KI REPORTS
KIReports.org
CLINICAL RESEARCH

Cost-Effectiveness of Clinical Decision Support to Improve CKD Outcomes Among First Nations Australians

Winnie Chen[1,2], Kirsten Howard[2], Gillian Gorham[1], Asanga Abeyaratne[1,3], Yuejen Zhao[4], Oyelola Adegboye[1], Nadarajah Kangaharan[5], Sean Taylor[1,4], Louise J. Maple-Brown[1,6], Samuel Heard[7], Mohammad Radwanur Talukder[1], Abdolvahab Baghbanian[7], Sandawana William Majoni[3] and Alan Cass[1]; on behalf of Territory Kidney Care Steering Committee[8]

[1]Menzies School of Health Research, Charles Darwin University, Casuarina, Northern Territory, Australia; [2]Leeder Centre for Health Policy and Economics, Faculty of Medicine and Health, University of Sydney, New South Wales, Australia; [3]Department of Nephrology, Division of Medicine, Royal Darwin Hospital, Northern Territory Health, Darwin, Northern Territory, Australia; [4]Northern Territory Health, Darwin, Northern Territory, Australia; [5]Division of Medicine, Northern Territory Health, Darwin, Northern Territory, Australia; [6]Division of Endocrinology, Northern Territory Health, Darwin, Northern Territory, Australia; and [7]Central Australian Aboriginal Congress, Alice Springs, Northern Territory, Australia

Introduction: The Northern Territory (NT) is a hotspot for chronic kidney disease (CKD) and has a high incidence of kidney replacement therapy (KRT). The Territory Kidney Care clinical decision support (CDS) tool aims to improve diagnosis and management of CKD in remote NT, particularly among First Nations Australians. We model the cost-effectiveness of the CDS versus usual care.

Methods: Taking a health care funder perspective, we modeled a cohort of people from remote NT at risk of or with CKD, as of January 1, 2017. A Markov cohort model was developed using 6 years of observed patient-level data (2017–2023), extrapolated to a 15-year time horizon. The CDS tool was modeled to improve CKD diagnosis (scenario 1), improve management (scenario 2), or improve both diagnosis and management (scenario 3).

Results: The remote NT cohort consisted of 23,195 people, predominantly (89%) First Nations, with a mean age of 42 years. Scenario 3 (improved diagnosis and management) was most cost-effective at an incremental cost-effectiveness ratio (ICER) of $96,684 per patient avoiding KRT, $30,086 per patient avoiding death. Scenario 1 (improved diagnosis) was less cost-effective, and scenario 2 (improved management) was the least cost-effective. The ICER per quality-adjusted life years (QALYs) gained ranged from $3427 (scenario 3) to $63,486 (scenario 2).

Conclusion: Territory Kidney Care is highly cost-effective when it supports early diagnosis of CKD and increases optimal management in diagnosed patients. These results support investing in CDS tools, implemented in strong partnerships, to improve outcomes in settings with a high burden of CKD.

Kidney Int Rep (2025) **10,** 549–564; https://doi.org/10.1016/j.ekir.2024.10.028
KEYWORDS: Aboriginal health; chronic kidney disease; clinical decision support; cost; cost-effectiveness; economic evaluation; First Nations; health economics; health informatics

The NT is a "hotspot" for CKD in Australia.[1,2] CKD prevalence in the NT is over 30% among First Nations adults,[3] compared to 10% in the overall NT adult population.[4] Incidence of end-stage kidney disease in the NT is also much higher among First Nations people (18.0/1000) compared to that of non-First Nations people (1.1/1000).[5] First Nations people are Australia's first people, with diverse cultures, languages, strong kinships, and connections to country.[6] As with other First Nations people globally, health inequity contributes to the disproportionate impacts of CKD among First Nations Australians.[7] CKD is associated with socioeconomic disadvantages such as remoteness, lower income, insecure housing, and other negative impacts of colonisation.[8,9]

End-stage kidney disease has enormous impacts on individuals and the health care system. Hemodialysis is

Correspondence: Winnie Chen, Menzies School of Health Research, Charles Darwin University, PO Box 41096, Casuarina, Northern Territory 0811, Australia. E-mail: winnie.chen@menzies.edu.au

[8]Members of the Territory Kidney Care Steering Committee are listed in the Appendix

Received 9 October 2024; accepted 28 October 2024; published online 9 November 2024

physically demanding and has profound psychosocial impacts. This is especially true for First Nations people living away from families and communities to access dialysis in urban centres.[10-12] For First Nations people across Australia, nearly half of all hospital admissions (44%) were for care involving dialysis.[13] Each dialysis patient in the NT incurs over $100,000 in total health care costs per year.[14] Dialysis-related costs in the NT have risen in recent decades because the number of people requiring dialysis has steadily increased.[15,16] Early interventions in CKD are key to slowing or halting disease progression, and improving the current situation.[17-19]

There are distinct challenges with delivering CKD care in the remote NT setting. The NT covers a large land mass of almost to 1.4 million km^2 but is sparsely populated with a total population of approximately 250,000 people.[20,21] First Nations people are over a quarter of the NT population, with the majority (75%) living in remote or very remote areas.[21] Caring for people with chronic disease is complicated by geographic isolation, workforce shortages,[22] highly mobile populations,[23,24] siloed electronic health records (EHRs) across health services, and suboptimal integration of care between primary health care and acute services.[25] The Territory Kidney Care project aims to use CDS tools, implemented in strong partnership with health services across the NT, to address some of these challenges in care for patients with CKD and related chronic conditions.

The Territory Kidney Care project and partnerships have been described in detail previously.[26] The Territory Kidney Care is a partnership between NT hospitals, primary health care, Aboriginal Community Controlled Health Services, and Aboriginal Medical Services Alliance Northern Territory. In brief, the Territory Kidney Care project began in 2017 and includes the following: (i) connecting EHRs within an individual patient–level linked database; (ii) developing algorithms to provide CDS; (iii) working together with partner health services to implement CDS for early detection and management of CKD into routine care; and (iv) evaluating the implementation and impact of the project using qualitative, effectiveness, and economic methods.

We conducted an economic evaluation of Territory Kidney Care alongside project implementation. CDS and similar digital health innovations are often implemented without a clear path for sustained implementation and funding.[27-30] Despite funder interest in CDS cost-effectiveness, there are surprisingly few instances of economic evaluations conducted for CDS interventions.[31-35] In a 2022 systematic review, we described cost-effectiveness of CDS interventions for chronic diseases to range widely between USD$2192 and USD$151,955 per QALY gained compared to usual care. The high heterogeneity observed is attributable to factors such as differences in study context, differences in the CDS tools themselves, and different modeling methods used to estimate cost-effectiveness.[32]

In this study, we aimed to model the cost-effectiveness of Territory Kidney Care as a CDS tool for early CKD diagnosis and management compared to usual care. Existing CKD economic evaluation models in the literature[36-39] have been developed using populations with different demographics and disease profiles to that of our target population. These models are not able to provide realistic estimates of CKD costs and effects for a predominantly remote First Nations cohort. Therefore, a secondary aim of this study was to develop a NT-specific CKD economic evaluation model, based on longitudinal individual-level data from the Territory Kidney Care database.

MATERIALS

Setting and Study Cohort

The Territory Kidney Care database, conceptually similar to a CKD registry, contains linked individual patient data from across the NT. Data sources include EHRs from all 6 public hospitals, all 56 NT Health–managed remote primary health care services, and 11 of 13 Aboriginal Community Controlled Health Services in the NT. The hospital dataset is linked with the national death registry. The cohort included for cost-effectiveness analysis were people within the database at baseline (January 1, 2017) prior to implementation of Territory Kidney Care CDS tools, who were at risk of CKD or living with CKD. Patients at risk of CKD were defined by having 1 or more documented risk factors for CKD (e.g., diabetes, hypertension, cardiovascular disease, and obesity). To ensure data completeness, only those with linked primary health care EHRs were included in the cohort; this meant that only remote NT patients were included, because Territory Kidney Care currently contains primary health care data from remote NT clinics. The full inclusion and exclusion criteria are described in Supplementary Figure S1.

Variables within the database include demographic information, comorbidities, and other structured EHR data (e.g., medications and laboratory results). Validated algorithms are used to process this EHR data to provide support for the diagnosis and management of CKD and related chronic conditions.[40] For example, CKD stages 1 to 5 are calculated based on 2012 Kidney Disease Improving Global Outcomes criteria using pathology results from estimated glomerular filtration rate and urine albumin-to-creatinine ratio.[41]

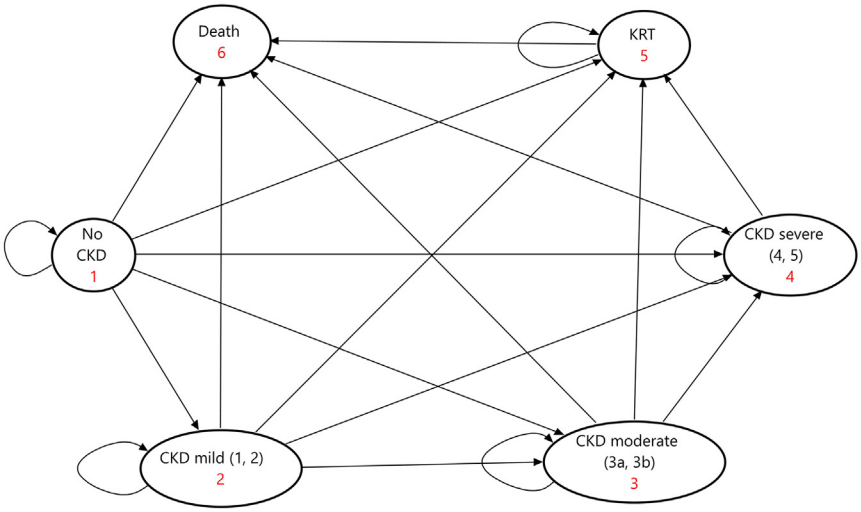

Figure 1. State transition diagram for the NT chronic kidney disease model. Mild is CKD stages 1 and 2, moderate is CKD stages 3a and 3b, severe is CKD stages 4 and 5, KRT includes both dialysis and transplant. CKD, chronic kidney disease; KRT, kidney replacement therapy; NT, Northern Territory.

