthly probability of other (all-cause) hospitalization admission in transplant recipients	0.0301	Poisson (0.37) distribution for annual event rate	See calculation note below. Jiang et al[15]
Days of retraining per person-y by modality	PD, 0.31; HHD, nocturnal, or short daily HHD: 3.56	PD: Poisson (0.31); HHD, nocturnal or short daily HHD, Poisson (3.56)	CADTH HTA Report[16]

Note: Normal distributions provided as normal (μ, σ); β distributions provided as Beta (α, β); Poisson distributions provided as Poisson (λ). For calculation of monthly probabilities see Item S2. For monthly model transitions probabilities see Table S2. For proportion of patients receiving continuous cycling PD versus continuous ambulatory PD see Table S7. For proportion of patients receiving satellite HD see Table S8.
Abbreviations: CADTH, Canadian Agency for Drugs and Technology in Health; CORR, Canadian Organ Replacement Register; CV, cardiovascular; HD, hemodialysis; HHD, home hemodialysis; HTA, health technology assessment; PD, peritoneal dialysis.

model could only transition to mortality or remain in that final state. Similarly, some transition sequences with fewer than 3 switches had too few patients ($n < 50$) to reliably define outcomes; therefore, we truncated such patient trajectories in the model and ascribed costs and outcomes to the last modality experienced by the patient in their truncated trajectory. This approach captured 98% of patients. Patient trajectories for all HD and PD starters are outlined in Tables S3 and S4. The probability of transition between treatment states was determined at monthly intervals for the first year, and then annual probabilities of transition were converted to monthly probabilities thereafter until 5 years, after which the monthly risk of transition was held constant (Table S5 and S6). Internal model validity was assessed by comparing survival rates and modality mix over time between model output and the CORR data.

We included all direct dialysis-related (human resources, consumables and equipment, dialysis-related drugs, hospital overhead, and capital expenditures) and hospitalization costs related to treatment for kidney failure.[16] Costs for dialysis modalities were estimated using capitation-based reimbursement rates from the Ontario Renal Network for facility-based HD (both conventional and intensive dosing regimens), PD (both continuous ambulatory PD and continuous cycling PD), and HHD (both conventional and intensive). The proportion of patients receiving continuous cycling PD versus continuous ambulatory PD over time is listed in Table S7.

We assumed that patients receiving treatment in a satellite dialysis center would experience similar costs to those receiving treatment at a tertiary care center in the baseline model (proportion of patients receiving satellite dialysis vs tertiary care center based listed in Table S8). Cost for the placement of PD or central venous catheters, HD access creation, home dialysis training and retraining, equipment installation, and home water testing were also taken from the Ontario Renal Network.[16] Maintenance costs for dialysis access were taken from a Canadian costing study.[17] Capital costs were taken from a Canadian study that estimated annual dialysis costs in Manitoba.[5] Costs related to transplantation (procedure, workup, donor-related expenses, and maintenance therapy) were estimated from a Canadian analysis of donor- and recipient-related costs for both living and deceased donor transplantation.[18] Costs of hospitalizations (all-cause and infection or cardiovascular related) were calculated using CIHI Case Mix Grouper codes used in a report from CADTH.[16] Costs and related assumptions are summarized in Table 2.

