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Cost-effectiveness of Interventions to Increase Utilization of Kidneys From Deceased Donors With Primary Brain Malignancy in an Australian Setting

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Background. Kidneys from potential deceased donors with brain cancer are often foregone due to concerns of cancer transmission risk to recipients. There may be uncertainty around donors' medical history and their absolute transmission risk or risk-averse decision-making among clinicians. However, brain cancer transmissions are rare, and prolonging waiting time for recipients is harmful. **Methods.** We assessed the cost-effectiveness of increasing utilization of potential deceased donors with brain cancer using a Markov model simulation of 1500 patients waitlisted for a kidney transplant, based on linked transplant registry data and with a payer perspective (Australian government). We estimated costs and quality-adjusted life-years (QALYs) for three interventions: decision support for clinicians in assessing donor risk, improved cancer classification accuracy with real-time data-linkage to hospital records and cancer registries, and increased risk tolerance to allow intermediate-risk donors (up to 6.4% potential transmission risk). **Results.** Compared with current practice, decision support provided 0.3% more donors with an average transmission risk of 2%. Real-time data-linkage provided 0.6% more donors (1.1% average transmission risk) and increasing risk tolerance (accepting intermediate-risk 6.4%) provided 2.1% more donors (4.9% average transmission risk). Interventions were dominant (improved QALYs and saved costs) in 78%, 80%, and 87% of simulations, respectively. The largest benefit was from increasing risk tolerance (mean +18.6 QALYs and AU$2.2 million [US$1.6 million] cost-savings). **Conclusions.** Despite the additional risk of cancer transmission, accepting intermediate-risk donors with brain cancer is likely to increase the number of donor kidneys available for transplant, improve patient outcomes, and reduce overall healthcare expenditure.

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Kidney transplantation is the optimal treatment for kidney failure[1-3] and is cost-effective, typically resulting in cost-savings compared with dialysis.[4] However, transplantation rates are limited by the global shortage of organs available for transplant.[3,5] Increasing the pool of donor organs available for transplant is an important objective internationally[6-8] and in Australia.[9]

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The authors confirm that the data supporting the findings of this study are available within the article and its supplementary materials.

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In Australia, potential organ donors are referred to state and territory donor services for detailed medical suitability assessment by a donation specialist. Next-of-kin consent is often sought simultaneously. If organs are considered unsuitable for transplantation (eg, due to the risk of infection or cancer transmission to a recipient), the potential donor may be declined. Primary brain malignancies (PBMs) have a lower transmission risk (<6.4%) than other similar grade cancers.[10-12] Despite this, classification of PBMs is complex and can lead to uncertainty for clinicians deciding whether to proceed with a potential donor. This is particularly challenging if detailed clinical information is lacking in the time-critical setting of donation decision-making. A recent study demonstrated that only 74% of perceived brain cancers among potential donors could be verified as malignant in linked medical records.[13] Furthermore, estimates of PBM transmission risk in clinical practice guidelines[14] are highly variable and based on studies with no observed transmissions.[11,12] These guidelines are similar to those used in the United States,[15] the United Kingdom,[16] and EU[17] and recommend accepting donors with a low risk of transmission (<2%) and permitting donors with an intermediate risk of transmission (6.4%) on a case-by-case basis. A summary of brain cancer transmission risk classifications is presented in **Table S1, SDC**, http://links.lww.com/TXD/A523. However, we know many potential donors with low- and intermediate-risk brain cancers are foregone. A recent study found that in New South Wales (NSW), Australia, 24% of potential deceased donors with a primary brain tumor were declined due to a perceived risk of cancer transmission.[18]

Reducing risk for patients is important but must be balanced against the adverse consequences of prolonging time spent waiting for a transplant. Potential donors with PBM are typically younger and otherwise healthier than other donors[19] and so are excellent organ donation candidates (apart from their PBM). In Australia, data are collected from all potential donors,[20] presenting an ideal opportunity to study donors foregone. It may be unclear how many potential donors with PBM are foregone internationally because reporting typically focuses on actual donors and neglects those who are declined or not contemplated.[21,22] In NSW, the largest state in Australia, 5% of potential donors are declined due to perceived history of PBM. However, only 74% of potential donors reported to have PBM when referred to donation services had corresponding records in the NSW cancer registry. The remaining 26% of these potential donors either never had PBM or had a benign tumor and could have safely donated.[13] These potential missed opportunities for donation may be even higher in the United States, where 1.1% of deceased donors reportedly had a brain tumor at the time of donation but only 44% could be verified in cancer registries.[23]