CDS presents intelligently filtered information to improve health outcomes.[42] Risk calculators, visualization summaries, and targeted guideline recommendations are all examples of CDS tools used in CKD.[32,43] Many contemporary CDS interventions remain centered around single-disease alerts, which are poorly suited for multimorbidity and lead to alert fatigue.[32,44] In Territory Kidney Care, the main CDS feature is an automated summary of derived diagnosis (based on EHR data) and relevant management information presented to users in a format similar to that of a problems list on a discharge summary or physician letter (Supplementary Figure S2). The summary provides concise and pertinent information for clinical decisions, reduces EHR information overload, and is a preferred form of CDS in some situations.[45,46] For example, the summary may quickly indicate to clinicians that the patient has an algorithm-derived diagnosis of CKD stage 3a and hypertension, which have not been formally entered as a coded diagnosis. This supports clinicians in making a CKD diagnosis, and initiating appropriate management, such as starting an angiotensin-converting enzyme inhibitor (ACE-i) and optimizing blood pressure control. Risk calculators (e.g., for cardiovascular risk) and population-level audit reports are available within the Territory Kidney Care user interface.

Model Overview

Taking a health care funder perspective, a modeled economic evaluation was conducted to compare Territory Kidney Care CDS intervention to usual care. A Markov model using NT data sources (described in the previous section) was used to extrapolate CKD costs and outcomes. The Markov model structure is displayed in Figure 1 (model structure in Supplementary Figure S3). The model has 6 mutually exclusive health states as follows: at risk of CKD, mild CKD (stages 1 and 2), moderate CKD (stages 3a and 3b), severe CKD (stages 4 and 5), KRT (dialysis and transplant, modeled separately), and death. CKD stages were grouped due to the relatively small numbers of individuals with severe CKD. The modeled cohort progresses through the health states in annual cycles, over a 15-year time horizon, with death as the absorbing state. Individuals were assumed to either remain in their current health state, or enter a more severe disease state, throughout the modeled period.

Transition probabilities were calculated using real-world individual patient disease progression from 2017 to 2023 (initial 6 years). These findings were extrapolated to 15 years to reflect the chronic nature of CKD and the plausible lifespan of the CDS tool. Costs were reported from an Australian healthcare funder perspective and in 2023 $AUD. Australian Institute of Health and Welfare (AIHW) health price deflators were used to convert costs to 2023 dollars where required.[47] Outcomes were reported as the incremental cost per (i) patient avoiding kidney replacement therapy (KRT), (ii) patient avoiding death, (iii) life year gained, and (iv) quality-adjusted life year (QALY) gained. In the base case discounting was set at 5% for both future costs and outcomes.[48,49] Statistical analyses were conducted in R (version 4.2.3),[50] and Python (version 3.9.12).[51] Modelled economic evaluation was performed in TreeAge Pro (version 2024).[52]

Scenarios Modeled

Proportions of people diagnosed and managed in the usual care scenario were estimated from the 2017 baseline data of the study population (Supplementary

Table S5). Three modeled scenarios were considered in the cost-effectiveness analysis of the CDS intervention. In scenario 1, we estimated the cost-effectiveness of the CDS in improving diagnosis of CKD by 30%. The proportion diagnosed refers to the number of people with a CKD-coded diagnosis within their EHR out of all patients meeting diagnostic criteria for CKD according to Kidney Disease Improving Global Outcomes guidelines based on estimated glomerular filtration rate and urine albumin-to-creatinine results. Coded diagnosis refers to hospital-based International Statistical Classification of Diseases 10th version, Australian Modification; and the primary care–based International Classification of Primary Care, version 2 coding systems. In scenario 2, we estimated the cost-effectiveness of the CDS in improving early management of CKD by 30%, in those who have been correctly diagnosed for CKD. Optimal early management is assumed to encompass evidence-based CKD care to slow CKD progression; such as, improved use of medications (e.g. ACE-i, angiotensin II receptor blockers), improved blood pressure, and enhanced blood glucose management. In scenario 3, we considered the cost-effectiveness of improvements in both diagnosis and management (30% in each).

Little published evidence is available on the effect size of a holistic early CKD intervention in First Nations people.[53] Baker *et al*. described an early CKD program in a single remote NT community, using a study-based relative risk (RR) of 0.43 for intervention versus usual care for disease progression to KRT.[48] We assumed the RR per year of CKD progression (any worsened health state) to be 0.76 in the optimally managed group, compared to those not diagnosed and/or not optimally managed. This is similar to effect sizes assumed in a range of CKD screening cost-effectiveness studies, where screening is assumed to increase early optimal management.[49,54] Technical details on intervention effect estimates are described in the Supplementary Methods.

Model Parameters

Costs are expressed in Australian dollars for the year 2023 unless otherwise stated. Annual health care costs were calculated using primary data from the NT study cohort where possible (e.g., emergency department, inpatient, outpatient, primary care, medication, and investigation costs) (Supplementary Table S3).[55] Hemodialysis costs were from an NT costing study by Gorham *et al*.[14] Transplant costs used previous national estimates.[56] All patients in the intervention arm

Table 1. Intervention costs

Cost type	Cost ($)/yr	Reference
Incremental CDS implementation + maintenance cost[a]		
Server costs	$50,000	Territory Kidney Care project costs
IT contractor – ongoing maintenance	$130,000	
Software developer – 1.0 FTE	$165,100	
Testing/validation officer – 0.4 FTE	$52,000	
Aboriginal Community Controlled Health Service implementation officers – 1.0 FTE total (0.2 FTE at 5 sites)	$165,100	
Aboriginal implementation and consumer engagement officer – 0.4 FTE	$39,000	
Health informatics nurse – 1.0 FTE	$175,500	
Senior researchers – 1.0 FTE (0.5 FTE x 2 researchers)	$210,600	
Total CDS cost for all patients	$987,300	
Total cost per patient (n = 37,398[b])	+$26	
Incremental CDS cost (additional health care resource use)		
Diagnosis	$80	MBS[57]
GP visits – standard consult $40 x 2	$30	
Pathology test – $15 per test x 2		
Management	$240	PBS[58]
Medication use (e.g., ACE-I or ARB) – $20 per month x 12 months		
Total cost per patient	+$350	
Incremental CDS cost (health care resource use efficiency gains)		
Medical practitioner 5 min/patient/yr (at $195 per hour)	-$16	Expert opinion
Nurse 10 min/patient/yr (at $100 per hour)	-$17	Expert opinion
Total cost per patient	-$33	
Overall incremental cost for CDS arm[c]		
CDS implementation/maintenance cost ($26) + CDS cost (additional health care resource use) ($350) − CDS cost (health care resource use efficiency gains) ($33) = Total incremental cost for CDS/patient/yr ($343)		

ACE-I, angiotensin-converting enzyme inhibitor; ARB, angiotensin II receptor blocker; CDS, clinical decision support; FTE, full time equivalent; MBS, Medicare Benefits Scheme; NT, Northern Territory; PBS, Pharmaceutical Benefits Scheme.
[a]Project staff costs all include 30% on-costs.
[b]Total project costs are divided by all active patients in the Territory Kidney Care database, with and without a primary health care–linked electronic health record (n=37,398).
[c]All patients in the intervention arm incurred an incremental CDS implementation and maintenance cost. For patients with mild and moderate CKD who underwent diagnosis and/or management, an incremental health care resource use cost and health care resource use efficiency gain was calculated.

Table 2. Parameters and sensitivity analysis

Parameter	Base case	One-way sensitivity range (minimum, maximum)	Probabilistic sensitivity analysis	Reference
Time horizon	15 yrs	10 yrs, 20 yrs	Not included	Assumed
Discount rate	5%	3%, 7%	Not included	PBAC/MSAC[59,60]
Transition probabilities	Time-dependent	Lower limit, higher limit[a]	PERT	Own data, Territory Kidney Care database
Cost – annual health care	CKD At risk: $6421 Mild: $10,290 Moderate: $17,282 Severe: $56,326 KRT HD total $127,569 ($78,898 HD + $48,671 other health care costs) Tx total $64,837 ($16,166 Tx + $48,671 other health care costs) – also add $93,807 in initial year for first year costs	± 15% for all costs	Gamma (mean, SD from original data source where available)	CKD Own data and NT costs[55] KRT Annual health care costs (other than HD, Tx) from NT costing study,[14] HD from NT costing study,[14] Tx from Kidney Health Australia report[56]
Cost – intervention (incremental)	CDS maintenance +$26 CDS health care cost +$350 CDS efficiency gains −$33	± 30% for all costs	Gamma (mean, SD assumed at 5% of mean)	Own data, Territory Kidney Care project costs – see also Table 1: Intervention costs
Utilities	CKD At risk: 1.0 Mild: 0.85 Moderate: 0.8 Severe: 0.65 KRT HD: 0.75 Tx: 0.8	+/- 15%	Beta (mean, SD assumed 0.10)	Published literature[61]
% improvement in diagnosis	30%	20%, 40%	Assumed	Expert opinion
% improvement in optimal management	30%	20%, 40%	Assumed	Expert opinion
Intervention effect	RR: 0.76	± 15%	PERT	Published literature,[49,54] expert opinion