Table 2. Model Inputs: Costs

Variable	Baseline Point Estimate	Range or Distribution for Probabilistic Sensitivity Analysis	Source and Notes
Cost of facility-based HD (annual)	$50,075.81	NA	Ontario Renal Network reimbursement[16]
Cost of PD (annual)	$39,289.38 (CCPD) $29,969.07 (CAPD)	NA	Ontario Renal Network reimbursement[16]
Cost of conventional HHD (annual)	$23,824.69	NA	Ontario Renal Network reimbursement[16]
Cost of intensive (nocturnal or short daily) facility-based HD (annual)	$83,467.02	NA	Ontario Renal Network reimbursement[16]
Cost of intensive (nocturnal or short daily) HHD (annual)	$36,661.16	NA	Ontario Renal Network reimbursement[16]
Cost of transplant procedure	Living donor: $22,628.11 Deceased donor: $26,803.07	Living donor: gamma (388.63, 0.017) Deceased donor: gamma (219.67, 0.008)	Barnieh et al[18]
Cost of transplant workup	Living donor: $2,667.03 Deceased donor: $3,282.58	Living donor: gamma (410.32, 0.154) Deceased donor: gamma (611.10, 0.186)	Barnieh et al[18]
Cost of transplant donor-related expenses	Living donor: graft, $20,401.08; workup, $2,544.37; follow-up, $672.95 Deceased donor: graft, $41,624.78; workup, $235.19; follow-up, $0	Living donor: graft, gamma (763.73, 0.037); workup, gamma (724.51, 0.285); follow-up, gamma (18.25, 0.027) Deceased donor: graft, gamma (796.05, 0.019)' workup, gamma (22.56, 0.096); follow-up, NA	Barnieh et al[18]
Cost of transplant maintenance treatment (per 30-d cycle)	Living donor: 0-90 d, $11,860.21; 91-360 d, $2,742.30; following years, $1,873.11 Deceased donor: 0-90 d, $10,578.09; 91-360 d, $3,238.82; following years, $2,084.95	Living donor: 0-90 d, gamma (62.14, 0.005); 91-360 d, gamma (27.11, 0.010); following years, gamma (29.21, 0.016) Deceased donor: 0-90 d, gamma (148.64, 0.014); 91-360 d, gamma (45.22, 0.014); following years, gamma (35.72, 0.017)	Barnieh et al[18]
Cost of PD training	$2,408.84 (CCPD) $2,277.75 (CAPD)	NA	Ontario Renal Network reimbursement[16]
Cost of PD retraining	$291.05 (CCPD) $264.83 (CAPD)	NA	Ontario Renal Network reimbursement[16]
Cost of HHD training	$11,399.64	NA	Ontario Renal Network reimbursement[16]
Cost of HHD equipment installation	$3,000	NA	Ontario Renal Network reimbursement[16]
Cost of HHD water testing (annual)	Feed water test: $1,872.97 Product water test: $242.38 Carbon tank exchange (4×/y): $231.08/exchange	NA	Ontario Renal Network reimbursement[16]
Cost of HHD retraining (similar for conventional and nocturnal)	$542.84	NA	Ontario Renal Network reimbursement[16]
Cost of physician reimbursement (annual; note: physician reimbursement for transplant is included in transplant-related costs)	$6,614	NA	Ontario Renal Network reimbursement[16]

(Continued)

Table 2 (Cont'd). Model Inputs: Costs

Variable	Baseline Point Estimate	Range or Distribution for Probabilistic Sensitivity Analysis	Source and Notes
Cost of PD catheter placement (assumed to be performed at transition to PD and repeated if off PD modality for ≥3 mo)	$1,069.96	NA	Ontario Renal Network reimbursement[16]
Capital cost for dialysis (annual)	Facility-based: $5,475 Home: $3,033	NA	Beaudry et al[5]
Cost of HD access (imaging, surgery, outpatient infections, tPA, and access monitoring) (annual)	$5,751.04	Surgical costs: inverted log-normal (−7.89, 0.2737) Diagnostic imaging: log-normal (7.46, 0.9536) Outpatient infection costs: log-normal (0, 3.3764) transformed by 1 unit due to median cost of 0 tPA: log-normal (0, 2.3971) transformed by 1 unit due to median cost of 0 Access monitoring: log-normal (0, 3.0549) transformed by 1 unit due to median cost of 0	Manns et al[17]
Cost of infection-related hospital admission	$11,938.53	Gamma (16, 0.001)	CIHI: CMG 654 other/unspecified sepsis and CADTH HTA report[16]
Cost of CV disease–related hospital admission	$7,389.67	Gamma (16, 0.002)	CIHI: mean of CMG 202 (arrhythmia without coronary angiogram) and 175 (PCI with MI/shock/arrest/heart failure) CADTH HTA report[16]
Cost of other all-cause hospital admission	$8,163.45 × 1.8085 = $14,763.60	Gamma (16, 0.001)	CIHI: CMG 480 kidney disease, adjusted by comorbidity factor 2 (1.8085) and CADTH HTA report[16]
Cost of erythropoietin (/mo)	HD: $157.89 HHD: $61.48 PD: $131.81	Conventional HD: gamma (16, 0.101) HHD: gamma (16, 0.260) PD: gamma (16, 0.121)	Manitoba Renal Program Statement of Operations (2016)

Note: Gamma distributions provided as gamma (α, β); log-normal distributions provided as log-normal (μ, σ). All cost values presented as 2016 Canadian dollars. For inflation calculations using values presented in references, see Item S1.
Abbreviations: CADTH, Canadian Agency for Drugs and Technology in Health; CAPD, continuous ambulatory peritoneal dialysis; CCPD, continuous cycler peritoneal dialysis; CIHI, Canadian Institute of Health Information; CMG, Case Mixed Grouper; CV, cardiovascular; HD, hemodialysis; HHD, home hemodialysis; HTA, Health Technology Assessment; MI, myocardial infarction; NA, not applicable; PCI, percutaneous coronary intervention; PD, peritoneal dialysis; tPA, tissue plasminogen activator.

Utility values for relevant health states, including facility-based HD, home PD, HHD, and transplantation were based on a systematic review of quality of life in maintenance kidney disease treatments. We assumed that patients receiving any form of dialysis had an annual utility score of 0.70 and assumed an annual utility score of 0.82 for a patient with a kidney transplant.[19] Although some literature suggests potentially improved quality of life with home dialysis or more intensive dialysis, we assumed no quality-of-life difference between dialysis modalities in the baseline model as because strength of the evidence for these was low[20-23] (Table 1).