The potential impact of policies to increase acceptance of donors with cancer has not been explored.[13] A recent systematic review identified economic evaluations surrounding kidney donation and allocation policies.[24] Many such policies have been found to be cost-effective, including developing donation protocols and teams with clearly defined responsibilities within hospitals,[25-27] accepting donation after circulatory death (DCD) donors,[28,29] accepting expanded criteria donors,[30] adopting an opt-out model of consent,[31] and accepting donors with potential hepatitis C infection.[32-34] In this study, we sought to determine the cost-effectiveness of increasing utilization of kidneys from potential deceased donors with PBM in the Australian setting and to explore how individual patients would be impacted.

MATERIALS AND METHODS

Model Structure

We developed a Markov model patient-level simulation, in which individual patients transition between health states (eg, waitlist, transplanted, dead) at discrete time intervals (cycles) with different probabilities under alternative scenarios. Markov models are commonly used in economic evaluations for kidney transplantation[24] to capture important aspects of kidney failure at the cohort level (eg, the proportion of patients receiving a transplant versus remaining on dialysis). We performed a patient-level simulation to additionally capture variability in characteristics and health outcomes among individual patients. We simulated a cohort of 1500 people with kidney failure waiting for a deceased-donor kidney transplant in Australia (the approximate number on the waitlist during 2021[35]). The modeled time-horizon was 25 y to capture outcomes over the lifetime for a typical person with kidney failure,[36] as is widely recommended for economic evaluations.[37] We assumed patients would transition between health states in discrete time intervals of 3 mo, and we applied a half-cycle correction to capture potential transitions within each interval.[38] To account for variability of our results due to randomness, we repeated our simulation 10 000 times ensuring estimated proportions had a 95% confidence interval (CI) of at most ±1%. We adopted a payer perspective (ie, Australian government) and discounted costs and quality-adjusted life-years (QALYs) 5% annually following Australian guidelines for economic evaluations.[38,39] The model was constructed using R software.[40-42] Our economic evaluation followed the consolidated health economic reporting standards (CHEERS).[43] Our cost calculations and R code are available here: https://github.com/james-hedley/PBM_economic_evaluation.

Patient and Donor Characteristics

We simulated characteristics for each patient upon entering the model, which determined their probabilities of transitioning between health states. Patient-level characteristics were age, sex, blood group, number of previous kidney transplants, and number of comorbidities (chronic lung disease, coronary artery disease, peripheral vascular disease, cerebrovascular disease, diabetes, hepatitis C, and history of cancer). If a patient received a kidney transplant, we also simulated donor characteristics: presence of PBM, donor type (living, DCD, donation after brain death [DBD], or DBD expanded criteria[14]), age, sex, and Australian kidney donor profile index.[44]

Distributions of characteristics were informed by data from the Australia and New Zealand Dialysis and Transplant Registry (ANZDATA) and Australia and New Zealand Organ Donor Registry (ANZOD). Data were provided for the Maximising Organ Donor Utility System-wide (MODUS) study,[45] which was approved by the University of Sydney Human Research Ethics Committee (project number 2020/828).

Health States and Transitions

We included five main health states: on waitlist, off waitlist, functioning transplant, transplant (graft) failure,

and death. We separated kidney transplants by donor type (DCD, DBD, or living) and separated all deceased donor transplant patients (functioning and failed) by their cancer status (none, de novo, or donor-transmitted). Because some transmitted cancers may be misattributed to the recipient as de novo, we included all recipient cancer sites in our model, not just transmitted PBMs. The model structure is presented in Figure 1.

Details of how patients transition between health states are provided in **Appendix 1, SDC**, http://links.lww.com/TXD/A523. Briefly, patients entered the model on waitlist and were then either removed due to de novo cancer, received a transplant, or died. Once transplanted, the transplant could fail, or the patient could develop de novo cancer. If they received a kidney from a deceased donor with PBM, there was a chance of cancer transmission. If transmission occurred, the patient would be diagnosed after 9 mo (see **Appendix 1, SDC**, http://links.lww.com/TXD/A523 for explanation), have their kidney removed, and remain in the transplant failure with cancer health state until death. Although it may be possible to treat a transmitted cancer without removing the transplanted kidney, our assumption that all patients would undergo nephrectomy was conservative (ie, favored current practice) and was consistent with available case-reports (**Appendix 1, SDC**, http://links.lww.com/TXD/A523).