CDS, clinical decision support; CKD, chronic kidney disease; HD, hemodialysis; KRT, kidney replacement therapy; MSAC, Medical Services Advisory Committee; NT, Northern Territory; PBAC, Pharmaceutical Benefits Advisory Committee; Tx, transplant.
[a]Hazards are used to extrapolate an initial 6 years of observed data to a 15-year time horizon. In sensitivity analysis, lower and higher limits for transition probabilities are derived from low and high hazard scenarios. Details are presented in the Supplementary Methods.

incurred an incremental CDS implementation and maintenance cost ($26 /person/yr). For patients with mild and moderate CKD who underwent diagnosis and/or optimal management, an incremental health care resource use cost was also added ($350/person/ yr). In these same patients benefiting from the CDS, additional costs were partially offset by health care resource use efficiency gains ($33/person/yr). Given that the CDS targeted improved CKD diagnosis and management before development of severe CKD, no change to costs or outcomes was applied to patients with severe CKD (intervention vs. usual care). In-kind contributions, such as opportunity costs associated with stakeholder meetings, were not included. CDS intervention cost calculations are presented in Table 1,[57,58] and all model parameters are presented in Table 2.[59-61]

Intermediate outcomes of the model included stages of CKD and KRT, as defined by Territory Kidney Care EHR-based algorithms.[40] Final outcome was reported as cost per patient avoiding KRT, and cost per patient avoiding death. As a secondary analysis, cost per life year gained, and cost per QALY gained were reported. The number of individual patients avoiding KRT and deaths are not additive outcomes, because some patients avoiding KRT would also have avoided death (double counting of effectiveness). To calculate QALYs, there were no First Nations people–specific utility weights available for CKD and KRT health states. Thus, published utility weights from a systematic review were used (Table 2).[61] With the negative impact of relocation for dialysis,[10,11] the utility of dialysis in the NT First Nations population is likely to be lower than that of the general population.

Transition Probabilities

Transition probabilities in the NT CKD model were calculated using hazard function features in TreeAge Pro. Flexible methods for survival analysis offer advantages over fixed transition probabilities or standard parametric survival models (e.g., Weibull and Gompertz distributions); flexibility accounts for changes to hazards over time.[62,63] In our CKD model, the first 6 years reflected observed disease progression in the modeled cohort, and the remaining years were extrapolated. Transition probabilities were calculated by first creating Kaplan-Meier tables to each outcome of

interest (e.g., KRT and death), which were then converted to hazards. In the base case, a linear progression in hazard rates was assumed beyond the observed period. The hazard rates were then converted using a rate to probability formula to derive time-dependent annual probabilities (e.g., 1-year, 2-year transition probabilities). Technical details of methods and formulas used are presented in Supplementary Tables S4 to S6, and Figure S4.

Model Validation

Face validation involved various consultations with clinician experts across nephrology, primary care, and other clinical specialties. This ensured that the model structure and assumptions were clinically valid and relevant to the NT context. Internal validation was conducted to assess the model's ability to accurately reflect survival data during the observed period. External validation was performed by comparing model projects of KRT and survival outcomes with known median survivals from the Australian and New Zealand Dialysis and Transplant Registry and other published sources.[16,64-66]

Sensitivity Analysis

In Table 2, we provide the range of parameters tested in 1-way sensitivity analysis, and distributions used in the probabilistic sensitivity analysis. One-way sensitivity analysis of transition probabilities involved testing hazard functions which remained constant beyond the observed period (low hazards scenario;,equivalent to exponential decline), and a hazard function that increased linearly at the same rate as the observed period (high hazards scenario) (Supplementary Figure S5). The base case had hazards at 15 years, which was halfway between the low and high hazard scenarios. Probabilistic sensitivity analysis was conducted with 10,000 second order Monte Carlo simulations involving most parameters in Table 2.

In Australia, there is substantial room for improved uptake of newer, effective medications for CKD, including sodium glucose cotransporter 2 (SGLT2) inhibitors.[67-70] Therefore, an additional scenario analysis was conducted, where the additional costs and the effect of SGLT2 inhibitors were used alongside other optimal CKD management (base case considered the yearly medication cost of ACE-i or angiotensin II receptor blocker only). In terms of costs, an additional yearly medication cost for SGLT2 inhibitors of $670 was included (base case $240),[58] with a RR per year of CKD progression to be 0.47 in the optimally managed group, compared to those not diagnosed and/or not optimally managed (base case 0.76).[71] This equates to a RR of 0.62 for CKD progression in those with additional SGLT2 inhibitor use, compared to those with optimal CKD management on ACE-I or angiotensin II receptor blockers alone.[67-69,71] An estimated 30% of people with mild to moderate CKD were estimated to be eligible for SGLT2 inhibitors based on diabetes or CKD indications. Details of the sensitivity analysis of hazard functions, and details of the scenario analysis involving increased SGLT2 inhibitor use in optimal CKD management are presented in the Supplementary Methods.

Ethics

The study protocol for the Territory Kidney Care evaluation, including economic evaluation, was approved by the Human Research Ethics Committee of NT Health and Menzies School of Health Research (NTHREC 2021-4102). The Territory Kidney Care Steering Committee, NT Health Research Governance Office, and partner organizations such as Aboriginal Medical Services Alliance Northern Territory and individual Aboriginal Community Controlled Health Services, reviewed and approved the evaluation protocol.

RESULTS

Modeled Cohort

The Territory Kidney Care cohort had 23,195 individuals at risk of CKD or with CKD, from remote or very remote NT. At the 2017 baseline, their mean age was 42 years. There were more females than males (55% vs. 45%), and the majority were First Nations people (89%). Common comorbidities included diabetes (34%), hypertension (34%), and obesity (31%). Additional baseline characteristics are presented in Supplementary Table S1.

CKD disease progression in this cohort was observed for 6 years (2017–2023) and projected to 15 years. The Markov cohort analysis report for the usual care group is shown in Supplementary Figure S4. Overall median survival for the entire cohort was 14 years (Supplementary Table S2). The median survival was much lower in those with severe CKD (4.8 years), hemodialysis (6.8 years), and transplant (9.2 years), compared to those at risk of CKD (27 years). Kaplan Meier survival curves (red) and fitted survival curves (blue) are presented in Figure 2.

Validation

In Figure 2, we show the internal validation results, where Kaplan-Meier survival curves are compared with modeled survival curves derived from fitted hazard functions for outcomes of KRT and death. Fitted survival curves (blue) closely follow Kaplan-Meier curves (red) for the first 6 years of observed data. For 6 years to 15 years the projected survival curves are shown.

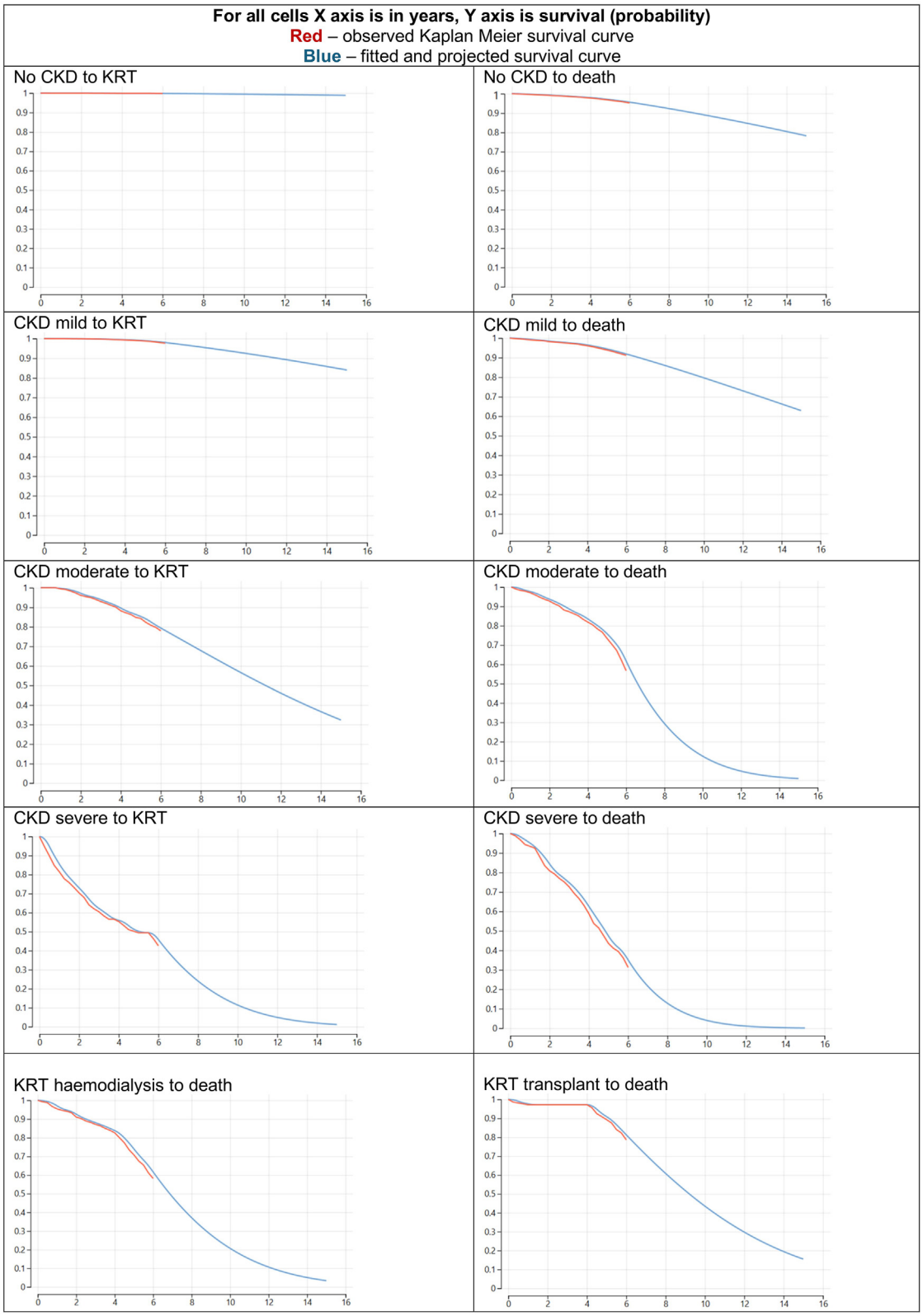

Figure 2. Observed Kaplan Meier survival curves for initial 6 years (red) and fitted survival curves (blue) for years 6 to 15. CKD, chronic kidney disease; KRT, kidney replacement therapy (includes hemodialysis and transplant).