Sensitivity Analyses

Univariate sensitivity analysis was performed by varying influential cost parameters by ± 50% from baseline to determine the impact of individual parameter variation on the estimated cost of kidney failure care. Influential cost parameters were defined as parameters that altered the predicted 10-year cost by >10% when varied by 50% from baseline. Probabilistic sensitivity analysis (second-order Monte Carlo simulation) was performed on 1,000 samples for baseline costs and effectiveness estimates to evaluate parameter uncertainty by varying model inputs over plausible distributions.

RESULTS

Demographics

The total sample consisted of 39,318 dialysis patients, with 31,148 initiated with facility-based HD and the remaining 8,170 initiated with home PD. Mean ages of facility-based HD and home PD starters were 64.6 and 61.3 years, respectively, and 60.6% of all facility-based HD starters were men, whereas 58.5% of all home PD starters were men. Patients who initiated dialysis with home PD had fewer comorbid conditions, with details outlined in Table 3.

Costs

Total mean costs of kidney failure care by starting modality are summarized in Table 4. Over 10 years, the total mean cost per patient for all dialysis starters was estimated at $350,774.39 ± $204,703.55. For those initiating with facility-based HD and home PD, 10-year total mean costs were $352,712.07 ± $211,269.26 and $336,308.65 ± $176,569.82 per patient, respectively.

Quality of Life

Estimated 10-year mean QALYs per patient for all dialysis starters were 3.38 ± 2.05. For patients initiating with home PD, 10-year mean QALYs were estimated at 3.86 ± 2.07. Conversely, 10-year mean QALYs for patients who initiated with facility-based HD were estimated at 3.25 ± 2.03. The 1-, 2-, 3-, 5-, and 10-year QALY estimations by initial modality are outlined in Table 5.

Cost-Utility

The cost-utility ratio associated with all patients initiating dialysis was $103,779.41/QALY in comparison to no treatment. For both facility-based HD and home PD starters, the corresponding cost-utility ratios were $108,526.79/QALY and $87,126.59/QALY, respectively, in comparison to no treatment.

Survival

Monthly predicted survival rates by modality start in comparison to observed survival rates from the CORR data are presented in Fig 1 and Tables S9 and S10. For facility-based HD starters, predicted survival rates at 60 and 120 months were 47.98% and 26.39%. Similarly, observed survival rates at these times were 48.40% and 27.60%. At 60 and 120 months, predicted survival rates for all home PD starters were estimated at 59.67% and 40.37%. The observed rates for all home PD starters at 60 and 120 months were 59.50% and 37.4%, respectively.

Modality Mix

Model estimates of treatment state transitions in comparison to observed values from CORR for both facility-based HD and home PD starters are presented in Table S11. At 24 months, the model estimated that 62.8% of conventional facility-based HD starters failed to transition to other states. Observed values at this time were 64.1%. At 36 months, the respective model estimated and observed values were 51.9% and 54.2%. Among PD starters, the model estimated that 57.4% would remain in their initial modality state at 24 months. Observed values at this time were 59.0%. At 36 months, the model estimated value was 42.3% compared to the observed value of 44.2%.

Sensitivity Analyses

In univariate sensitivity analyses, the most influential parameters were identified as the cost of facility-based conventional dialysis and the cost of an all-cause hospitalization event. A variation in the cost of facility-based conventional dialysis of 50% altered the 10-year cost by $82,242.25 (23.4%). Full results of univariate sensitivity analyses are provided in Fig 2 for the entire dialysis population. For results separated by PD and HD starters, findings are presented in Tables S12 and S13.

As summarized in Fig 3, Table S14, and Figs S2 and S3, probabilistic sensitivity analysis drawing from 1,000 random samples yielded an estimated average 10-year cost of kidney failure care for all patients of $346,554.83 ± $66,869.44 and 3.37 ± 0.16 QALYs. For those initiating with facility-based HD, expected average 10-year cost of kidney failure care and QALYs were $349,942.93 ± $72,123.06 and 3.24 ± 0.16 QALYs. For home PD starters, the expected average 10-year cost of kidney failure care and QALYs were $334,003.67 ± $53,566.75 and 3.88 ± 0.17 QALYs, respectively.