Comparators

We considered 3 interventions that have previously been proposed to increase utilization of organs from deceased donors with cancer[13] and compared them with current practice (ie, individual clinicians deciding which potential donors with PBM to accept or decline). Comparators were (1) decision support for clinicians in accurately estimating absolute donor risk for cancer transmission; (2) improved clinical information with greater accuracy through real-time data-linkage to hospital records and cancer registries to improve classification of potential donor cancer type and hence transmission risk; and (3) increased risk tolerance to allow use of donors with intermediate-risk PBM (estimated transmission risk 6.4%).[13,14] More detail about these comparators is provided in **Appendix 2, SDC**, http://links.lww.com/TXD/A523.

Model Inputs

Transition probabilities between health states were based on Australian life tables,[46] Australian Institute for Health and Welfare cancer data,[47] ANZDATA annual reports,[48,49] and time-to-event analysis of ANZDATA and ANZOD data. Utility values (QALY weights) for each health state were based on quality of life studies in patients with kidney failure[50,51] and cancer.[52] Costs in 2021 Australian dollars were based on National Hospitals Cost Data Collection,[53] Pharmaceutical Benefits Scheme,[54] Medicare Benefits Schedule,[55] and previous costing studies.[56-58] Details of the derivation of all transition probabilities, utilities, and costs are reported in **Appendix 2, SDC**, http://links.lww.com/TXD/A523.

Economic Evaluation

We assessed cost-effectiveness by comparing incremental costs with incremental QALYs. Our willingness-to-pay threshold was $28 000 per QALY,[59,60] which is more conservative than the typical $50 000 threshold[61] (**Appendix 2, SDC**, http://links.lww.com/TXD/A523). We calculated 95% CIs for costs and QALYs based on the 2.5th and 97.5th percentiles across all simulations. We also compared interventions by the number of deceased and living donor transplants, life-years spent with transplant, and cancer transmission rate. To account for variability across patients, we reported the proportion who would have decreased, increased, or unchanged QALYs.