For external validation, median survival on hemodialysis and transplant were compared with previously published literature. Unadjusted median survival on dialysis for the predominantly First Nations population in this cohort were higher than the previously described median survival of hemodialysis in the NT population in 2005 to 2009 (6.8 vs. 5.5 years).[16] Our estimate was close to the Australian and

Table 3. Incremental cost-effectiveness ratio results

	Strategy	Usual care	Scenario 1: improve diagnosis	Scenario 2: improve management	Scenario 3: improve both
Costs	Cost	$124,931	$125,323	$125,592	$125,216
	Incremental	-	$392	$661	$285
Outcome - KRT	KRT	0.206	0.204	0.205	0.203
	Incremental	-	0.002	0.001	0.003
	ICER ($ per patient avoiding KRT)	-	162,046	1,213,064	96,684
Outcome - death	Deaths	0.633	0.624	0.632	0.623
	Incremental	-	0.009	0.001	0.009
	ICER ($ per patient avoiding death)	-	44,427	998,603	30,086
Outcome - LYs	LYs	6.846	6.930	6.859	6.942
	Incremental	-	0.084	0.013	0.096
	ICER ($ per LY gained)	-	4670	51,512	2954
Outcome - QALYs	QALYs	6.022	6.095	6.033	6.105
	Incremental	-	0.073	0.010	0.083
	ICER ($ per QALY gained)	-	5,372	63,486	3,427

Dx, diagnosis; ICER, incremental cost-effectiveness ratio; KRT, kidney replacement therapy; LY, life years; Mx, management; QALYs, quality-adjusted life years.
Costs and outcomes are reported for a cohort size of "1" over the 15-year time horizon, that is, average values per individual. Costs include intervention costs, as well as health care costs. Rounded to 3 decimal places for outcomes and whole dollars.

New Zealand Dialysis and Transplant Registry overall median survival of the Australian population aged 45 to 64 years at 6.4 years. Median transplant survival was described to be approximately 5 years in the NT in early 2000s;[64] however, current (2010–2019) transplant survival at 5 years for First Nations Australians is estimated to be 84%.[65] Noting the relatively small number of people in the transplant group available for analysis ($n = 71$), the modeled cohort had a 5-year transplant survival of approximately 90%, with a median survival of 9.2 years. Life expectancy in the at-risk cohort with no CKD was 67 years, similar to the population-wide life expectancy of First Nations men (65.6 years) and women (69.7 years) in a recent NT study.[66]

Cost-Effectiveness Results

In Table 3, we show that the Territory Kidney Care CDS intervention groups had fewer cases of KRT and deaths compared to usual care over the 15-year time horizon. In the optimal scenario (scenario 3: improved diagnosis and management) versus usual care, 68 people were projected to avoid KRT and 219 people were projected to avoid death over 15 years. Between the intervention groups, incremental costs were lowest for scenario 3 ($611/person, over 15-year time horizon), due to downstream cost savings.

For KRT and deaths as outcomes, ICERs ranged from scenario 3 (improved diagnosis and management) being most cost-effective at $96,684 per patient avoiding KRT and $30,086 per patient avoiding death, to scenario 2 (improved management only) being least cost-effective in at $1.2 million per patient avoiding KRT and close to $1 million per patient avoiding death. In our cohort, which includes fewer patients with severe CKD (than mild or moderate CKD), the overall risk of death was higher than the risk of KRT (Figure 2). Thus, the CDS intervention had a greater impact (lower cost) for preventing death than preventing people starting KRT.

In terms of QALYs, scenario 3 (improved diagnosis and management) was most cost-effective at an ICER of $3,427 per QALY gained. Scenario 1 (improved diagnosis only) had a similar ICER at $5372 per QALY gained. Scenario 2 (improved management only) had a higher ICER of $63,486 per QALY gained. Improving the proportion of people diagnosed with early CKD has a greater impact than improving the proportion of people with optimally managed CKD because the model assumes that accurate diagnosis is a necessary prior step to optimal management.

Sensitivity Analysis

In Figure 3, we display the 1-way sensitivity tornado diagram; and in Table 4, we display results of other scenario analyses. One-way sensitivity analysis on scenario 3 showed that ICERs were most sensitive to changes to intervention effect (RR of CKD progression in optimal management), time horizon, and assumed proportion of people with improved diagnosis of early CKD in the intervention group. Decreasing the time horizon and assuming slower progression (lower transition probabilities) improved cost-effectiveness of the CDS intervention because improvements seen in the CDS group compared to usual care occurred early in the time horizon (disease process). Within all scenarios tested, the CDS intervention remained $<$ $18,000 per QALY gained. The inclusion of costs and effects of SGLT2 inhibitors in optimal CKD management further improved cost-effectiveness of the CDS intervention across all outcomes. The probabilistic sensitivity analysis found that $>$95% of simulations were cost-effective, if the willingness-to-pay threshold is set at $50,000 per QALY (Figure 4).

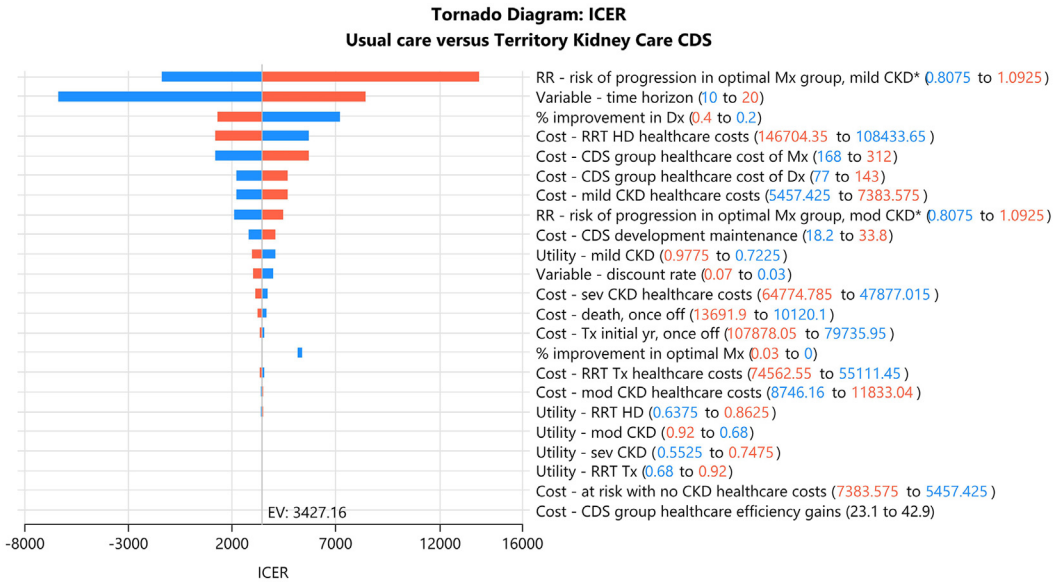

Figure 3. One-way sensitivity analysis results – tornado diagram, usual care versus Territory Kidney Care. ***In the Markov model, the denominator for this variable is 1.25. Therefore, the upper and lower limits of RR tested in the sensitivity analysis are 0.65 and 0.87, respectively. Red represents scenarios where ICER is higher than the base case, blue represents scenarios where ICER is lower than the base case, and grey line represents expected value in the base case.** CDS, chronic kidney disease; CKD, chronic kidney disease; Dx, diagnosis; EV, expected value; HD, hemodialysis; ICER, incremental cost-effectiveness ratio; KRT, kidney replacement therapy; Mx, management; RR, relative risk; Tx, transplant.

DISCUSSION

Early detection and management are a key focus in tackling the social and economic burdens of CKD among First Nations Australians.[18,19] We show that Territory Kidney Care, as a CDS tool for facilitating early CKD care in a predominantly First Nations remote NT population with a high burden of CKD and KRT, is likely to be highly cost-effective. In the optimal scenario, where diagnosis and management are both improved by 30% (scenario 3), the ICER was $96,684 per KRT averted, $30,086 per death averted, and $3427 per QALY gained. The ICER for scenario 3 remained <$18,000 per QALY gained under all sensitivity analyses tested. Together, this provides evidence that the CDS tool, if implemented effectively alongside strong partnerships across health services, represents a high-value investment.