Table 3. Demographic Characteristics of the CORR Cohort by Initial Dialysis Modality

Characteristic	HD Starters (n = 31,148)	PD Starters (n = 8,170)	*P*
Demographics			
Age, y	64.6 ± 15.2	61.3 ± 15.0	<0.001
Male sex	18,880 (60.6%)	4,779 (58.5%)	<0.001
Comorbid conditions			
Previous unstable angina			<0.001
Yes	5,385 (17.3%)	936 (11.5%)	
No	22,386 (71.9%)	6,480 (79.3%)	
Missing/uncertain	3,377 (10.8%)	754 (9.2%)	
Previous myocardial infarction			<0.001
Yes	6,220 (20.0%)	1,089 (13.3%)	
No	21,829 (70.1%)	6,388 (78.2%)	
Missing/uncertain	3,099 (9.9%)	693 (8.5%)	
Pulmonary edema			<0.001
Yes	7,669 (24.6%)	861 (10.5%)	
No	20,297 (65.2%)	6,573 (80.5%)	
Missing/uncertain	3,182 (10.2%)	736 (9.0%)	
Diabetes (type 1 & 2)			<0.001
Yes	15,938 (51.2%)	3,880 (47.5%)	
No	13,410 (43.0%)	3,857 (47.2%)	
Missing/uncertain	1,800 (5.8%)	433 (5.3%)	
Previous cerebrovascular accident			<0.001
Yes	4,212 (13.5%)	771 (9.4%)	
No	23,861 (76.6%)	6,709 (82.2%)	
Missing/uncertain	3,075 (9.9%)	690 (8.4%)	
Peripheral vascular disease			<0.001
Yes	5,256 (16.9%)	909 (11.1%)	
No	22,605 (72.6%)	6,516 (79.8%)	
Missing/uncertain	3,287 (10.5%)	745 (9.1%)	
Lung disease			<0.001
Yes	3,585 (11.5%)	446 (5.5%)	
No	24,034 (77.2%)	6,955 (85.1%)	
Missing/uncertain	3,529 (11.3%)	769 (9.4%)	
Hypertension			<0.001
Yes	24,024 (77.1%)	6,599 (80.8%)	
No	4,915 (15.8%)	1,002 (12.3%)	
Missing/uncertain	2,209 (7.1%)	569 (7.0%)	
Current smoker			<0.001
Yes	4,208 (13.5%)	966 (11.8%)	
No	22,416 (72.0%)	6,329 (77.5%)	
Missing/uncertain	4,524 (14.5%)	875 (10.7%)	
Previous CABG			<0.001
Yes	4,589 (14.7%)	837 (10.2%)	
No	23,483 (75.4%)	6,644 (81.3%)	
Missing/uncertain	3,076 (9.9%)	689 (8.4%)	
Malignancy			<0.001
Yes	4,156 (13.3%)	646 (7.9%)	
No	2,833 (73.3%)	6,663 (81.6%)	
Missing/uncertain	4,159 (13.4%)	861 (10.5%)	

Abbreviations: CABG, coronary artery bypass graft; CORR, Canadian Organ Replacement Register; HD, hemodialysis; PD, peritoneal dialysis.

DISCUSSION

During the 10-year period considered in the model's current simulation, patients who were selected to initiate with facility-based HD were treated at a cost-utility ratio of $104,879.66/QALY and patients who were selected to initiate with home PD were treated at a cost-utility ratio of $83,762.00/QALY. Our model provides a comprehensive tool by which the cost-utility of KRT can be described in

Table 4. Dialysis-Specific Costs per Patient (first-order Monte Carlo simulation)

Modality	1 Year	2 Year	3 Year	5 Year	10 Year
HD, mean ± SD	$79,444.44 ± $16,087.40	$142,966.39 ± $40,929.63	$193,704.34 ± $68,412.88	$266,634.45 ± $121,411.50	$352,712.07 ± $211,269.26
25%	$82,808.75	$135,297.10	$162,676.52	$162,676.52	$162,676.52
50%	$82,808.75	$161,344.49	$236,137.21	$306,940.76	$350,198.06
75%	$82,808.75	$161,344.49	$236,137.21	$375,260.62	$533,582.20
PD, mean ± SD	$67,556.57 ± $18,100.47	$125,257.68 ± $32,525.11	$173,065.11 ± $51,314.28	$242,774.34 ± $92,981.29	$336,308.65 ± $176,569.82
25%	$63,628.91	$122,314.40	$178,537.73	$180,822.98	$180,822.98
50%	$63,628.91	$122,314.40	$178,537.73	$283,322.74	$360,566.84
75%	$63,628.91	$130,955.49	$200,505.14	$295,948.23	$484,236.61
All, mean ± SD	$77,212.19 ± $17,014.49	$139,683.67 ± $39,664.74	$190,062.61 ± $65,468.49	$262,556.41 ± $116,016.13	$350,774.39 ± $204,703.55
25%	$67,338.63	$122,314.40	$167,054.88	$167,054.88	$167,054.88
50%	$82,808.75	$161,344.49	$222,343.40	$288,434.12	$353,868.69
75%	$82,808.75	$161,344.49	$236,137.21	$375,260.62	$513,920.43

Abbreviations: All, all dialysis starts; HD, hemodialysis starts, PD, peritoneal dialysis starts; SD, standard deviation.

an incident adult maintenance dialysis population. In addition, this tool can account for changes in patient dialysis modality, and model inputs can be adjusted to account for differences in cost assumptions between locations and populations.

