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Expanding Access to High KDPI Kidney Transplant for Recipients Aged 60 y and Older: Cost Utility and Survival

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Background. Modern organ allocation systems are tasked with equitably maximizing the utility of transplanted organs. Increasing the use of deceased donor organs at risk of discard may be a cost-effective strategy to improve overall transplant benefit. We determined the survival implications and cost utility of increasing the use of marginal kidneys in an older adult Canadian population of patients with end-stage kidney disease. **Methods.** We constructed a cost-utility model with microsimulation from the perspective of the Canadian single-payer health system for incident transplant waitlisted patients aged 60 y and older. A kidney donor profile index score of ≥86 was considered a marginal kidney. Donor- and recipient-level characteristics encompassed in the kidney donor profile index and estimated posttransplant survival scores were used to derive survival posttransplant. Patients were followed up for 10 y from the date of waitlist initiation. Our analysis compared the routine use of marginal kidneys (marginal kidney scenario) with the current practice of limited use (status quo scenario). **Results.** The 10-y mean cost and quality-adjusted life-years per patient in the marginal kidney scenario were estimated at $379 485.33 (SD: $156 872.49) and 4.77 (SD: 1.87). In the status quo scenario, the mean cost and quality-adjusted life-years per patient were $402 937.68 (SD: $168 508.85) and 4.37 (SD: 1.87); thus, the intervention was considered dominant. At 10 y, 62.8% and 57.0% of the respective cohorts in the marginal kidney and status quo scenarios remained alive. **Conclusions.** Increasing the use of marginal kidneys in patients with end-stage kidney disease aged 60 y and older may offer cost savings, improved quality of life, and greater patient survival in comparison with usual care.

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Modern organ allocation systems combine donor and recipient characteristics to maximize transplant benefit, balancing justice with utility.[1] The kidney donor profile index (KDPI) is a predictor of graft failure and other outcomes, including delayed graft function,[2,3] whereas survival after transplant is predicted with the estimated posttransplant survival (EPTS) score. In the United States, the Organ Procurement and Transplantation Network uses KDPI and EPTS scores to facilitate longevity matching in organ allocation such that patients expected to survive longer (low EPTS) receive higher priority for better quality (low KDPI) organs.[4]

Expanding the donor pool to increase the number of transplantable kidneys is foundational to reducing the organ shortage[5,6] and is an especially timely goal because transplant programs address the backlog created by the interruption of services from the COVID-19 pandemic.[7,8] A seminal study using the 2008–2015 United Network for Organ Sharing data examined the outcomes of waitlisted patients who received deceased donor kidney offers that were declined and subsequently transplanted to a lower-priority recipient. An average of 10 waitlisted patients died each day, and those who died had received a median of 16 offers (declined: 92.6% for donor quality by transplant programs and 2.6% for patient-related factors).[9] The risks of waiting for a better offer are amplified in older patients such that the time to the equivalent risk of transplant compared with death/waitlist removal is only

41 mo for those aged 65–69 y.[10] There is growing evidence that longevity matching marginal donors (high KDPI) to older recipients (high EPTS) offers improved survival compared with remaining on the waitlist in hopes of a better offer.[11-13] However, outside the Eurotransplant Senior Program this longevity matching is predominantly a transplant program practice and not organ allocation policy.[14-16]

US data show high KDPI transplants cost 12.2% less per quality-adjusted life-years (QALYs) than dialysis, suggesting that this is a dominant strategy.[17] However, high KDPI transplant cost-effectiveness data are lacking outside the United States and would be helpful to inform organ allocation policy revision in a single-payer health system. Therefore, the purpose of this study was to describe the survival implications and cost utility of increasing the use of high KDPI kidneys in an older adult population of patients with end-stage kidney disease (ESKD) from a Canadian provincial transplant program. Our goal was to create a transparent cost-utility model that could inform the allocation of high KDPI kidneys in other countries and health systems.

MATERIALS AND METHODS

Population and Health System

Manitoba is the fifth largest Canadian province with a population of approximately 1.3 million citizens.[18] Manitoba has the highest rate of ESKD in Canada, estimated at 1,703 per million population, and has a universal healthcare system, which is both provincially and federally administered.[19,20] Northern rural regions of Manitoba are exceedingly burdened by ESKD, with rates being estimated to be 3-fold higher than other regions in the Canadian province.[21] With respect to treatment mix, Manitoba has among the lowest proportion of patients receiving kidney transplants in Canada, resulting in the highest utilization of dialysis countrywide.[19] Providing in-center dialysis therapy for patients with kidney failure imposes a high cost burden on the provincial healthcare system, exceeding $200 000 per patient per year in certain rural and remote regions of Manitoba[22] with the comparable treatment in an urban setting costing approximately $64 000.[23]

Model Overview

A decision-analytic Markov model using microsimulation with TreeAge Pro 2022 (Williamstown, MA) was developed from the perspective of the Canadian health payer, following published economic evaluations in healthcare guidelines.[24,25] Our model simulated 584 patients, mirroring the waitlist population of patients aged 60 y and older in Manitoba from January 2010 to November 2020. Primary model outcomes included mean costs (in 2022 Canadian dollars) and utility (QALYs) per patient, the incremental cost-effectiveness ratio (ICER) between the intervention and usual care, overall cohort survival, and mean patient survival between marginal kidney recipients and transplant-naive patients in months. The status quo scenario (usual care) follows provincial allocation guidelines being that kidneys with a KDPI <20 are never allocated to those aged 60 y and older and with a KDPI of ≥85 are routinely discarded and only used in exceptional circumstances. Comparatively, the marginal kidney scenario (intervention) follows the same allocation practices for kidneys with a KDPI of <20 but assumes routine acceptance of high KDPI transplants to recipients aged 60 y and older. Our model considered a 10-y time horizon (120 monthly cycles) and discounted all future costs and utilities at 5%.[24]

Patients transitioned through various health states included in the model: on the waitlist, death on the waitlist, transplant-ineligible, on transplant (KDPI groupings: ≥86, 60–85, 36–59, and 20–35), surviving posttransplant with functioning graft, death-censored graft failure, permanent dialysis, and death. Primary model inputs included patient waiting time, transplant ineligibility, mortality, and death-censored graft failure rates associated with patients aged 60 y and older. Waiting times were incorporated with a modifiable variable for ease of interchangeability, reflecting changes in organ supply and organ acceptance rate. Transplant ineligibility was determined whether the patient was coded as "ineligible," "moved," "no interest," or "unknown" as their most recent status. Transplant-naive patients were those who never received a kidney transplant within the duration of the model (eg, patients who remain on the waitlist throughout the full model duration, patients who transition to death before receiving a transplant, and who become ineligible before receiving a transplant). This model used a half-cycle correction to account for the overestimation of state membership as patients ultimately transition from state to state at different times within cycles. An overview of each model section is shown in Figure 1.