Digital tools are unlikely to be effective in isolation. A strength of the Territory Kidney Care CDS intervention is that it has been codeveloped and implemented with the effort of both government and

Table 4. Base case and other scenario analysis

Scenario	ICER ($ per patient avoiding KRT)	ICER ($ per patient avoiding death	ICER ($ per LY gained)	ICER ($ per QALY gained)
Base case (scenario 3 with improved Dx + Mx)	96,684	30,086	2954	3427
Transition probabilities – lower limit[a]	Intervention was cost saving and more effective than usual care (dominant)			
Transition probabilities – upper limit[a]	472,383	116,865	7847	9202
Time horizon 10 yrs (base, 15 yrs)	Intervention was cost saving and more effective than usual care (dominant)			
Time horizon 20 yrs	365,163	114,221	7198	8399
Discounting 3% costs and outcomes (base, 5%)	135,862	40,771	3407	3965
Discounting 7%	71,161	22,748	2576	2981
Intervention effect RR 0.65 (base RR, 0.76)	Intervention was cost saving and more effective than usual care (dominant)			
Intervention effect RR, 0.87	516,989	159,260	14,928	17,344
Proportion with improved diagnosis and management 20% (base, 30%)	237,617	73,832	7186	8340
Proportion with improved diagnosis and management, 40%	30,933	9501	949	1099
SGLT2 inhibitor costs and effects included in optimal management – RR 0.47 (base RR 0.76)	87,102	27,143	2656	3085

Dx, diagnosis; ICER, incremental cost-effectiveness ratio; KRT, kidney replacement therapy; LY, life year; Mx, management; QALY, quality adjusted life year; RR, relative risk; SGLT2, sodium glucose cotransporter 2.
[a]Hazards are used to extrapolate an initial 6 years of observed data to a 15-year time horizon. In sensitivity analysis, lower and higher limits for transition probabilities are derived from low and high hazard scenarios. See Supplementary Methods for details.

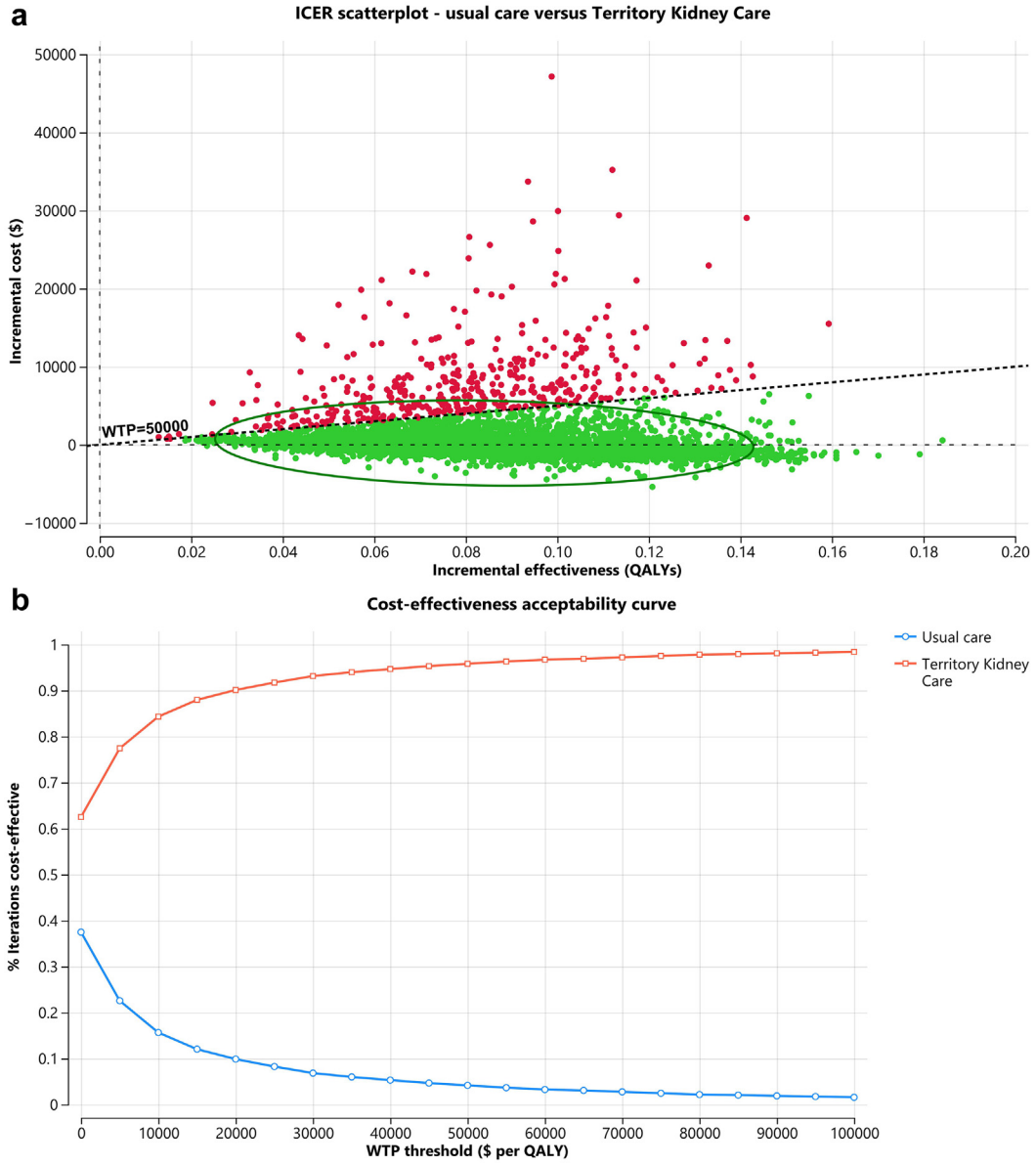

Figure 4. Probabilistic sensitivity analysis results. (a) **shows the probabilistic sensitivity analysis results with 10,000 second order Monte Carlo simulations on an incremental cost-effectiveness plane. The dotted line indicates the WTP threshold of $50,000 per QALY. Red dots above the line are considered not cost-effective, whereas green dots below the line are considered cost-effective.** (b) shows results of the probabilistic sensitivity analysis on a cost-effectiveness acceptability curve. The red line indicates likelihood (%) of the CDS intervention being cost-effective and the blue line indicates likelihood of usual care being more cost-effective. ICER, incremental cost-effectiveness ratio; QALY, quality-adjusted life year; WTP, willingness-to-pay.

Aboriginal Community Controlled Health Services sectors, hospital and primary health care, and clinicians across many clinical domains.[26] The CDS tool is continuously developed with clinician input, and can be updated to incorporate the latest Australian diagnosis and management guidelines for CKD and related chronic conditions. Within this context, it is realistic for the CDS to achieve a 30% improvement in both CKD diagnosis and management once it is fully rolled out across partner organizations.

The strength of our NT CKD model is that it represents one of few CKD economic evaluation models developed for a predominantly First Nations cohort, a population known to have a disproportionately high burden of CKD and rapid disease progression.[2,4,5] The model was built on observed individual-level longitudinal data for the modeled cohort. The CKD cohort within Territory Kidney Care were younger than similar CKD registry cohorts in other states of Australia,[72,73] which is reflective of a strikingly high diabetes prevalence among First Nations people in the NT from a young age.[74–76] The use of real-world estimates of disease progression is important in reflecting the comparatively worse CKD outcomes experienced by

our cohort compared to the general population. Model validation showed that the modeled outcomes closely reflect observed data and is consistent with known published estimates of KRT survival.

Previous NT research has demonstrated that early chronic disease care for First Nations people in the NT is highly cost-effective for preventing morbidity and mortality.[48,77,78] In a trial-based economic evaluation, Baker *et al*. described a First Nations CKD program that saved costs, and reduced cases of KRT in a remote community.[48] Our findings are consistent with studies in the wider Australian population.[37,79] Howard *et al*. modeled cost-effectiveness of early CKD strategies in a nationally representative cohort and found that most strategies for screening or management of risk factors (e.g., enhanced blood pressure control) saved costs, or represent good cost-effectiveness (ICER up to a maximum of $13,781 per QALY gained).[37] Internationally, Ferguson *et al*. estimated the cost-effectiveness of early CKD screening and management in First Nations Canadians to be $23,700 per QALY gained compared to usual care.[54] However, the studies mentioned in the above comparisons were not evaluations of CDS interventions. HealthTracker is an Australian cardiovascular risk CDS tool targeting conditions related to CKD, but without an explicit focus on CKD; the results of the 2020 modeled evaluation showed that cost-effectiveness was $7406 per major cardiovascular event averted.[80] Direct ICER comparison across CDS studies is limited by changes in CDS technology over time, vast differences in implementation strategies and uptake, and differences in health care settings.[31-33]

There are limitations to using EHR data for secondary purposes. First, the Territory Kidney Care database encompasses EHR data across the NT; however, not all health services are current partners. There is potentially missing information about CKD progression for people with earlier stages of CKD not requiring hospital care. Second, although registry-based retrospective cohort studies have the advantage of extending beyond the follow-up periods of most prospective studies, a limitation of using it for survival analysis is that loss to follow-up is unmeasurable.[81] For example, it is not possible to discern whether a person with moderate CKD did not need to attend health services in the last several years, or was lost to follow-up (e.g., moved interstate). Third, people who were deceased before 2015 are not included in the database, and there can be a lag time of up to 12 months before deaths are registered in the database. Therefore, it was not feasible to extend the survival analysis to a longer follow-up period (e.g., 10-year period between 2013 and 2023).

Using a direct health care cost perspective in this cost-effectiveness analysis has limitations. In the NT, eligible patient travel (within NT or interstate) are publicly funded and includes transport and accommodation costs. These costs contribute substantially to public hospital budgets in the NT. There are opportunities to include indirect health care costs, and societal costs in future economic evaluations.