Our model improves on the existing literature by accounting for costs associated with the modality switching that occurred in approximately one-third of all dialysis patients in the CORR population. Previous analyses have assessed this cost but limited to a single modality switch,[7,8] whereas our model allowed for additional switches beyond the first and used conditional probabilities based on treatment history. For example, outcome and transition probabilities are different for patients receiving PD as a first versus second versus third modality. Our model also adds to previous analyses by simulating risk for mortality and infection incorporating treatment history.[24,25] As such, we are able to more accurately describe the costs associated with kidney failure requiring dialysis treatment.

Using historical data from CORR, our model showed that patients selected for treatment with PD had a more favorable cost-utility ratio relative to those selected to receive treatment with facility-based HD, likely because these patients are often younger and have a lower burden of comorbid conditions.[26] This assessment aligns with that of a 2017 report released by CADTH that described the greater cost-effectiveness of home PD given current patient characteristics.[16] Previous literature has shown that home PD as an initial dialysis therapy is a more or equally efficacious modality relative to facility-based HD.[23] The relative cost-effectiveness of the 2 therapies remains an important question for many systems, particularly given that with a cost-utility ratio between $80,000 and $100,000/QALY, both modalities approach the upper end of the World Health Organization's recommended willingness-to-pay threshold of between 1 and 3 times gross domestic product per capita.

There are important potential applications of this economic model. Because our model contains transition probabilities that track a patient's dialysis-related treatment history, we believe that it can be applied to more accurately describe the economic outcomes associated with scenarios in which the initial dialysis modality mix or costing inputs are altered. These scenarios could result in patients starting with home PD who would have characteristics different from patients who have historically initiated with this modality, such as a higher burden of comorbid conditions, older age, or other characteristics that have precluded the adoption of home therapy. For example, outcomes could be estimated by considering patients with similar characteristics to those who begin suboptimally with facility dialysis for initiation of PD and evaluating the model

Table 5. Quality-Adjusted Life-Years per Patient (first-order Monte Carlo simulation)

Modality	1 Year	2 Year	3 Year	5 Year	10 Year
HD, mean ± SD	0.66 ± 0.11	1.2 ± 0.33	1.65 ± 0.57	2.32 ± 1.06	3.25 ± 2.03
25%	$0.69	$1.35	$1.38	$1.38	$1.38
50%	$0.69	$1.35	$1.98	$3.03	$3.03
75%	$0.69	$1.35	$1.98	$3.15	$5.62
PD, mean ± SD	0.68 ± 0.08	1.27 ± 0.25	1.78 ± 0.48	2.58 ± 0.96	3.86 ± 2.07
25%	$0.69	$1.35	$1.90	$1.90	$1.90
50%	$0.69	$1.35	$1.98	$3.15	$4.10
75%	$0.69	$1.35	$1.98	$3.15	$5.66
All, mean ± SD	0.66 ± 0.1	1.22 ± 0.31	1.68 ± 0.55	2.38 ± 1.04	3.38 ± 2.05
25%	$0.69	$1.35	$1.49	$1.49	$1.49
50%	$0.69	$1.35	$1.98	$3.15	$3.17
75%	$0.69	$1.35	$1.98	$3.15	$5.62

Abbreviations: All, all dialysis starts; HD, hemodialysis starts, PD, peritoneal dialysis starts; SD, standard deviation.