Model Inputs

Five-year posttransplant survival benefits by EPTS/KDPI combination (KDPI grouped: ≥86, 85–60, 59–36, and 35–20) compared with remaining on the waitlist were determined by using an online tool developed by the Epidemiology Research Group for Organ Transplantation at the John Hopkins School of Medicine and are based on US data (**Item S1, SDC,** http://links.lww.com/TXD/A646).[26] Because 10-y survival benefits were publicly unavailable, a life table approach incorporating relative survival estimates of patients after first deceased donor kidney transplant compared with those who have never received a kidney transplant, by age group, was used to determine patient survival after 60 mo posttransplant (**Item S2, SDC,** http://links.lww.com/TXD/A646).[27,28]

Data sourced from Transplant Manitoba was used to derive the probabilities of the following events: death on the waitlist pretransplant, becoming ineligible for a transplant and receiving a transplant.[29] The probability of death, once patients transition to permanent dialysis because of ineligibility, was assumed to be that of the national Canadian dialysis population (**Item S3, SDC,** http://links.lww.com/TXD/A646).[30] The rate of death-censored graft failure (KDPI groupings <85 and ≥86) was sourced from the literature.[17] Death after death-censored graft failure was derived by applying a hazard ratio to waitlist mortality rates.[29,31]

The probability of receiving a transplant in the marginal kidney scenario was proportionately increased by the factor in which the supply of kidneys with a KDPI of 86–100 increased. The increase in kidney supply was based on the number of kidneys that declined for transplant because of their quality, with a KDPI of 86–100 in the years 2018–2020 in Manitoba.[29,32] Within this pool, all were from donations after circulatory death. The distribution of KDPI scores for available donor organs in the status quo scenario was derived from KDPI scores of transplanted kidneys in Manitoba.[29] The

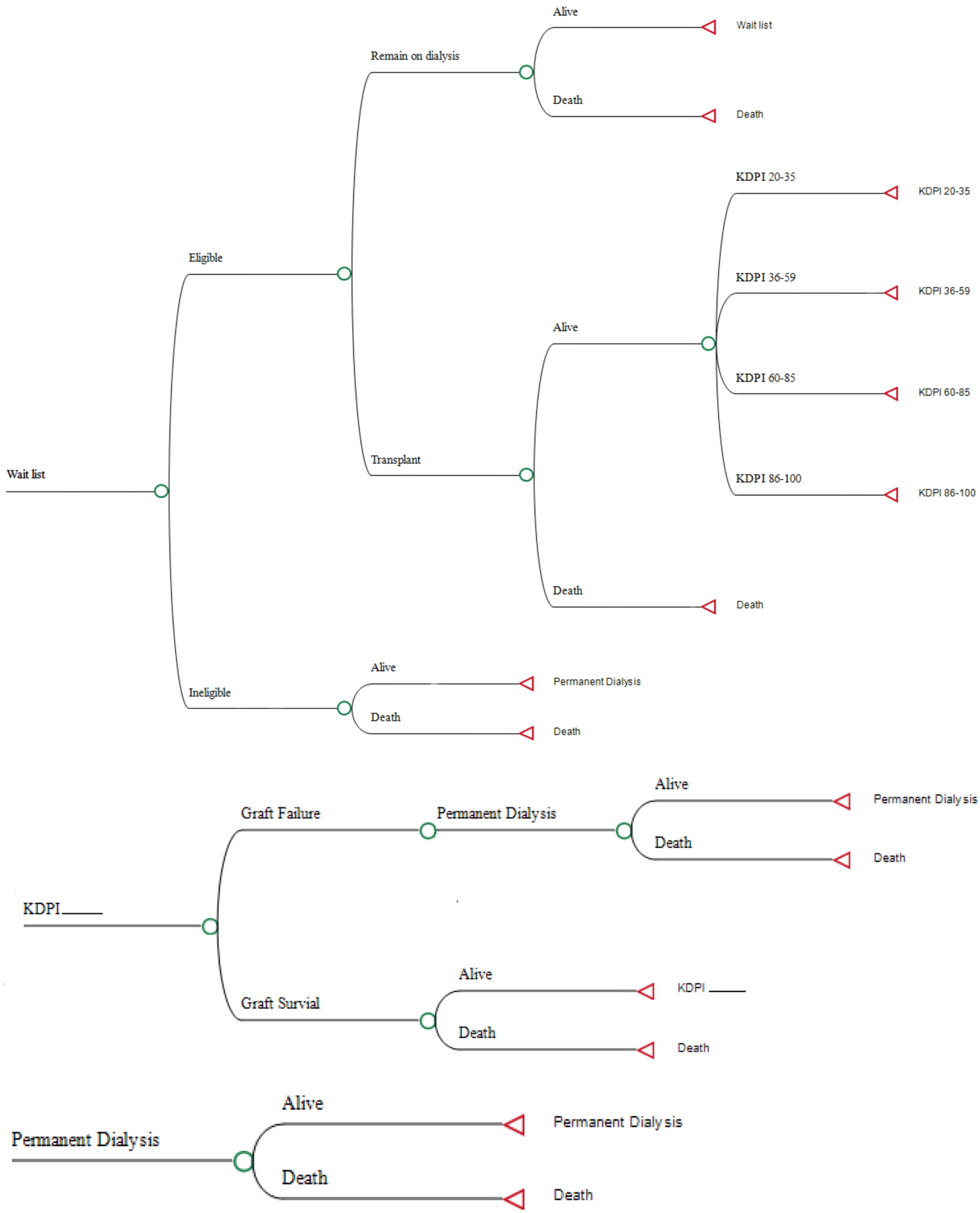

FIGURE 1. Model overview. KDPI, kidney donor profile index.