Modeled scenarios and effect sizes in this study are based on best available evidence in terms of local data, published literature, and expert opinion; however, these will need to be confirmed with future study-based evaluation of clinical effectiveness. The CKD model is a limited and simplified representation of clinical complexity. Given that most First Nations people requiring KRT are on center-based hemodialysis, all forms of dialysis were combined to 1 health state. Therefore, the costs and outcomes may not reflect other forms of dialysis (e.g., peritoneal dialysis). The modeled scenario also considers early CKD management as a bundled intervention uniform effect size on disease progression. In practice, CKD interventions would also have different effect sizes within the cohort. For example, people with diabetes and albuminuria are more likely to benefit from ACE-i use than those without. Microsimulation may be helpful in addressing heterogeneity and examining cost-effectiveness within subgroups of interest.[36,82,83] Furthermore, our modeled benefit of optimal management is relatively conservative (RR of 0.76 for CKD progression) compared to reported benefits of individual CKD medications, such as that of SGLT2 inhibitors in recent clinical trials.[67,68,84]

We assessed the cost-effectiveness of CDS-facilitated CKD early detection and management, primarily focusing on those with mild to moderate CKD (the majority of our study cohort), which may not apply to individuals with severe CKD. Furthermore, our study was conducted within a remote NT population, focusing on First Nations Australians with a high burden of CKD. Thus, the cost-effectiveness results may not be generalizable to settings with different CKD disease burdens, different health care settings, and countries with substantially different health care costs and resources.

As with many CDS interventions, the Territory Kidney Care CDS does not only address a single disease but extends to a multiplicity of conditions.[31] The potential additive effects of improvements in related chronic conditions (e.g., diabetes and cardiovascular disease) were not modeled in this evaluation. Future work could focus on incorporating these related chronic conditions and their outcomes into a CKD model. Observed effectiveness results post-implementation could be used to update modeled

estimates of cost-effectiveness. Our unpublished formative qualitative work indicates the possibility of efficiency gains across other clinical domains such as emergency and anesthetic departments in the NT. Thus, the true efficiency and outcome gains in using the CDS are likely to be greater than what is currently modeled.

CONCLUSION

We modeled cost-effectiveness of a CDS implementation for remote NT, with a predominantly First Nations population. Compared to usual care, Territory Kidney Care can improve early diagnosis and management of CKD at an ICER of $96,684 per patient avoiding KRT, and $30,086 per patient avoiding death. When considering QALY outcomes, the CDS intervention is highly cost-effective at an ICER of $3427 per QALY gained. Furthermore, the impact of the CDS may be far greater if it is fully implemented to improve management of related chronic conditions such as diabetes and cardiovascular disease. Our study supports an investment into effective implementation of digital tools and health service partnerships such as Territory Kidney Care, which can both improve CKD outcomes and be cost-effective to the health care system.

APPENDIX

List of the Territory Kidney Care Steering Committee

Ali Lloyd, NT Primary Health Network; Andrew Bell, NT Health; Christine Connors, NT Health; Craig Castillon, NT Health; David McGuiness, Katherine West Health Board Aboriginal Corporation; Emma Kennedy, Pandanus Medical; Jenny Jobst, Miwatj Health Aboriginal Corporation; Liz Moore, Aboriginal Medical Services Alliance Northern Territory; Molly Shorthouse, NT Health; Nathan Garrawurra, Miwatj Health Aboriginal Corporation; Nathan Rosas, Wurli Wurlinjang Health Service; Pratish George, NT Health; Rama Nair, NT Cardiac Pty Ltd; Rebecca Bond, Sunrise Health Service Aboriginal Corporation; Robert Forbes, NT Health; Ronald Ogilvie, Sunrise Health Service; Satpinder Daroch, NT Department of Corporate and Digital Development; and Velma King, Wurli Wurlinjang Health Service.

DISCLOSURE

All the authors declared no competing interests.

ACKNOWLEDGMENTS

The authors would like to thank Belinda Orme for her mathematical and economic modeling expertise, and assistance with TreeAge Pro software. We thank Ben Creswick and Emidio Coccetti for assisting with data access. We gratefully acknowledge the Territory Kidney Care (TKC) team; members of the TKC Steering Committee; TKC collaborators, including the NT government and partner Aboriginal community-controlled health services; and TKC software developer Radical Systems. The TKC Steering Committee members, in addition to the listed authors are listed in Supplementary Materials, Territory Kidney Care Steering Committee.

Funding

WC was supported by an Australian Government Research Training Program Scholarship and Menzies School of Health Research scholarship. The TKC project has been supported by several sources of funding, including philanthropic funding. Current funding is provided by the Ian Potter Foundation for TKC evaluation; the Australian Government Medical Research Future Fund Grant (#PHRD1000027) for developing TKC infrastructure in general practice; and Australian Government Medical Research Future Fund Grant (#RARUR000143) for rapid translation and uptake of TKC in remote primary health services. AC is a recipient of NHMRC Investigator Grant #1196477. LMB is supported by NHMRC Investigator Grant #1194698. Funders had no role in the study design, preparation of manuscript, or decision to publish.

AUTHOR CONTRIBUTIONS

WC, KH, GG, AA, and AC conceived the project. WC conducted data analysis and drafted the manuscript. KH, GG, AA, and AC supervised the methodological approach and interpretation of results. YZ, NK, ST, LMB, SH, MT, VB, SWM contributed to study design and critical interpretation of results. OA and AA provided biostatistics expertise. GG and MT led ethics application and project management. GG and AC led the funding acquisition. All the authors critically revised the manuscript for intellectual content. All the authors read and approved the final manuscript.

SUPPLEMENTARY MATERIAL

Supplementary File (PDF)

Figure S1. Flowchart of included participants.

Figure S2. Territory Kidney Care clinical decision support screenshot.

Figure S3. Markov cohort simplified model structure.

Figure S4 (Supplementary Methods). Example of Kaplan Meier curve to hazard function conversion.

Figure S5 (Supplementary Methods). Example of hazards extrapolation beyond observed period to 15-year time horizon.

Table S1. Baseline characteristics of study cohort on January 1, 2017 – primary health care–linked.

Table S2. Projected median survival (years) by CKD category.

Table S3. Annual health care costs for patients from Territory Kidney Care patients with linked primary health care records (mean, SD).

Table S4 (Supplementary Methods). Kaplan Meier table example – severe CKD to KRT.

Table S5 (Supplementary Methods). The proportion of people assumed to have been diagnosed and optimally managed.

Table S6 (Supplementary Methods). SGLT2 inhibitor-use in mild and moderate CKD.

Territory Kidney Care Steering Committee.

CHEERS checklist.

REFERENCES

1. Kidney Health Australia. State of the Nation 2016 Kidney Health Week—Chronic Kidney Disease Hot Spots Melbourne. Accessed January 1, 2024. Published 2016. https://kidney.org.au/uploads/resources/state-of-the-nation-kidney-health-week-2016-chronic-kidney-disease-hot-spots.pdf
2. Hoy WE. Kidney disease in Aboriginal Australians: a perspective from the Northern Territory. *Clin Kidney J*. 2014;7:524–530. https://doi.org/10.1093/ckj/sfu109
3. Australian Institute of Health Welfare. Profiles of Aboriginal and Torres Strait Islander people with kidney disease, AIHW. Accessed January 1, 2024. 2020. https://www.aihw.gov.au/reports/indigenous-australians/profiles-of-aboriginal-and-tsi-people-with-kidney
4. Li SQ. Prevalence of chronic diseases in the Northern Territory, 2019. Northern Territory Government. Accessed January 2024. Health Statistics and Informatics, NT Health. Accessed January 1, 2024. https://hdl.handle.net/10137/12352
5. Li L, Guthridge S, Li SQ, Zhao Y, Lawton P, Cass A. Estimating the total prevalence and incidence of end-stage kidney disease among Aboriginal and non-Aboriginal populations in the Northern Territory of Australia, using multiple data sources. *BMC Nephrol*. 2018;19:15. https://doi.org/10.1186/s12882-017-0791-3
6. Australian Institute of Health Welfare. Profile of first nations people. AIHW. Accessed January 1, 2024. https://www.aihw.gov.au/reports/australias-welfare/profile-of-indigenous-australians
7. Huria T, Pitama SG, Beckert L, et al. Reported sources of health inequities in Indigenous Peoples with chronic kidney disease: a systematic review of quantitative studies. *BMC Public Health*. 2021;21:1447. https://doi.org/10.1186/s12889-021-11180-2
8. Cass A, Cunningham J, Snelling P, Wang Z, Hoy W. Exploring the pathways leading from disadvantage to end-stage renal disease for Indigenous Australians. *Soc Sci Med*. 2004;58:767–785. https://doi.org/10.1016/s0277-9536(03)00243-0
9. Tunnicliffe DJ, Bateman S, Arnold-Chamney M, et al. Recommendations for culturally safe and clinical kidney care for First Nations Australians CARI Guidelines: Sydney. Accessed January 1, 2024. Published 2022. https://www.cariguidelines.org/first-nations-australian-guidelines/
10. Rix EF, Barclay L, Stirling J, Tong A, Wilson S. 'Beats the alternative but it messes up your life': aboriginal people's experience of haemodialysis in rural Australia. *BMJ Open*. 2014;4:e005945. https://doi.org/10.1136/bmjopen-2014-005945
11. Anderson K, Cunningham J, Devitt J, Preece C, Cass A. "Looking back to my family": Indigenous Australian patients' experience of hemodialysis. *BMC Nephrol*. 2012;13:114. https://doi.org/10.1186/1471-2369-13-114
12. Dingwall KM, Sweet M, Cass A, et al. Effectiveness of Well-being Intervention for Chronic Kidney Disease (WICKD): results of a randomised controlled trial. *BMC Nephrol*. 2021;22:136. https://doi.org/10.1186/s12882-021-02344-8
13. Australian Institute of Health and Welfare, National Indigenous Australians Agency. Tier 1 - Health status and outcomes: 1.02 Top reasons for hospitalizationAustralian Government. Accessed January 1, 2024. 2023. https://www.indigenoushpf.gov.au/measures/1-02-top-reasons-hospitalisation
14. Gorham G, Howard K, Cunningham J, Barzi F, Lawton P, Cass A. Do remote dialysis services really cost more? An economic analysis of hospital and dialysis modality costs associated with dialysis services in urban, rural and remote settings. *BMC Health Serv Res*. 2021;21:582. https://doi.org/10.1186/s12913-021-06612-z
15. You J, Zhao Y, Lawton P, Guthridge S, McDonald SP, Cass A. Projecting demands for renal replacement therapy in the Northern Territory: a stochastic Markov model. *Aust Health Rev*. 2018;42:380–386. https://doi.org/10.1071/AH16156
16. You J, Lawton P, Zhao Y, Poppe S, Cameron N, Guthridge S. Renal replacement therapy demand study, Northern Territory, 2001 to 2022 NT: NT Health. Accessed September 1, 2023. Published 2015. https://digitallibrary.health.nt.gov.au/prodjspui/handle/10137/633
17. Shlipak MG, Tummalapalli SL, Boulware LE, et al. The case for early identification and intervention of chronic kidney disease: conclusions from a Kidney Disease: improving Global Outcomes (KDIGO) Controversies Conference. *Kidney Int*. 2021;99:34–47. https://doi.org/10.1016/j.kint.2020.10.012
18. Kidney Health Australia. National strategic action plan for kidney diseaseAustralian Government. Accessed January 1, 2024. 2019. https://www.health.gov.au/sites/default/files/documents/2020/03/national-strategic-action-plan-for-kidney-disease_0.pdf
19. Northern Territory. Department Health, Renal Services. Northern territory renal services strategy 2017 - 2022. Accessed September 1, 2023. https://digitallibrary.health.nt.gov.au/prodjspui/handle/10137/1438
20. Australian Government, Geoscience Australia. Area of Australia - states and territories. Accessed March 1, 2024. Published 2023. https://www.ga.gov.au/scientific-topics/national-location-information/dimensions/area-of-australia-states-and-territories
21. Department of Treasury and Finance. Northern territory economy. Northern Territory Government. Accessed March 1, 2024. Published 2023. https://nteconomy.nt.gov.au/population
22. Russell DJ, Zhao Y, Guthridge S, et al. Patterns of resident health workforce turnover and retention in remote communities of the Northern Territory of Australia, 2013-2015. *Hum Resour Health*. 2017;15:52. https://doi.org/10.1186/s12960-017-0229-9
23. Goldsmith JJ, Campbell PT, Villanueva-Cabezas JP, et al. Capturing household structure and mobility within and between remote aboriginal communities in Northern Australia