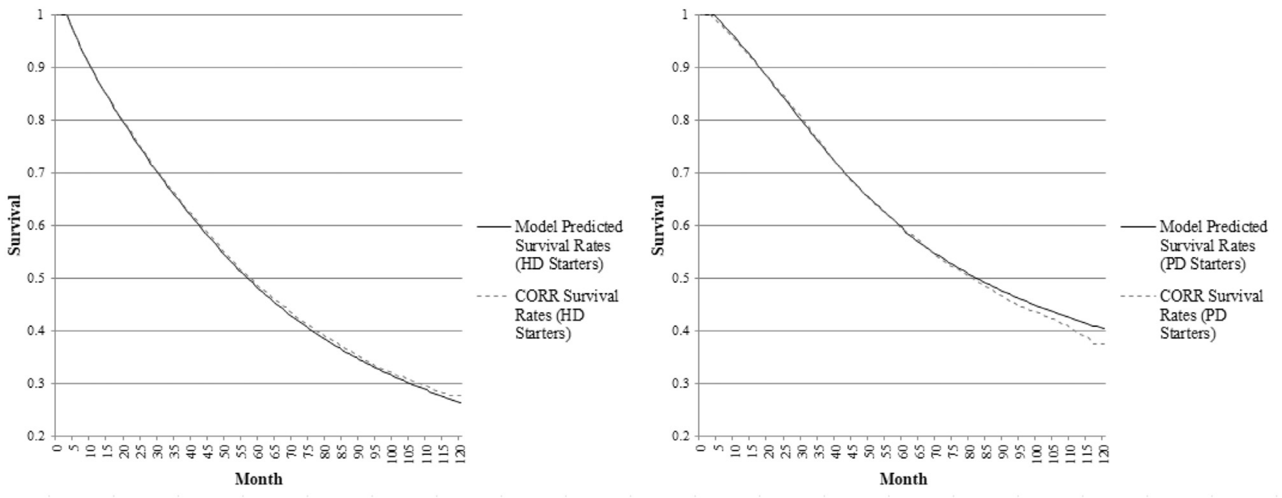
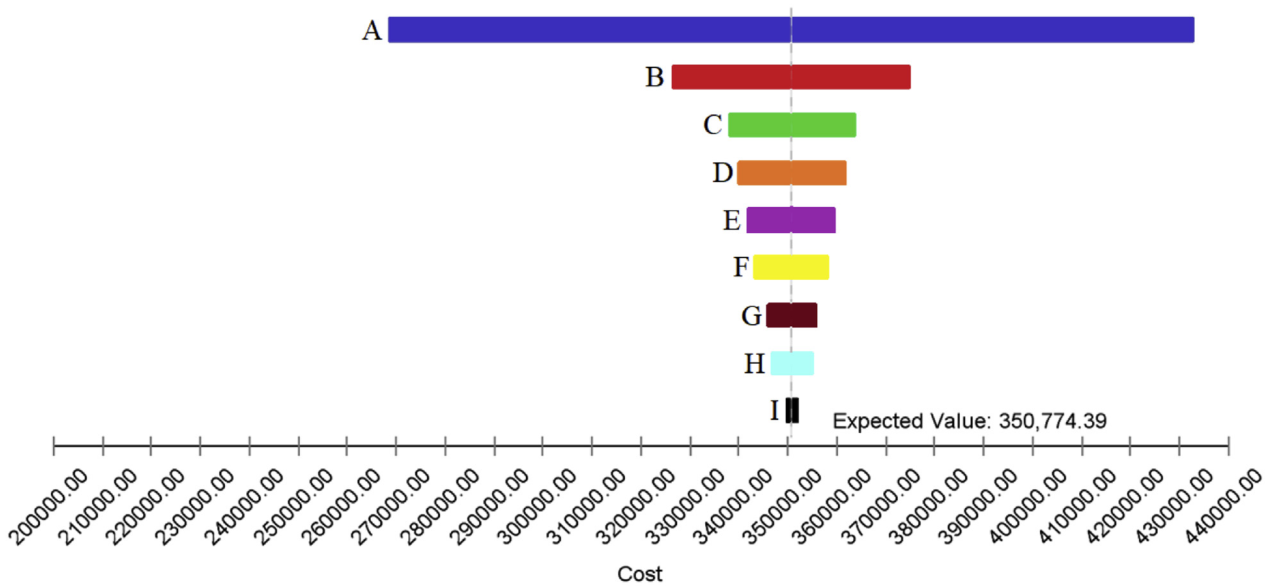


Figure 1. The 10-year model predicted survival versus observed survival for hemodialysis (HD) and peritoneal dialysis (PD) starters. Abbreviation: CORR, Canadian Organ Replacement Register.



Code	Variable Description	Value (Low)	Value (High)	Spread
A	Cost of in-centre HD (annual)	$268,532.14	$433,016.63	$164,484.49
B	Cost of all-cause hospitalization	$326,502.95	$375,045.82	$48,542.87
C	Cost of physician reimbursement (annual)	$337,887.13	$363,661.65	$25,774.52
D	Cost of CCPD (annual)	$339,712.83	$362,049.24	$22,336.41
E	Cost of HD access (annual)	$341,845.16	$359,703.61	$17,858.45
F	Cost of transplant maintenance (360 days to end)	$343,356.29	$358,192.48	$14,836.18
G	Cost of CV-related hospitalization	$345,675.27	$355,873.50	$10,198.23
H	Cost of CAPD (annual)	$346,371.73	$355,272.06	$8,900.32
I	Capital cost (home)	$349,417.38	$352,131.39	$2,714.02

CCPD - Continuous cycling peritoneal dialysis, CV - Cardiovascular, PD - Peritoneal dialysis starts, CAPD - Continuous Ambulatory PD

Figure 2. Univariate sensitivity analysis: lifetime cost for all dialysis patients. Abbreviations: CAPD, continuous ambulatory peritoneal dialysis; CCPD, continuous cycling peritoneal dialysis; CV, cardiovascular; HD, hemodialysis.