KDPI distribution in the marginal kidney scenario was derived by adding the additional marginal kidneys available for transplant to this distribution.[12,32] Unless otherwise specified, the analysis assumed a 100% marginal kidney acceptance rate at both the clinician and patient levels. Graphical representations of the KDPI distribution for the original and new kidney supplies are shown in Items S4 and S5 (**SDC,** http://links.lww.com/TXD/A646).

Regarding EPTS inputs, a Canadian study was used to create the distribution of diabetes diagnoses (yes or no) in the waitlist population.[33] Candidate time on dialysis before entering the model was assumed to be 0 mo. Candidate age entering the model was assumed to be 60, based on data demonstrating the benefit in recipients aged 60 y and older.[13] Candidate age was then tracked by month within the model. All rates were converted into monthly probabilities, taking into consideration their respective timeframe differences. Utility estimates (as measured in QALY weights) for dialysis and transplant patients were sourced from a systematic review.[34] An assumption was made that kidney transplants yield the same baseline utility scores regardless of KDPI rating.

Costs

Annual dialysis costs were sourced from a recently published study conducted from the perspective of the public payer.[23] This study considered costs related to dialysis care, such as labor, supplies, equipment, dialysis-specific pharmaceuticals, overhead, initial patient training, and capital costs, which were split out by modality (in-center hemodialysis, home hemodialysis, and peritoneal dialysis).[23] A blended approach taking into consideration both program-specific dialysis modality mix[35] and modality-specific costs to determine the average cost of dialysis per patient. Recipient transplant costs related to outpatient care, diagnostic imaging, inpatient care, physician claims, and laboratory tests were drawn from a Canada-specific study.[36] The cost of organ procurement was sourced from the 2023 interprovincial billing rates for designated high-cost transplants of the Interprovincial Health Insurance Agreements Coordinating Committee in Canada.[37] This encompasses all costs related to acquisition, storage, shipment, and maintenance of the organ as well as hospital and medical costs of the donor.[37] Transplant-related medication costs are specific to the local transplant program.[38] Costs were converted to 2022 Canadian dollars (CAD) using the Canadian Consumer Price Index (**Item S6, SDC,** http://links.lww.com/TXD/A646).[39,40] All model inputs and costs are located in Table 1.

Sensitivity and Scenario Analyses

Univariate sensitivity analysis was performed on main cost parameters by varying their estimates by ±25% from baseline to determine their individual impact on the costs. Waiting times varied by altering the percentage of marginal kidneys accepted for transplant (100%, 75%, 50%, and 25%) to evaluate the new cost and QALY estimates. Deterministic and probabilistic sensitivity analysis (first- and second-order Monte Carlo simulation) were performed concurrently on 584 random first-order Monte Carlo trials on 100 different samples to estimate the variation among individual expected lifetime costs and effectiveness and parameter uncertainty. Finally, mean cost and effectiveness estimates for marginal kidney recipients and transplant-naive patients in the marginal kidney scenario were estimated in scenario analysis.

Guidelines

Our analysis follows the Consolidated Health Economic Evaluation Reporting Standards 2022 (CHEERS 2022) statement.[25] The checklist is provided in Item S10 (**SDC,** http://links.lww.com/TXD/A646). Ethical approval for this proposed project was obtained from the University of Manitoba Research Ethics Board (Ethics No. HS23415 [H2019:344]).

RESULTS

Internal Validation

Model predictions for the number of patients on the waitlist becoming ineligible for a transplant, the number of transplants performed, and deaths on the waitlist were all in close agreement with the observed rates found in Transplant Manitoba data during a 10-y period (Table 2).

Costs

Total mean (SD) and associated 25%, 50%, and 75% percentile costs at 1, 2, 3, 5, and 10 y for 60-y-old incident kidney transplant waitlist patients are summarized in Table 3. During 10 y, the total mean cost per patient in the status quo scenario was estimated at $402 937.68 (SD: $168 508.85). In the marginal kidney scenario, the total mean cost per patient during 10 y was $379 485.33 (SD: $156 872.49), representing a $23 452.35 reduction in cost per patient in comparison with the status quo scenario.

Quality of Life

Table 4 outlines 1, 2, 3, 5, and 10 y mean (SD) and associated 25%, 50%, and 75% percentile QALY estimates per patient by scenario. During 10 y, the mean QALYs per patient in the status quo and marginal kidney scenarios were 4.37 (SD: 1.81) and 4.77 (SD: 1.87), representing a difference of 0.4 QALYs per patient in favor of the marginal kidney scenario.

Cost Utility

During a 10-y time horizon, the mean cost-utility ratio in the status quo and marginal kidney scenarios were $92 205.42 and $79 556.67 per waitlisted patient. The difference in cost-utility ratios between the status quo and marginal kidney scenarios was $12 648.75 per QALY in favor of the marginal kidney scenario. The ICER between the 2 scenarios indicated that the new intervention was dominant in comparison with the usual care scenario. The full results are presented in Table 5.

Survival

Patient survival rates by scenario are presented in Figure 2. Overall, 57.0% of the incident waitlisted patients survived for 10 y in the status quo scenario. In the marginal kidney scenario, 62.8% of the incident waitlisted patients survived for 10 y, representing a difference of 5.8%. As per Table 6, patients who received a marginal kidney in the marginal kidney scenario survived 114.71 mo on average. In comparison, mean survival in months for patients who never received a transplant (including patients who remain on the waitlist throughout the full model duration, patients who transition to death before receiving a transplant, and who become ineligible before receiving a transplant) was 74.07 mo on, representing a difference of 40.64 mo between these subsets of patients.

Sensitivity and Scenario Analyses

Deterministic and probabilistic sensitivity analysis yielded a mean 10-y cost per patient in the status quo scenario of $411 858.75 (SD: $82 889.13), with QALYs during the same time period of 4.38 (SD: 0.20). In the marginal kidney

TABLE 1.