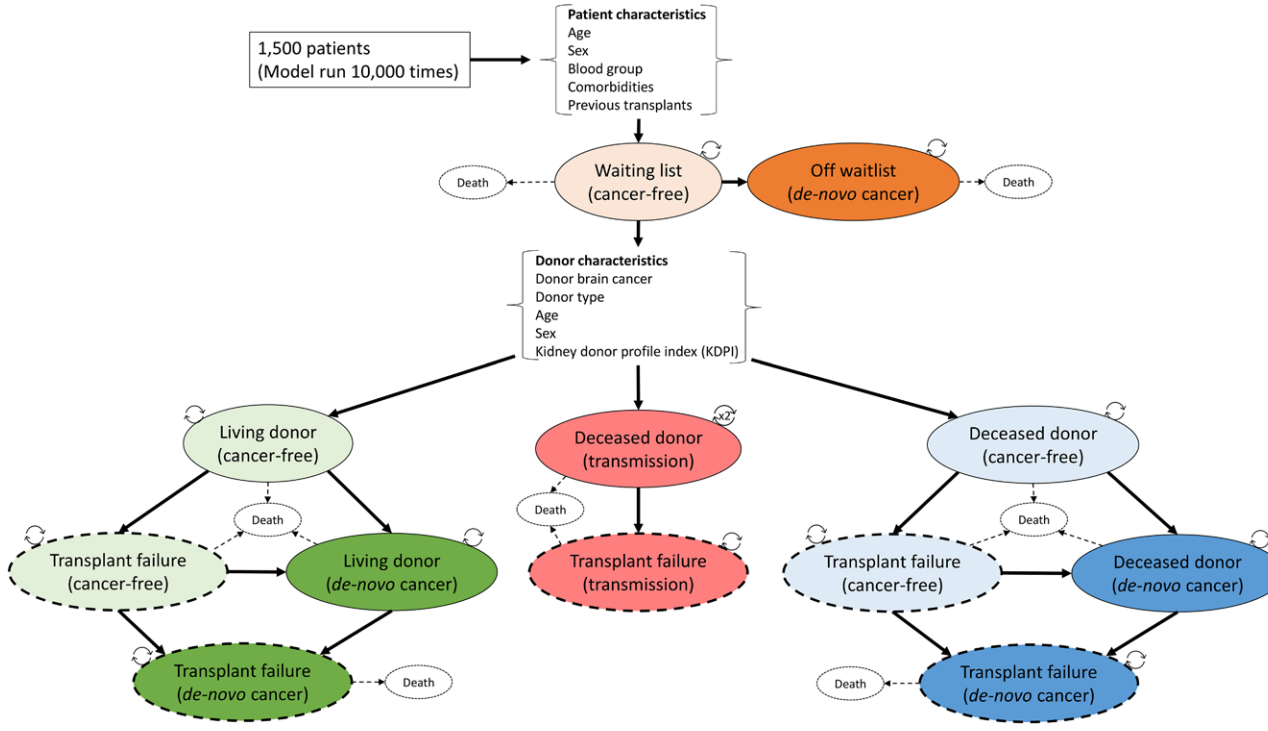

FIGURE 1. Structure of the Markov model used to simulate individual patients.

Uncertainty Analyses

We performed a probabilistic sensitivity analysis to assess uncertainty in model parameters, a worst-case scenario where transmission resulted in immediate death, and a threshold analysis to determine the transmission risk at which increased risk tolerance would no longer be cost-effective. Further detail about uncertainty analyses is provided in **Appendix 2, SDC**, http://links.lww.com/TXD/A523.

RESULTS

Patient and Donor Characteristics

The typical waitlisted patient was a 50-y-old male with blood group O, no prior transplants, and one comorbidity. The typical deceased donor was a 37-y-old male DBD donor without PBM and with an Australian kidney donor profile index of 33.7. Distributions and parameters for patient characteristics are presented in **Table S2, SDC**, http://links.lww.com/TXD/A523, and for donor characteristics in **Table S3, SDC**, http://links.lww.com/TXD/A523.

Impact of Proposed Interventions

Among 172 potential donors declined due to cancer,[13] with decision support one additional donor with low-risk PBM (2%) would have been accepted, increasing overall donation 0.3%. With real-time data-linkage, 2 additional donors would have been accepted: one low-risk (2%) and one not contraindicated (0.1%). Overall donation would increase 0.6%, and these new donors would have an average transmission risk of 1.1%. With increased risk tolerance, 7 additional donors would have been accepted, including 1 low-risk (2%), 1 not contraindicated (0.1%), and 5 intermediate-risk (6.4%). Overall donation would increase 2.1%, and these new donors would have an average transmission risk of 4.9%.

Model Inputs

For a typical waitlisted patient (50-y-old male, blood group O, no previous transplants, and one comorbidity), the probability of receiving a transplant within the first year was 38.6% from a deceased donor and 36.9% from a living donor. After receiving a deceased-donor transplant, the probability of developing cancer within the first year was 0.2%. Without developing cancer, the probability of transplant failure within the first year was 1.4%. If the recipient did develop cancer, the probability of transplant failure within the first year was 13.5%. Incidence rates and model parameters used to calculate transition probabilities are presented in **Tables S4–S4, SDC**, http://links.lww.com/TXD/A523-S9 http://links.lww.com/TXD/A523.

We applied utilities to each health state to reflect relative quality of life. Patients on dialysis had utility 0.73 (0.52 with de novo cancer or 0.45 with transmitted cancer if their transplant failed and they returned to dialysis). Transplanted patients had utility 0.83 (0.59 with de novo cancer or 0.51 with transmitted cancer). Calculation of utility values for cancer is presented in **Table S10, SDC**, http://links.lww.com/TXD/A523.

The annual cost of dialysis was $78 845, whereas a deceased-donor transplant cost $78 836 in the first year but only $3949 annually thereafter. In the first year after cancer diagnosis, de novo cancers cost $45 425, while transmitted cancers cost $48 018 plus $10 478 if nephrectomy was required. All costs associated with each modeled health state (based on nationally reported prices and previous costing studies) are summarized in **Appendix 2, SDC**, http://links.lww.com/TXD/A523.