using longitudinal data: a pilot study. *Int J Environ Res Public Health*. 2022;19:12002. https://doi.org/10.3390/ijerph191912002

24. Warchivker I, Tjapangati T, Wakerman J. The turmoil of Aboriginal enumeration: mobility and service population analysis in a Central Australian community. *Aust N Z J Public Health*. 2000;24:444–449. https://doi.org/10.1111/j.1467-842x.2000.tb01610.x
25. Nous Group. Evaluation of the Northern Territory Chronic Conditions Prevention and Management Strategy 2010-2020: final report, Published May 25, 2020, Northern Territory Department of Health. Accessed January 1, 2024. https://health.nt.gov.au/__data/assets/pdf_file/0011/925067/Evaluation-of-the-Northern-Territory-Chronic-Conditions-Prevention-and-Management-Strategy-2010-2020.pdf
26. Gorham G, Abeyaratne A, Heard S, et al. Developing an integrated clinical decision support system for the early identification and management of kidney disease—building cross-sectoral partnerships. *BMC Med Inform Decis Mak*. 2024;24:69. https://doi.org/10.1186/s12911-024-02471-w
27. Chen W, O'Bryan CM, Gorham G, et al. Barriers and enablers to implementing and using clinical decision support systems for chronic diseases: a qualitative systematic review and meta-aggregation. *Implement Sci Commun*. 2022;3:81. https://doi.org/10.1186/s43058-022-00326-x
28. Tcheng JE, Bakken S, Bates DW, et al. Optimizing Strategies for Clinical Decision Support: Summary of a Meeting SeriesNational Academy of Medicine. Accessed November 26, 2024. 2017. https://www.ncbi.nlm.nih.gov/books/NBK594831/
29. Abimbola S, Patel B, Peiris D, et al. The NASSS framework for ex post theorisation of technology-supported change in healthcare: worked example of the Torpedo programme. *BMC Med*. 2019;17:233. https://doi.org/10.1186/s12916-019-1463-x
30. Sutton RT, Pincock D, Baumgart DC, Sadowski DC, Fedorak RN, Kroeker KI. An overview of clinical decision support systems: benefits, risks, and strategies for success. *NPJ Digit Med*. 2020;3:17. https://doi.org/10.1038/s41746-020-0221-y
31. Jacob V, Thota AB, Chattopadhyay SK, et al. Cost and economic benefit of clinical decision support systems for cardiovascular disease prevention: a community guide systematic review. *J Am Med Inform Assoc*. 2017;24:669–676. https://doi.org/10.1093/jamia/ocw160
32. Chen W, Howard K, Gorham G, et al. Design, effectiveness, and economic outcomes of contemporary chronic disease clinical decision support systems: a systematic review and meta-analysis. *J Am Med Inform Assoc*. 2022;29:1757–1772. https://doi.org/10.1093/jamia/ocac110
33. Lewkowicz D, Wohlbrandt A, Boettinger E. Economic impact of clinical decision support interventions based on electronic health records. *BMC Health Serv Res*. 2020;20:871. https://doi.org/10.1186/s12913-020-05688-3
34. White NM, Carter HE, Kularatna S, et al. Evaluating the costs and consequences of computerized clinical decision support systems in hospitals: a scoping review and recommendations for future practice. *J Am Med Inform Assoc*. 2023;30:1205–1218. https://doi.org/10.1093/jamia/ocad040
35. Fillmore CL, Bray BE, Kawamoto K. Systematic review of clinical decision support interventions with potential for inpatient cost reduction. *BMC Med Inform Decis Mak*. 2013;13:135. https://doi.org/10.1186/1472-6947-13-135
36. Sugrue DM, Ward T, Rai S, McEwan P, van Haalen HGM. Economic modelling of chronic kidney disease: a systematic literature review to inform conceptual model design. *Pharmacoeconomics*. 2019;37:1451–1468. https://doi.org/10.1007/s40273-019-00835-z
37. Howard K, White S, Salkeld G, et al. Cost-effectiveness of screening and optimal management for diabetes, hypertension, and chronic kidney disease: a modeled analysis. *Value Health*. 2010;13:196–208. https://doi.org/10.1111/j.1524-4733.2009.00668.x
38. Orlando LA, Belasco EJ, Patel UD, Matchar DB. The chronic kidney disease model: a general purpose model of disease progression and treatment. *BMC Med Inform Decis Mak*. 2011;11:41. https://doi.org/10.1186/1472-6947-11-41
39. Schlackow I, Kent S, Herrington W, et al. A policy model of cardiovascular disease in moderate-to-advanced chronic kidney disease. *Heart*. 2017;103:1880–1890. https://doi.org/10.1136/heartjnl-2016-310970
40. Chen W, Abeyaratne A, Gorham G, et al. Development and validation of algorithms to identify patients with chronic kidney disease and related chronic diseases across the Northern Territory, Australia. *BMC Nephrol*. 2022;23:320. https://doi.org/10.1186/s12882-022-02947-9
41. Kidney disease: improving global outcomes (KDIGO CKD work group). KDIGO 2012 Clinical Practice Guideline for the Evaluation and Management of Chronic Kidney Disease. *Kidney Int Suppl*. 2013;3:1–150.
42. Osheroff J, Teich J, Levick D, et al. *Improving Outcomes With Clinical Decision Support: an Implementer's Guide*, 2nd ed. HIMSS Publishing; 2012.
43. Alexiuk M, Elgubtan H, Tangri N. Clinical decision support tools in the electronic medical record. *Kidney Int Rep*. 2024;9:29–38. https://doi.org/10.1016/j.ekir.2023.10.019
44. Fraccaro P, Arguello Casteleiro M, Ainsworth J, Buchan I. Adoption of clinical decision support in multimorbidity: a systematic review. *JMIR Med Inform*. 2015;3:e4. https://doi.org/10.2196/medinform.3503
45. Sirajuddin AM, Osheroff JA, Sittig DF, Chuo J, Velasco F, Collins DA. Implementation pearls from a new guidebook on improving medication use and outcomes with clinical decision support. Effective CDS is essential for addressing healthcare performance improvement imperatives. *J Healthc Inf Manag*. 2009;23:38–45.
46. Keszthelyi D, Gaudet-Blavignac C, Bjelogrlic M, Lovis C. Patient information summarization in clinical settings: scoping review. *JMIR Med Inform*. 2023;11:e44639. https://doi.org/10.2196/44639
47. Australian Institute of Health and Welfare. Health expenditure Australia 2020-21, Published 2022, Australian Government. Accessed September 1, 2023. https://www.aihw.gov.au/reports/health-welfare-expenditure/health-expenditure-australia-2020-21/contents/overview-of-data-sources-and-methodology/concepts-and-definitions#Deflators
48. Baker PR, Hoy WE, Thomas RE. Cost-effectiveness analysis of a kidney and cardiovascular disease treatment program in an Australian Aboriginal population. *Adv Chronic Kidney Dis*. 2005;12:22–31. https://doi.org/10.1053/j.ackd.2004.10.001
49. Yeo SC, Wang H, Ang YG, Lim CK, Ooi XY. Cost-effectiveness of screening for chronic kidney disease in the general adult

population: a systematic review. *Clin Kidney J*. 2024;17:sfad137. https://doi.org/10.1093/ckj/sfad137