Model inputs

Variable	Point estimate	Distribution	Source
Recipient EPTS score			
Diagnosis of diabetes	0.937	–	Arora et al[33]
Candidate time on dialysis	Enter model at 0	–	Assumption + model dependent
Prior organ transplants	0	–	Assumption
Candidate age	60	–	Assumption/model determined
Monthly dialysis costs			
Peritoneal dialysis, month 1 (2016 CAD)	$10 378.50	Gamma–alpha: 16, beta: 0.00154	Beaudry et al[23]
Peritoneal dialysis, month 2 + (2016 CAD)	$3221.50	Gamma–alpha: 16, beta: 0.00497	Beaudry et al[23]
Home hemodialysis, month 1 (2016 CAD)	$15 459.17	Gamma–alpha: 16, beta: 0.00104	Beaudry et al[23]
Home hemodialysis, month 2 + (2016 CAD)	$3269.67	Gamma–alpha: 16, beta: 0.00489	Beaudry et al[23]
In-center hemodialysis, month 1 + (2016 CAD)	$5351.17	Gamma–alpha: 16, beta: 0.00299	Beaudry et al[23]
Dialysis modality proportions			
Peritoneal dialysis	14.70%	–	Manitoba Renal Program[35]
Home hemodialysis	7.00%	–	Manitoba Renal Program[35]
In-center hemodialysis	78.30%	–	Manitoba Renal Program[35]
Recipient related transplant costs			
Labs, year 1 (2008 CAD)	$5292.00	Gamma–alpha: 89.00, beta: 0.0168	Barnieh et al[36]
Labs, year 2 + (2008 CAD)	$1759.00	Gamma–alpha: 110.80, beta: 0.063	Barnieh et al[36]
Diagnostic imaging, year 1 (2008 CAD)	$285.00	Gamma–alpha: 89.00, beta: 0.0373	Barnieh et al[36]
Diagnostic imaging, year 2 + (2008 CAD)	$712.00	Gamma–alpha: 110.80, beta: 0.1556	Barnieh et al[36]
Physician services, year 1 (2008 CAD)	$6330.00	Gamma–alpha: 89.00, beta: 0.0141	Barnieh et al[36]
Physician services, year 2 + (2008 CAD)	$2049.00	Gamma–alpha: 110.80, beta: 0.0541	Barnieh et al[36]
Inpatient services, year 1 (2008 CAD)	$32 005.00	Gamma–alpha: 89.00, beta: 0.0028	Barnieh et al[36]
Inpatient services, year 2 + (2008 CAD)	$3344.00	Gamma–alpha: 110.80, beta: 0.0331	Barnieh et al[36]
Outpatient services, year 1 (2008 CAD)	$8647.00	Gamma–alpha: 89.00, beta: 0.0103	Barnieh et al[36]
Outpatient services, year 2 + (2008 CAD)	$4248.00	Gamma–alpha: 110.80, beta: 0.0261	Barnieh et al[36]
Medication, year 1 (2019 CAD)	$10 059.47	Gamma–alpha: 89.00, beta: 0.0088	Transplant Manitoba + McKesson[38]
Medication, year 2 + (2019 CAD)	$33 338.83	Gamma–alpha: 110.80, beta: 0.0332	Transplant Manitoba + McKesson[38]
Donor-related transplant costs			
Organ procurement (April 2023 CAD)	$31 780	–	Interprovincial Health Insurance Agreements Coordinating Committee[37]
Other			
Estimated original and new kidney supply by KDPI	See Items S4 and S5 (**SDC,** http://links.lww.com/TXD/A646)	–	Bae et al[12] + Transplant Manitoba[32]
Model calibrated probability of death on the waitlist	See Item S7 (**SDC,** http://links.lww.com/TXD/A646)	–	Transplant Manitoba[29]
Model calibrated probability ineligible for a transplant	See Item S8 (**SDC,** http://links.lww.com/TXD/A646)	–	Transplant Manitoba[29]
Model calibrated probability of receiving a transplant	See Item S9 (**SDC,** http://links.lww.com/TXD/A646)	–	Transplant Manitoba[29]
Time to death-censored graft failure KDPI ≤85	–	Weibull scale: 0.002616, shape: 0.8666	Axelrod et al[17]
Time to death-censored graft failure KDPI >85	–	Weibull scale: 0.00185948, shape: 1.0776	Axelrod et al[17]
Probability of death posttransplant	See Items S1, S2, and S7 (**SDC,** http://links.lww.com/TXD/A646)	–	Transplant Manitoba[29] + Bae et al[12] and Gondos et al[27] + Arias et al[28]
Probability of death, permanent dialysis because of ineligibility	See Item S3 (**SDC,** http://links.lww.com/TXD/A646)	–	CORR[30]
Probability of death, permanent dialysis after graft failure (hazard ratio applied to waitlist death rates)	1.78	–	Rao et al[31]
Discount rate, costs	0.5	–	CADTH[24]
Discount rate, utilities	0.5	–	CADTH[24]
CPI	See Item S6 (**SDC,** http://links.lww.com/TXD/A646)	–	Statistics Canada[39]
Utility, hemodialysis facility-based	0.71	Normal mean: 0.71, SD: 0.04	Wyld et al[34]
Utility, peritoneal dialysis	0.71	Normal mean: 0.71, SD: 0.04	Wyld et al[34]
Utility, home hemodialysis	0.71	Normal mean: 0.71, SD: 0.04	Wyld et al[34]
Utility, transplant	0.82	Normal mean: 0.82, SD: 0.04	Wyld et al[34]

CAD, Canadian dollar; CADTH, Canadian Agencies for Drugs and Technologies in Health; CORR, Canadian Organ Replacement Registry; CPI, Consumer Price Index; EPTS, estimated posttransplant survival; KDPI, kidney donor profile index.

TABLE 2.