Economic Evaluation

Among 1500 simulated patients entering the waitlist under current practice, on average over 10 000 simulations, there were 1135 or 75.7% (95% CI 73.5%-88.7%) who received a deceased donor transplant and 112 or 7.5% (95% CI 6.2%-8.9%) who received a living-donor transplant. On average, all proposed interventions resulted in increased QALYs and cost-savings (i.e., dominant) compared with current practice. Decision support with increased risk tolerance was the most likely to be cost-effective (dominant in 87%, <$28 000/QALY gained in 88%, and <$50 000/QALY gained in 89% of simulations). Under this intervention, health outcomes would improve (+18.8 QALYs, 95% CI –9.5 to 51.1), and healthcare expenditure would reduce by $2.2 million (95% CI $121 000 higher to $4.6 million lower). Most patients would be unaffected; however, a small proportion (1.2%) would benefit (mean +1.5 QALYs), while an even smaller proportion (0.2%) would have worse outcomes (mean –3.4 QALYs). The overall cost-effectiveness of each intervention is presented in Figure 2, and all results from the economic evaluation are summarized in Table 1. The cumulative average incremental costs and QALYs after each simulation compared with the results after all 10 000 simulations quickly approached zero, demonstrating that 10 000 simulations were sufficient (**Figure S1, SDC**, http://links.lww.com/TXD/A523).

Overall, patients in every subgroup were more likely to benefit than be harmed, but benefits were not shared evenly. Older patients were least likely to benefit (age 65+ versus 0–44, relative risk ratio (RRR) 0.56, 95% CI 0.54-0.59, $P < 0.001$). Characteristics for all 15 million simulated patients (1500 patients × 10 000 simulations) and their probability of having higher versus lower QALYs under decision support with increased risk tolerance is summarized in Table 2.

Uncertainty Analyses

Incremental costs and QALYs from probabilistic sensitivity analysis were similar to the base-case; hence, results were robust to uncertainty in model parameters. Results were most sensitive to the probability of deceased-donor transplant and the probability of deceased-donor transplant failure. All interventions remained dominant even in the worst-case scenario with immediate death after cancer transmission (increased risk tolerance +15.7 QALYs and $2.7 million cost-savings). Decision support with increased risk tolerance would improve health outcomes until the average transmission risk for new donors reaches 20% and would reduce costs until the average transmission risk reaches 32% (Figure 3). The cost-effectiveness from each simulation of the sensitivity analysis is presented in **Figure S2, SDC**, http://links.lww.com/TXD/A523, and the marginal impact of parameter changes is presented in **Figure S3, SDC**, http://links.lww.com/TXD/A523.

DISCUSSION

We found that despite the increased transmission risk to recipients, any increase in donation from donors with PBM would improve patient outcomes (QALYs) and save

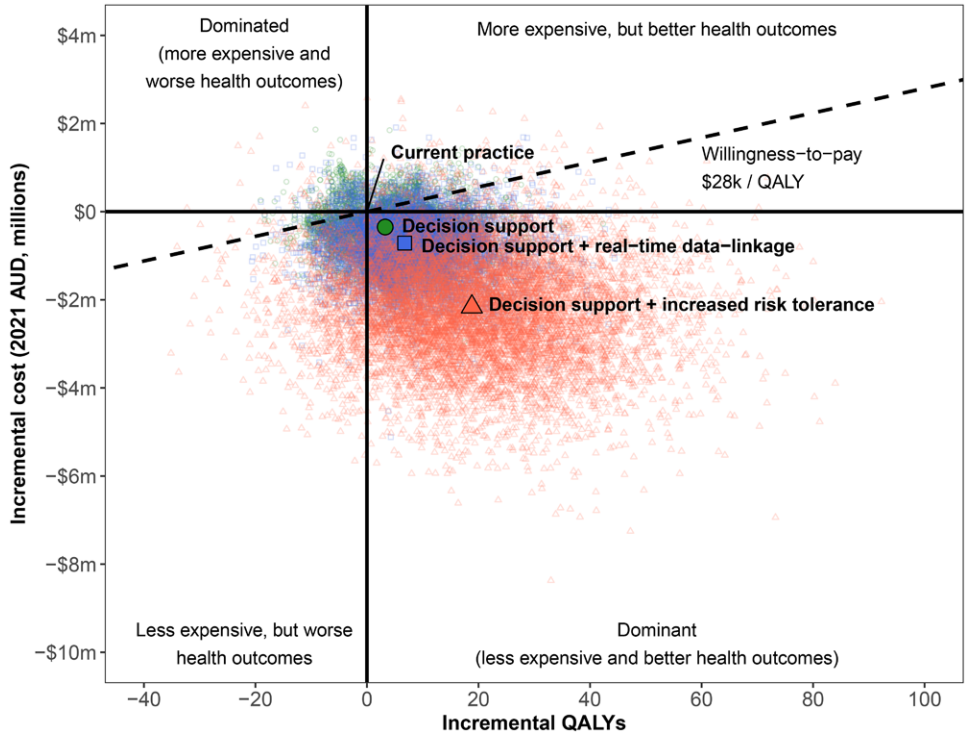

FIGURE 2. Incremental costs and quality-adjusted life-years (QALYs) gained compared with current practice from 10 000 simulations of each intervention.