50. R Core Team. R: A Language and Environment for Statistical Computing, Published 2023, R Foundation for Statistical Computing; Vienna, Austria. Accessed September 1, 2023. https://www.R-project.org/
51. Python Software Foundation. Python 2023. Accessed September 1, 2023. https://www.python.org/
52. TreeAge. TreeAge Software LLC. Published 2024. Accessed January 1, 2024. https://www.treeage.com/
53. Reilly R, Evans K, Gomersall J, et al. Effectiveness, cost effectiveness, acceptability and implementation barriers/enablers of chronic kidney disease management programs for Indigenous people in Australia, New Zealand and Canada: a systematic review of mixed evidence. *BMC Health Serv Res*. 2016;16:119. https://doi.org/10.1186/s12913-016-1363-0
54. Ferguson TW, Tangri N, Tan Z, et al. Screening for chronic kidney disease in Canadian indigenous peoples is cost-effective. *Kidney Int*. 2017;92:192–200. https://doi.org/10.1016/j.kint.2017.02.022
55. Chen W, Howard K, Gorham G, et al. Costs and healthcare use of patients with chronic kidney disease in the Northern Territory, Australia. *BMC Health Serv Res*. 2024;24:791. https://doi.org/10.1186/s12913-024-11258-8
56. Cass A, Chadban S, Craig J, et al. The economic impact of end-stage kidney disease in Australia Melbourne, Kidney Health Australia, Published 2006. Accessed January 1, 2024. https://apo.org.au/sites/default/files/resource-files/2006-11/apo-nid3711.pdf
57. Department of Health and Aged Care. MBS-Medicare benefits scheme ACT, Published 2023, Australian Government. Accessed September 1, 2023. http://www.mbsonline.gov.au/internet/mbsonline/publishing.nsf/Content/Home
58. Department of Health and Aged Care. The pharmaceutical benefits scheme ACTAustralian Government. Accessed September 1, 2024. 2024. https://www.pbs.gov.au/pbs/home
59. Department of Health and Aged Care. Guidelines for preparing assessments for the Medical Services Advisory Committee, Published 2021, Australian Government. Accessed January 1, 2024. http://www.msac.gov.au/internet/msac/publishing.nsf/Content/MSAC-Guidelines
60. Department of Health and Aged Care. The pharmaceutical benefits advisory committee guidelines, Published 2016, Australian Government. Accessed January 1, 2024. https://pbac.pbs.gov.au/section-3a/3a-1-overview-and-rationale-of-economic-evaluation.html
61. Cooper JT, Lloyd A, Sanchez JJG, Sörstadius E, Briggs A, McFarlane P. Health related quality of life utility weights for economic evaluation through different stages of chronic kidney disease: a systematic literature review. *Health Qual Life Outcomes*. 2020;18:310. https://doi.org/10.1186/s12955-020-01559-x
62. Latimer NR, Adler AI. Extrapolation beyond the end of trials to estimate long term survival and cost effectiveness. *BMJ Med*. 2022;1:e000094. https://doi.org/10.1136/bmjmed-2021-000094
63. Rutherford M, Lambert P, Sweeting M, et al. Flexible methods for survival analysis sheffield TDS, Published 2020, NICE Decision Support Unit. University of Sheffield. Accessed January 1, 2024. https://www.sheffield.ac.uk/nice-dsu/tsds/flexible-methods-survival-analysis
64. Majoni SW, Abeyaratne A. Renal transplantation in Indigenous Australians of the Northern Territory: closing the gap. *Intern Med J*. 2013;43:1059–1066. https://doi.org/10.1111/imj.12274
65. ANZDATA registry. 43rd Report, Chapter 10: End stage kidney disease in aboriginal and Torres strait islander Australians. Australia and New Zealand Dialysis and Transplant Registry. Published 2021. Accessed January 1, 2024. Published 2021. https://www.anzdata.org.au/wp-content/uploads/2020/09/c10_indigenous_2019_ar_2020_v0.11_20210215.pdf
66. Zhao Y, Li SQ, Wilson T, Burgess CP. Improved life expectancy for Indigenous and non-indigenous people in the Northern Territory, 1999-2018: overall and by underlying cause of death. *Med J Aust*. 2022;217:30–35. https://doi.org/10.5694/mja2.51553
67. Herrington WG, Staplin N, Wanner C, et al. Empagliflozin in patients with chronic kidney disease. *N Engl J Med*. 2023;388:117–127. https://doi.org/10.1056/NEJMoa2204233
68. Heerspink HJL, Stefánsson BV, Correa-Rotter R, et al. Dapagliflozin in patients with chronic kidney disease. *N Engl J Med*. 2020;383:1436–1446. https://doi.org/10.1056/NEJMoa2024816
69. Perkovic V, Jardine MJ, Neal B, et al. Canagliflozin and renal outcomes in type 2 diabetes and nephropathy. *N Engl J Med*. 2019;380:2295–2306. https://doi.org/10.1056/NEJMoa1811744
70. Neuen BL, Jun M, Wick J, et al. Estimating the population-level impacts of improved uptake of sglt2 inhibitors in patients with chronic kidney disease: a cross-sectional observational study using routinely collected australian primary care data. *Lancet Reg Health West Pac*. 2023;43:100988.
71. Baigent C, Emberson J, Haynes R, Herrington WG, Judge P, Landray MJ. Impact of diabetes on the effects of sodium glucose co-transporter-2 inhibitors on kidney outcomes: collaborative meta-analysis of large placebo-controlled trials. *Lancet*. 2022;400:1788–1801. https://doi.org/10.1016/S0140-6736(22)02074-8
72. Saunder T, Kitsos A, Radford J, et al. Chronic kidney disease in Tasmania: protocol for a data linkage study. *JMIR Res Protoc*. 2020;9:e20160. https://doi.org/10.2196/20160
73. Hoy WE, Wang Z, Zhang J, et al. Chronic kidney disease in public renal practices in Queensland, Australia, 2011-2018. *Nephrol (Carlton)*. 2022;27:934–944. https://doi.org/10.1111/nep.14111
74. Hare MJL, Zhao Y, Guthridge S, et al. Prevalence and incidence of diabetes among Aboriginal people in remote communities of the Northern Territory, Australia: a retrospective, longitudinal data-linkage study. *BMJ Open*. 2022;12:e059716. https://doi.org/10.1136/bmjopen-2021-059716
75. Titmuss A, Davis EA, O'Donnell V, et al. Youth-onset type 2 diabetes among First Nations young people in northern Australia: a retrospective, cross-sectional study. *Lancet Diabetes Endocrinol*. 2022;10:11–13. https://doi.org/10.1016/S2213-8587(21)00286-2
76. Hare MJL, Maple-Brown LJ, Shaw JE, et al. Risk of kidney disease following a pregnancy complicated by diabetes: a longitudinal, population-based data-linkage study among Aboriginal women in the Northern Territory, Australia. *Diabetologia*. 2023;66:837–846. https://doi.org/10.1007/s00125-023-05868-w
77. Zhao Y, Thomas SL, Guthridge SL, Wakerman J. Better health outcomes at lower costs: the benefits of primary care utilisation for chronic disease management in remote Indigenous communities in Australia's Northern Territory. *BMC Health Serv Res*. 2014;14:463. https://doi.org/10.1186/1472-6963-14-463

78. Thomas SL, Zhao Y, Guthridge SL, Wakerman J. The cost-effectiveness of primary care for Indigenous Australians with diabetes living in remote Northern Territory communities. *Med J Aust*. 2014;200:658–662. https://doi.org/10.5694/mja13.11316

79. Deloitte Access Economics. Changing the chronic kidney disease landscape: the economic benefits of early detection and treatment, Kidney Health Australia, Published 2023. Accessed September 1, 2023. https://www.deloitte.com/content/dam/assets-zone1/au/en/docs/services/economics/deloitte-au-economics-kidney-health-australia-report-80323.pdf

80. Patel B, Peiris DP, Patel A, et al. A computer-guided quality improvement tool for primary health care: cost-effectiveness analysis based on Torpedo trial data. *Med J Aust*. 2020;213:73–78. https://doi.org/10.5694/mja2.50667

81. Gliklich RE, Dreyer N, Leavy MB. Registries for evaluating patient outcomes: a user's guide, 3rd ed, 2014, Agency for Healthcare Research and Quality. Accessed November 26, 2024. https://www.ncbi.nlm.nih.gov/books/NBK208632/

82. Claxton K, Sculpher M, Briggs A. *Decision Modelling for Health Economic Evaluation*. Oxford University Press; 2006.

83. Chen W, Howell M, Cass A, Gorham G, Howard K. Understanding modelled economic evaluations: a reader's guide for clinicians. *Med J Aust*. 2024;221:302–307. https://doi.org/10.5694/mja2.52409

84. Correa-Rotter R, Maple-Brown LJ, Sahay R, Tuttle KR, Ulasi II. New and emerging therapies for diabetic kidney disease. *Nat Rev Nephrol*. 2024;20:156–160. https://doi.org/10.1038/s41581-023-00782-1