Waitlist validation, transplant Manitoba data vs model output

	Ineligible			Waitlist deaths			Transplants		
Year	Transplant Manitoba data	Model output	Validation	Transplant Manitoba data	Model output	Validation	Transplant Manitoba data	Model output	Validation
1	27	27	100.0%	8	8	100.0%	13	13	100.0%
2	28	28	100.0%	15	15	100.0%	14	14	100.0%
3	28	28	100.0%	10	10	100.0%	11	11	100.0%
4	29	29	100.0%	13	13	100.0%	6	6	100.0%
5	15	15	100.0%	10	10	100.0%	9	9	100.0%
6	9	9	100.0%	9	9	100.0%	13	13	100.0%
7	10	10	100.0%	6	6	100.0%	4	4	100.0%
8	9	9	100.0%	6	6	100.0%	2	2	100.0%
9	7	7	100.0%	0	0	100.0%	2	2	100.0%
10	7	7	100.0%	2	2	100.0%	5	5	100.0%

TABLE 3.

Treatment specific costs per patient (first-order Monte Carlo simulation)

Scenario	1 y	2 y	3 y	5 y	10 y
Status quo					
Mean (SD)	$70 064.06 (6832.84)	$130 797.43 (17 738.47)	$183 514.54 (34 435.36)	$266 512.25 (73 272.11)	$402 937.68 (168 508.85)
Quartile 1	$69 605.38	$133 880.58	$195 095.05	239 413.35	257 277.31
Median	$69 605.38	$133 880.58	$195 095.05	308 917.88	486 966.35
Quartile 3	$69 605.38	$133 880.58	$195 095.05	308 917.88	549 304.86
Marginal kidney					
Mean (SD)	$73 316.30 (12 431.55)	$135 559.58 (21 233.88)	$187 957.88 (37 062.38)	$261 935.41 (72 792.91)	$379 485.33 (156 872.49)
Quartile 1	$69 605.38	$133 880.58	$195 095.05	220 189.99	264 109.83
Median	$69 605.38	$133 880.58	$195 095.05	306 572.43	367 563.42
Quartile 3	$69 605.38	$133 880.58	$197 918.54	308 917.88	549 304.86

TABLE 4.

Quality-adjusted life-years per patient (first-order Monte Carlo simulation)

Scenario	1 y	2 y	3 y	5 y	10 y
Status quo					
Mean (SD)	0.69 (0.04)	1.32 (0.17)	1.87 (0.35)	2.78 (0.76)	4.37 (1.81)
Quartile 1	0.69	1.35	1.98	2.65	2.65
Median	0.69	1.35	1.98	3.15	5.62
Quartile 3	0.69	1.35	1.98	3.15	5.62
Marginal kidney					
Mean (SD)	0.70 (0.05)	1.34 (0.17)	1.92 (0.35)	2.91 (0.78)	4.77 (1.87)
Quartile 1	0.69	1.35	1.98	3.15	3.30
Median	0.69	1.35	1.98	3.15	5.62
Quartile 3	0.69	1.35	2.05	3.38	6.20

scenario, the mean 10-y cost and QALYs were $386 494.89 (SD: $65 304.42) and 4.77 (SD: 0.18) per patient, respectively. The marginal kidney scenario remained dominant in 90% of random samples, with 10% yielding higher mean QALYs and costs in comparison with the status quo scenario. All samples were within a willingness-to-pay threshold of $100 000 CAD. Mean and 25%, 50%, and 75% percentile results by scenario can be found in Table 7, with graphical results shown in Figure 3.

In univariate sensitivity analyses, the most influential cost parameter in both scenarios was identified as the monthly cost of dialysis. Altering the monthly cost of dialysis by ±25% varied the 10-y mean cost of care by ±$95 532.71 (spread = $191 065.42) in the status quo scenario and by ±$75 785.13 (spread = $151 570.28) in the marginal kidney scenario. The 10-y mean cost of care per patient in the marginal kidney scenario remained below that in the status quo scenario in all univariate sensitivity analyses performed. Full results are shown in Table 8, with graphical results represented in Figures 4 and 5.

During 10 y, the mean cost and QALYs for transplant-naive patients in the marginal kidney scenario were $353 966.35 and 3.63, respectively. Comparatively, for marginal kidney recipients, the mean cost and QALYs were $411 112.67

TABLE 5.

Cost per quality-adjusted life-years per patient (first-order Monte Carlo simulation)

Scenario	1 y	2 y	3 y	5 y	10 y
Status quo					
Mean	$101 542.12	$99 088.96	$98 136.12	$95 867.72	$92 205.42
Quartile 1	$100 877.36	$99 170.80	$98 532.85	$90 344.66	$97 085.78
Median	$100 877.36	$99 170.80	$98 532.85	$98 069.17	$86 648.82
Quartile 3	$100 877.36	$99 170.80	$98 532.85	$98 069.17	$97 741.08
Marginal kidney					
Mean	$104 737.57	$101 163.87	$97 894.73	$90 012.17	$79 556.67
Quartile 1	$100 877.36	$99 170.80	$98 532.85	$69 901.58	$80 033.28
Median	$100 877.36	$99 170.80	$98 532.85	$97 324.58	$65 402.74
Quartile 3	$100 877.36	$99 170.80	$96 545.63	$91 395.82	$88 597.56

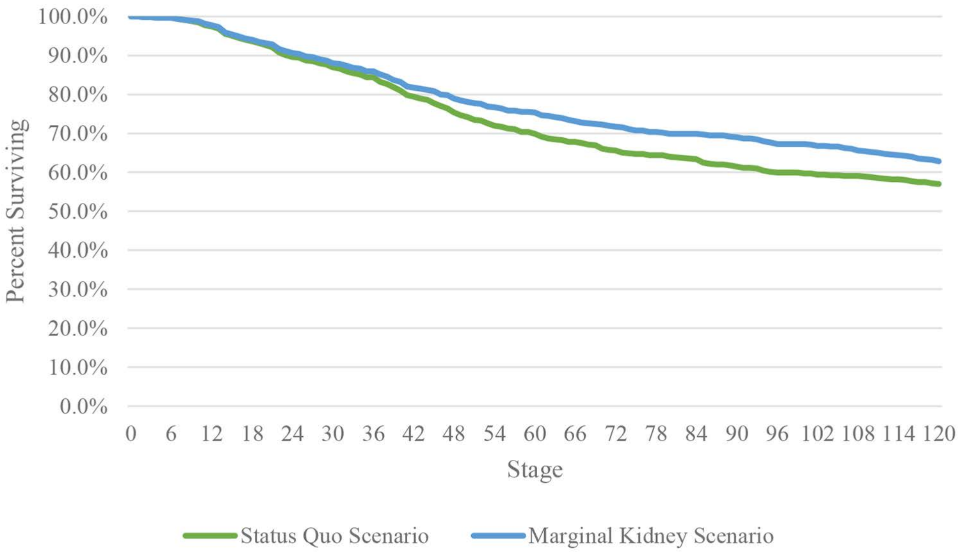

FIGURE 2. Ten-year patient survival by scenario.