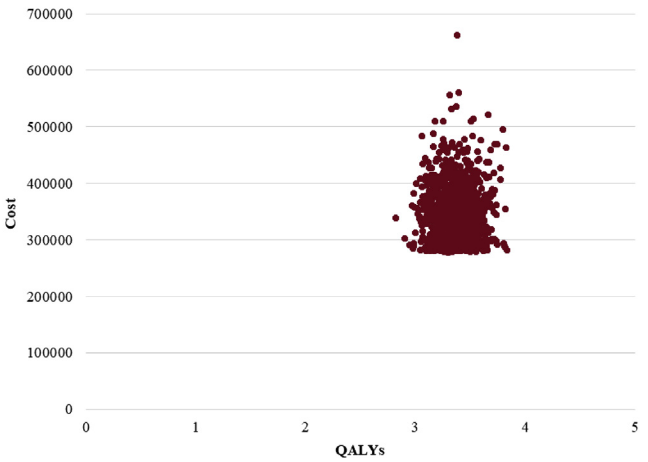


Figure 3. Probabilistic sensitivity analysis: costs and quality-adjusted life-years (QALYs) for all dialysis patients.

for uncertainty using threshold analysis on adverse events (eg, an increase in infection rates).

Our model has several strengths. Using data from CORR, we were able to capture all facility-based HD and home PD starts between 2004 and 2013 (n = 39,318) and their subsequent modality transitions (>100,000). As such, the survival and modality transition states in our model are internally valid for the entire Canadian dialysis population (excluding Quebec). In addition, our model addresses limitations of Markov decision models by including time on treatment and treatment history in deriving states and associated transition probabilities.[25]

There are limitations to our model. Due to small sample sizes in uncommon pathways (eg, initiating HHD as a first therapy or >3 modality switches), we were unable to completely account for rare patient trajectories. However, the model was able to account for ∼98% of all patients and model validation demonstrated excellent agreement with crude survival and modality mix over time. Participation in assisted home dialysis programs and the intensity of care provided were not ascertainable using CORR data and as such it was not accounted for in our model. We assumed no difference in costs between satellite dialysis units and tertiary care center units; although these units may be more cost-effective in densely populated urban settings,[27] there are often extra costs for patients receiving treatment in rural and/or remote locations.[28] In addition, our model did not consider indirect societal costs, such as transportation, productivity, and employment, considerations for caregivers, and utilities (eg, heat and water) for home dialysis patients, which are considerable even in the universal payer context in Canada.[29] Last, in future interpretations of the findings from the model, it is important to consider whether underlying assumptions have changed over time that may reflect results (eg, prices of drugs and the composition of the kidney failure population), and these changes would need to be accounted for by adjusting model inputs to derive new estimates.

In conclusion, we have developed a model that accurately simulates the costs and utilities of initiating dialysis for an incident kidney failure population during a 10-year time horizon. This model presents a health policy tool that can be used to inform system-wide policy decisions regarding the assignment of dialysis modalities.

SUPPLEMENTARY MATERIAL

Supplementary File (PDF)

Figure S1: Model Diagram

Figure S2: Probabilistic Sensitivity Analysis – Costs and QALYs for HD Starters

Figure S3: Probabilistic Sensitivity Analysis – Costs and QALYs for PD Starters

Item S1: *ICD-10-CA* Codes Used to Identify Infection Events

Item S2: Calculation of Monthly Probabilities

Table S1: Annual Consumer Price Index (CPI) – Canada

Table S2: Probability of Infection Requiring Hospitalization per Model Cycle and Dialysis Modality Pathway

Table S3: Renal Replacement Pathway Trajectories: HD Starters

Table S4: Renal Replacement Pathway Trajectories: PD Starters

Table S5: Monthly Transition Probabilities – HD Starters

Table S6: Monthly Transition Probabilities – PD Starters

Table S7: Proportion of Patients Receiving CCPD (vs CAPD) for Patients Receiving Peritoneal Dialysis

Table S8: Proportion of Patients Receiving Satellite Dialysis vs Tertiary Care Center-Based Dialysis for Patients Receiving Facility-Based Hemodialysis