TABLE 1.

Results of the economic evaluation for 3 interventions to increase utilization of deceased kidney donors with brain cancer

Outcome	Current practice	Decision support	Decision support + real-time data-linkage	Decision support + increased risk tolerance
Cost-effectiveness				
Total QALYs	12 612.6	12 615.9	12 619.4	12 631.5
Total costs	$408 257 368	$407 907 806	$407 544 457	$406 097 633
Incremental QALYs	—	3.3	6.8	18.8
Incremental QALYs 95% CI	—	(–7.0, 17.3)	(–6.8, 25.4)	(–9.5, 51.1)
Incremental costs	—	–$349 563	–$712 912	–$2 159 736
Incremental costs 95% CI	—	(–$1 387 484, $521 979)	(–$2 093 160, $414 348)	(–$4 607 211, $120 887)
Proportion dominant	—	78%	80%	87%
Proportion cost-effective	—	82%	84%	88%
Individual patients				
Proportion worse-off	—	0.02%	0.04%	0.19%
Mean QALYs among worse-off	—	–2.99	–2.80	–3.40
Proportion unaffected	—	99.8%	99.6%	98.6%
Proportion better-off	—	0.18%	0.37%	1.23%
Mean QALYs among better-off	—	1.55	1.53	1.53
Transplants and transmissions				
Change in living donor transplants	—	–0.2%	–0.4%	–1.2%
Change in life-years with living donor transplant	—	–3.2	–6.4	–22.2
Change in deceased donor transplants	—	0.1%	0.2%	0.5%
Change in life-years with deceased donor transplant	—	16.0	32.5	99.4
Additional cancer transmissions (per 100 000 patients)	—	4.2	4.4	70.1

95% CI, 95% confidence interval; QALYs, quality-adjusted life-years.

money. Our conclusions were robust to sensitivity analysis, and even if the risk of transmission were four times greater (20%), accepting intermediate-risk donors would remain cost-effective.

TABLE 2.

Characteristics of simulated patients and comparison of those with lower vs higher QALYs under decision support with increased risk tolerance.

		Lower QALYs		Higher QALYs			
Characteristic	**Simulated patients, N (column %)**	**N (column %)**	**Row %**	**N (column %)**	**Row %**	**RRR (95% CI)**	***P***
Overall	15 000 000 (100)	28 121 (100)	0.19	184 999 (100)	1.23	—	
Age, y, mean (SD)	49.1 (14.59)	50.4 (15.25)		47.6 (14.07)			<0.001
0–44	5 646 864 (38)	9896 (35)	0.18	75 960 (41)	1.35	Ref	
45–54	4 023 930 (27)	7073 (25)	0.18	51 299 (28)	1.27	0.95 (0.92, 0.98)	
55–64	3 150 066 (21)	6168 (22)	0.20	36 745 (20)	1.17	0.78 (0.76, 0.81)	
65+	2 179 140 (15)	4986 (18)	0.23	21 243 (11)	0.97	0.56 (0.54, 0.59)	
Sex							<0.001
Male	5 505 593 (37)	9926 (35)	0.18	67 799 (37)	1.23	Ref	
Female	9 494 407 (63)	18 197 (65)	0.19	117 448 (63)	1.24	1.04 (1.01, 1.06)	
Blood group							<0.001
O	6 745 358 (45)	12 154 (43)	0.18	81 594 (44)	1.21	Ref	
A	5 565 829 (37)	11 065 (39)	0.20	71 198 (38)	1.28	0.96 (0.94, 0.99)	
B	2 011 989 (13)	3662 (13)	0.18	23 716 (13)	1.18	0.96 (0.93, 1.00)	
AB	676 824 (5)	1242 (4)	0.18	8739 (5)	1.29	1.05 (0.99, 1.12)	
Previous transplants							0.002
0	14 664 378 (98)	27 447 (98)	0.19	180 920 (98)	1.23	Ref	
1+	335 622 (2)	676 (2)	0.20	4327 (2)	1.29	0.89 (0.82, 0.96)	
Comorbidities, mean (SD)	0.8 (0.99)	0.9 (1.03)		0.8 (0.96)			<0.001
0	6 890 415 (46)	12 292 (44)	0.18	87 013 (47)	1.26	Ref	
1	4 993 441 (33)	9456 (34)	0.19	61 502 (33)	1.23	0.97 (0.94, 1.00)	
2+	3 116 144 (21)	6375 (23)	0.20	36 732 (20)	1.18	0.96 (0.92, 0.99)	

[a]One thousand five hundred patients were simulated 10 000 times; hence, there were 15 million simulated patients in total.