TABLE 6.

Ten-year mean survival in months, transplant-naive vs marginal kidney recipients, marginal kidney scenario

Group	Mean survival (mo)
Transplant-naive recipient	74.07
Marginal kidney recipient	114.71

and 5.94, respectively, representing an ICER of $24 738.67 between scenarios. Results are shown in Table 9.

Scenario analysis considering varying levels of marginal kidneys accepted for transplant are in Table 10. When accepting from 75% to 25% of potential kidneys, the mean costs and QALYS ranged from $389 291.33 to $398 662.76, and 4.70 to 4.50, respectively. All scenarios remained dominant in comparison with the status quo scenario.

TABLE 7.

Deterministic and probabilistic sensitivity analysis: costs and QALYs

Scenario	Cost	QALYs
Status quo		
Mean (SD)	$411 858.75 (82 889.13)	4.38 (0.20)
Quartile 1	$348 961.52	4.25
Median	$415 121.99	4.37
Quartile 3	$475 119.31	4.51
Marginal kidney		
Mean (SD)	$386 494.89 (65 304.42)	4.77 (0.18)
Quartile 1	$336 163.09	4.65
Median	$385 390.79	4.75
Quartile 3	$437 539.35	4.88

QALY, quality-adjusted life-year.

DISCUSSION

Using data from a Canadian provincial transplant program, our model demonstrates the cost, utility, and patient survival implications related to increasing the use of high KDPI kidneys. Our results suggest that the marginal kidney scenario is dominant because patients were treated at a lower mean cost and experienced higher mean QALYs during a 10-y time horizon in comparison with the status quo scenario. Additionally, our model estimated that 57.0% and 62.8% of the status quo scenario and marginal kidney scenario cohorts, respectively, would remain living at the end of 10 y. In comparison with transplant-naive patients, our

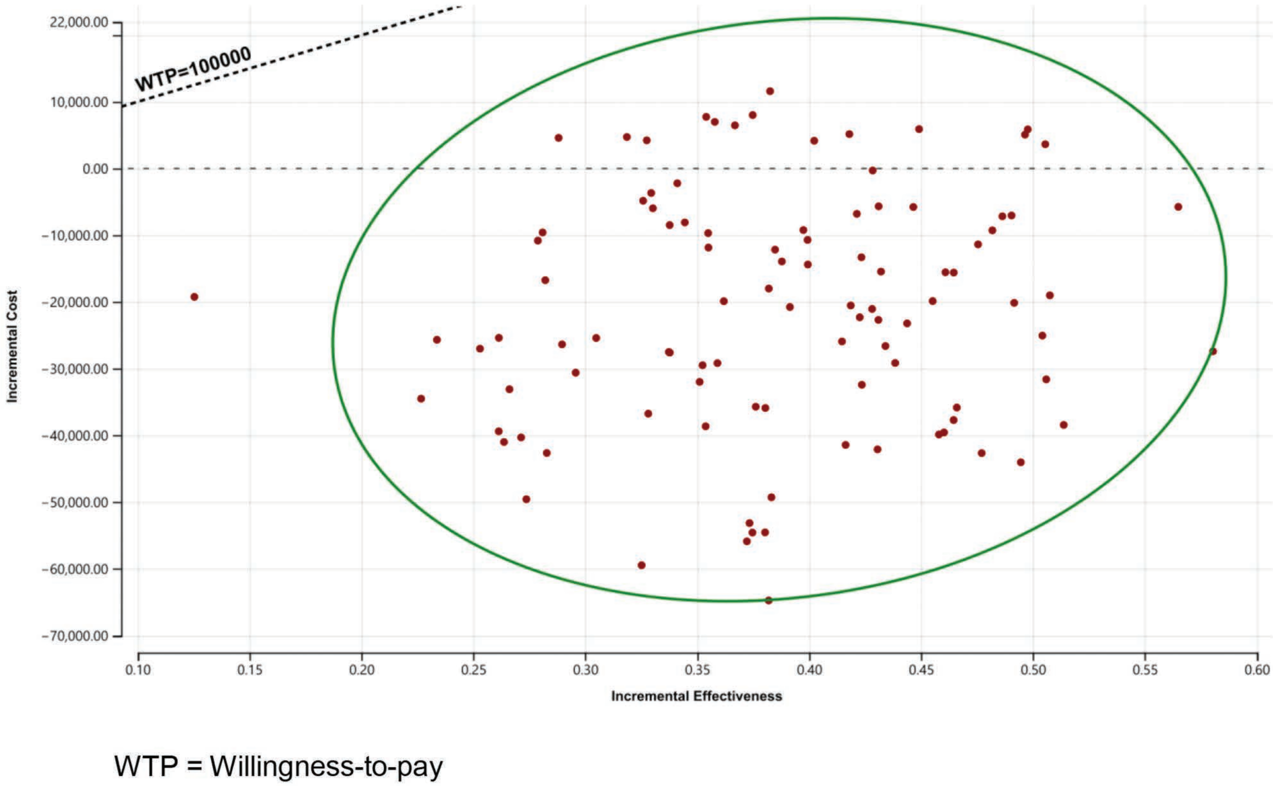

FIGURE 3. Incremental cost-effectiveness, marginal kidney scenario vs the status quo scenario. Each dot represents the results of a simulation, plotting the incremental cost and incremental effectiveness, and the circle represents the 95% confidence interval.