Table S9: Predicted Survival in CORR and Pathway Simulation Model – HD

Table S10: Predicted Survival in CORR and Pathway Simulation Model – PD

Table S11: Modality Mix Over Time by Initial Modality

Table S12: Univariate Sensitivity Analysis - Lifetime Cost for HD Starters

Table S13: Univariate Sensitivity Analysis - Lifetime Cost for PD Starters

Table S14: Probabilistic Sensitivity Analysis – Costs and QALYs Results

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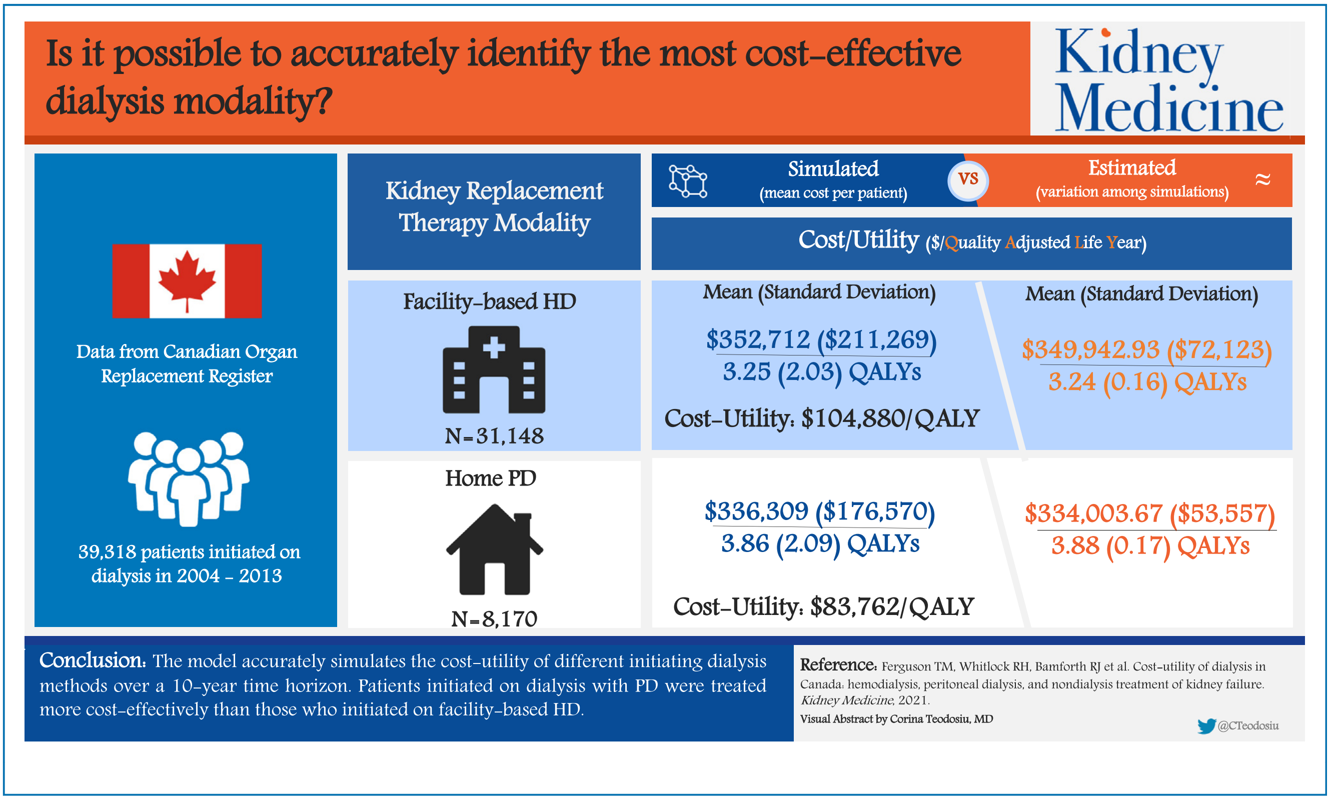
Is it possible to accurately identify the most cost-effective dialysis modality?
Kidney Medicine
Data from Canadian Organ Replacement Register
39,318 patients initiated on dialysis in 2004 - 2013
Kidney Replacement Therapy Modality
Simulated (mean cost per patient)
VS
Estimated (variation among simulations)
≈
Cost/Utility ($/Quality Adjusted Life Year)
Facility-based HD
N=31,148
Mean (Standard Deviation)
$352,712 ($211,269)
3.25 (2.03) QALYs
Cost-Utility: $104,880/QALY
Mean (Standard Deviation)
$349,942.93 ($72,123)
3.24 (0.16) QALYs
Home PD
N=8,170
$336,309 ($176,570)
3.86 (2.09) QALYs
Cost-Utility: $83,762/QALY
$334,003.67 ($53,557)
3.88 (0.17) QALYs
Conclusion: The model accurately simulates the cost-utility of different initiating dialysis methods over a 10-year time horizon. Patients initiated on dialysis with PD were treated more cost-effectively than those who initiated on facility-based HD.
Reference: Ferguson TM, Whitlock RH, Bamforth RJ et al. Cost-utility of dialysis in Canada: hemodialysis, peritoneal dialysis, and nondialysis treatment of kidney failure. Kidney Medicine, 2021.
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