Rates of lower vs higher QALYs show whether a subgroup of patients is more likely to have improved or reduced health outcomes under the intervention. RRR compares whether a subgroup is more likely (RRR > 1) or less likely (RRR < 1) to have better health outcomes compared with a reference group. For example, those aged 65+ are more likely to have higher QALYs than lower QALYs under the intervention (0.97% vs 0.23%). However, the benefit <44% would be expected in those age 0–44 (RRR 0.56, 95% CI 0.54-0.59, $P < 0.001$). These patients are likely to benefit from the intervention, but they receive a less than equitable share of the total benefits.

95% CI, 95% confidence interval; QALYs, quality-adjusted life-years; RRR, (adjusted) relative risk ratio; SD, standard deviation.

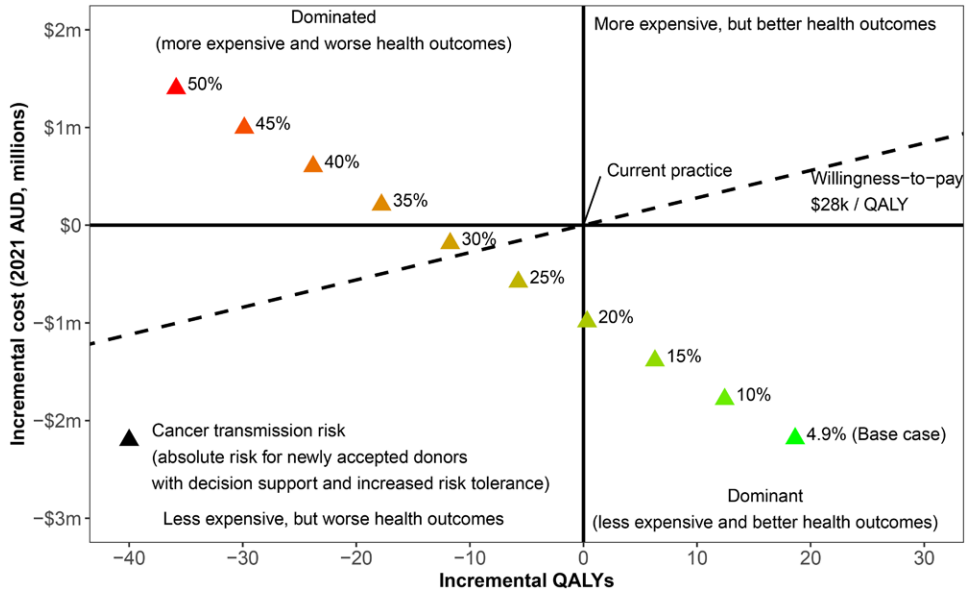

FIGURE 3. Threshold analysis—incremental costs and quality-adjusted life-years (QALYs) gained from 10 000 simulations of decision support with increased risk tolerance, with alternative transmission risks.

Our findings were consistent with results from previous economic evaluations of improvements to kidney donation policies.[24] Economic evaluations typically focus on average outcomes across the population, whereas our simulation of individual patients allowed us to explore variability between patients. We found that a small proportion of patients (0.19%) would experience cancer transmission and be worse-off than if they had remained on dialysis. A much larger proportion (1.23%) would be better-off because most transplants from donors with PBM do not result in transmission. Most patients, however, would be unaffected. Real-time data-linkage resulted in the smallest average QALYs lost among those worse-off, while decision support alone resulted in the largest average QALYs gained among those better-off. However, when considering the proportion of patients better-off, increased risk tolerance was clearly the most beneficial intervention. Benefits were not shared evenly among all patient subgroups, but all patients were much more likely to benefit than be harmed; hence, the potential for inequity should not discourage adoption of the proposed interventions.