TABLE 8.

Univariate sensitivity analysis: 10-y cost variation by scenario

Scenario	Cost input	Mean cost per scenario	–25%	25%	Spread
Status quo	Dialysis	$402 937.68	$307 404.98	$498 470.39	$95 532.70
	Transplant, recipient all years	$402 937.68	$398 609.10	$407 266.27	$4328.58
	Transplant, recipient year 1	$402 937.68	$400 732.38	$405 142.99	$2205.30
	Transplant, recipient year 2+	$402 937.68	$400 814.40	$405 060.97	$2123.28
	Transplant, donor	$402 937.68	$402 064.56	$403 810.81	$873.12
Marginal kidney	Dialysis	$379 485.33	$303 700.19	$455 270.47	$75 785.14
	Transplant, recipient all years	$379 485.33	$363 639.70	$395 330.96	$15 845.63
	Transplant, recipient year 1	$379 485.33	$371 325.41	$387 645.24	$8159.92
	Transplant, recipient year 2+	$379 485.33	$371 799.62	$387 171.04	$7685.71
	Transplant, donor	$379 485.33	$376 244.76	$382 725.89	$3240.57

model estimated that those who received marginal kidneys on average survived for 40.64 more months (transplant-naive recipient = 74.07 mo versus marginal kidney recipient = 114.71 mo).

Our model represents a comprehensive tool that can describe the associated costs, utility, and survival in older adults (aged 60 y and older) on the kidney transplant waitlist, accounting easily for variation in kidney supply and quality. Furthermore, this model can be easily adapted to fit unique healthcare settings and populations by adjusting parameters and assumptions accordingly. To our knowledge, this is the first study to incorporate both KDPI and EPTS scores to derive the cost utility of marginal kidney uses in a single health-payer (Canadian) setting, which we hope will be useful in informing organ allocation policy revision.

Both marginal kidney and status quo scenarios approach the upper limit of the World Health Organization's recommended willingness-to-pay threshold of between 1× to 3× GDP per capita ($70 000–$100 000/QALY in the current setting); nevertheless, the lower cost-utility ratio in the marginal kidney scenario makes it an attractive policy strategy. These results correspond with other recent research demonstrating that the cost-effectiveness of high KDPI deceased donor transplants is <$100 000 per QALY in the United States.[17]

The cost-neutrality point between scenarios occurs between years 4 and 5 after waitlist initiation, after which the marginal kidney scenario offers reduced costs per patient. This delay is primarily driven by high upfront transplant-related costs, which diminish with time. As preemptive kidney transplantation can offer both improved patient and graft survival in comparison with those who received their donor organ after being on dialysis,[41] facilitating early patient access to deceased donor organs promotes the full realization of the

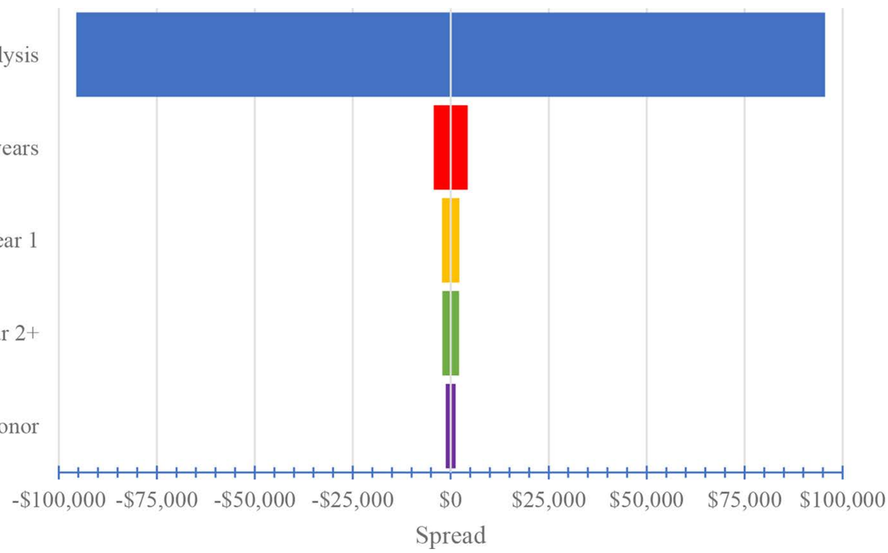

FIGURE 4. Univariate sensitivity analysis: 10-y cost variation, status quo scenario. Each box represents the effect on mean cost per patient when the related cost input is varied by ±25%. The cost input on the y-axis corresponds to the boxes positioned in line in the figure: blue = dialysis; red = transplant, recipient all years; yellow = transplant, recipient year 1; green = transplant, recipient year 2+; purple = transplant, donor.

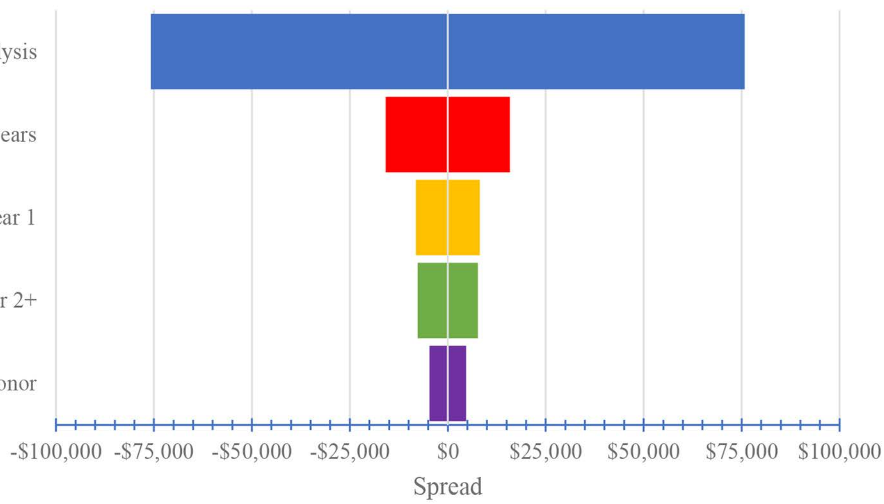

FIGURE 5. Univariate sensitivity analysis: 10-y cost variation, marginal kidney scenario. Each box represents the effect on mean cost per patient when the related cost input is varied by ±25%. The cost input on the y-axis corresponds to the boxes positioned in line in the figure: blue = dialysis; red = transplant, recipient all years; yellow = transplant, recipient year 1; green = transplant, recipient year 2+; purple = transplant, donor.