In Australia, organ transplantation is regulated though guidelines rather than legislation. Ethical guidelines for transplantation state that the "expected benefit to the recipient must outweigh any expected risk,"[62] which in the context of our results demonstrating net health benefits to patients, could be interpreted as supportive of accepting kidneys from deceased donors with brain cancer. Similarly, the good medical practice code of conduct promotes "making patient safety your first priority,"[63] which may also be considered supportive of accepting a kidney transplant with a cancer transmission risk since expected survival is greater than remaining on dialysis. These principles of prioritizing patient health outcomes and safety are reflected in medical guidelines internationally.[64-66]

A major strength of our study is our use of data for all potential donors from NSW,[13] which has a centralized donation service. This allowed us to capture missed opportunities for donation from donors with PBM that may not have been reported in other jurisdictions. Furthermore, our use of national transplant registry data to estimate patient and donor characteristics and transition probabilities provides confidence that our findings are applicable to the Australian kidney waitlist. Due to variability in healthcare systems, it is unclear whether the magnitude of cost-savings we report would be generalizable to other jurisdictions, but the direction of the effect is likely to be consistent. However, underutilization of potential deceased donors with PBM is an issue internationally,[67] and our findings of improved health outcomes may therefore be applicable to other countries. We found that accepting intermediate-risk PBM donors (6.4% transmission risk) increased donation by 2.1%, which could mean an additional 17 kidneys transplanted annually in Australia,[68] 49 in the United Kingdom,[21] 90 in the Eurotransplant network,[69] and 582 in the United States.[70]

Our economic model was comprehensive and incorporated a wide range of benefits of increasing kidney donation from donors with PBM. For example, we considered not only the increase in the number of donors available for transplant but also the improved quality of these donors in terms of their characteristics such as age and comorbidities.[19] A limitation of our model is that it does not account for a dynamic waitlist, where people may be temporarily made inactive for medical reasons and where a patient being transplanted increases the chances of receiving a transplant for those remaining waiting. We do not expect that the effect of waitlist dynamics would substantially change our results or conclusions. Our study is also limited to assessing the impact of increasing utilization of donors with only one type of cancer (PBM) and donation of only one organ (kidneys). It is unclear whether accepting more donors with other types of cancer would be beneficial, but we expect that increasing utilization of other organs (eg, liver, heart, and lungs) would be even more cost-effective because these recipients often have no alternative treatment.

Our study is limited to assessing the impact of several proposed interventions, without accounting for the potential administrative costs associated with their implementation. A decision support tool for donation specialists such as an app would incur setup and maintenance costs, as would establishing real-time access to cancer registry or hospital

admissions data. While increasing risk tolerance would theoretically not have any direct cost, it would require additional patient education and informed consent, and increased capacity for shared decision-making between clinicians and patients. It would also require a change in donation specialists' attitudes, and behavior change is difficult to achieve. Individual clinicians may wish to avoid the psychological consequence of an active decision that may inadvertently bring harm to their own patient, even with the knowledge that inaction (ie, declining a donor) will likely harm their patient more. Furthermore, if a recipient of a transmitted cancer were to seek compensation, the potential fees to defend or settle a case could exceed the overall system-wide cost-savings from increasing donation. Ensuring that recipients are fully informed of the potential harms involved and that decision-making is shared between clinicians and their patients could help mitigate this risk. However, if our analysis were expanded to include potential donors with other cancers (also with low but nonzero risk of transmission), or other organs, the overall impact of our proposed interventions would likely increase with virtually no additional implementation costs.

The magnitude of health benefits and cost-savings realized relies on our assumption that all additional donors would proceed to transplantation, which may be an overestimate. However, the direction of our findings is independent of the number of new donors available. Even with changes to the assumed increase in donation under each intervention or to the incidence or prevalence of brain cancers in the potential donor population, our conclusion that increasing utilization of kidneys from donors with brain cancer is beneficial remains unchanged.

We have demonstrated that increasing utilization of kidneys from deceased donors with PBM would benefit people waiting for a kidney transplant while also reducing healthcare expenditure. Although the overall impacts are relatively minor, a small proportion of patients stand to benefit greatly while freeing up sorely needed healthcare funding. Our results provide a framework for determining whether the benefits of the proposed interventions (in terms of cost-savings and increased QALYs) outweigh the costs of implementation.

CONCLUSIONS

We have shown that any increase in utilization of kidneys from deceased donors with PBM both improves health outcomes for patients waiting for a kidney transplant and reduces healthcare costs. The greatest benefit was from increasing clinician risk tolerance to accept donors with intermediate-risk PBMs, and policy makers should consider this as a strategy to increase rates of transplantation.

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