TABLE 9.

Scenario analysis: 10-y cost and QALYs, transplant-naive vs marginal kidney recipients, and marginal kidney scenario

Group	Mean cost	Mean QALYs	ICER
Transplant-naive recipient	$353 966.35	3.63	$24 738.67
Marginal kidney recipient	$411 112.67	5.94	

ICER, incremental cost-effectiveness ratio; QALY, quality-adjusted life-year.

TABLE 10.

Scenario analysis: mean cost and QALYs by marginal kidney acceptance rate, and marginal kidney scenario

Percent of marginal kidneys accepted	Mean cost	Mean QALYs
100%	$379 485.33	4.77
75%	$389 291.33	4.70
50%	$396 909.03	4.60
25%	$398 662.76	4.50

QALY, quality-adjusted life-year.

cost benefits associated with transplantation because of improved survival.

Our base case assumed a 100% acceptance rate of marginal kidneys both at the clinical and patient level. However, there are many reasons why a donor organ may be declined,[42] and some patients may reject a high KDPI kidney offer, opting to remain on the waitlist in hopes of receiving a higher-quality kidney. Therefore, our sensitivity analyses modeling lower acceptance rates demonstrated that the marginal kidney scenario remained dominant down to an acceptance rate as low as 25%, demonstrating the robustness of our model to variations in acceptance rate.

Univariate sensitivity analysis results indicated that dialysis was the most influential cost parameter in the model. Although the mean cost per patient was lower during 10 y in the marginal kidney scenario when the cost of dialysis was varied by ±25%, the difference between scenarios was significantly more pronounced when it was increased. Although reimbursement schemes vary by program, spending per patient with end-stage renal disease in countries such as the United States is unlikely to fall in the near future because of the marked differences between reimbursement for Medicare and non–Medicare patients coupled with the increased enrollment of non–Medicare patients.[43,44] This contributes to the potential upside risk associated with the marginal kidney scenario from a strictly costing perspective. Transplant-related costs impacted the 10 y mean cost of care marginally compared with the cost of dialysis, highlighting the importance of reducing dialysis use to influence overall costs.

Notably, the KDPI score is based on its relative quality in comparison with kidneys recovered within the previous year.[2] The conclusions drawn from this model may change if unusual or large fluctuations occur with respect to the quality of kidneys recovered within the previous year. Considering changes in the KDPI score relative to previous years is needed when applying this model to forecast healthcare resource use in future scenarios.

The use of KDPI in organ allocation may contribute to high organ discard rates because of a harmful labeling effect.[45,46] One in 5 kidneys procured for donation is discarded, and this number increases to more than half with a KDPI of ≥86%.[5,47] This is a concerning phenomenon, given the growing evidence that high KDPI transplants offer a survival advantage over remaining on the waitlist, particularly for older recipients.[11,12,48] As utility estimates in patients posttransplant are improved in comparison with those on maintenance dialysis (0.82 versus 0.71),[34] this also suggests that high KDPI transplants may offer improved quality of life. The use of all transplantable kidneys is recognized as foundational in reducing the organ shortage[5,6] and is an especially timely goal because transplant programs address the backlog created by the interruption of services from the COVID-19 pandemic.[7,8]

Preemptive kidney transplantation has been shown to offer both improved patient and graft survival in comparison with patients who underwent dialysis before transplant.[41] These benefits may also translate to older patients receiving marginal kidneys (KDPI ≥85) preemptively, with research suggesting a similar risk of graft failure and improved risk of mortality in comparison with waitlisted maintenance dialysis patients who received higher-quality organs (KDPI 35–84).[49] Although our model considers dialysis vintage in the EPTS score calculation, the effects of preemptive transplantation were not directly considered.

There are limitations to this model. As local data were unavailable, probability inputs regarding patient survival posttransplant were derived from existing literature and based on data from the United States.[12] Evidence suggests that patient survival in the first year posttransplant is similar between Canada and the United States yet elevated in the United States beyond that point.[50] As such, our results may be considered conservative. Furthermore, because a life table approach was taken to derive survival probabilities with a functioning graft after 60 mo posttransplant, patient and donor characteristics encompassed in the EPTS and KDPI score were not taken into consideration for those surviving with a functioning graft for >5 y. A main limitation of this model is encompassed in the perspective taken. From the perspective of the public health payer, indirect costs of care, such as patient transportation costs, caregiver costs, and patient opportunity costs, were not considered. Additionally, costs related to adverse events, such as infections, hospitalizations, or those associated with patient modality transitions, were not accounted for. As a relatively lower proportion of waitlist patients in the marginal kidney scenario rely upon dialysis care, these costs may have a larger impact for patients in the status quo scenario. Moreover, our model assumed costs sourced from a Canadian urban dialysis program, which may understate the cost of care in rural and remote locations, which can be up to $215 918 per patient per year.[22] In this model, patients were assumed to accept any kidney offered to them and may not be indicative of real-world circumstances because patients may decline an offer, opting to remain on the waitlist. Nonetheless, our model remained dominant in sensitivity analyses, assuming an acceptance rate as low as 25%. Finally, although our model accurately represents the utility in Manitoba, Canada, its generalizability to other transplant programs is unknown. In jurisdictions with shorter wait times in this model, the comparative attractiveness of using additional high KDPI kidneys may be reduced.

In conclusion, we have developed a model that simulates the cost and utility of care and patient survival for kidney transplant waitlisted adults aged 60 y and older. Our model suggests that the routine use of high KDPI transplants is likely a cost-effective intervention compared with the high discard rates currently seen. Further research is required to determine the effects of blood type, the allowance for multiple transplants, and the effects of preemptive transplants on costs, QALYs, and survival in this patient population.

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