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Cost Effectiveness and Resource Allocation

RESEARCH

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Cost-effectiveness analysis of nephroprotection programs for patients with type 2 diabetes mellitus in insurers in Colombia

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Abstract

Background This research aimed to determine the cost-effectiveness of nephroprotection programs compared to no intervention in adults with type 2 diabetes mellitus (T2DM) in the Colombian national health system.

Methods A Markov analysis with 3 disease states (controlled, uncontrolled and death) was modeled using a 1-year cycle and a 10-year time horizon based on T2DM and chronic kidney disease (CKD) data in Colombia from 2020 to 2023 from the perspective of the health insurance system. Effectiveness was considered as the control of CKD progression, with a decrease of estimated glomerular filtration rate (eGFR using CKD-EPI) of less than 5 ml/min/1.73 m^2, and glycated hemoglobin (HBA1c) of less than or equal to 7%. Costs are expressed in 2023 $USD. Univariate and multivariate probabilistic sensitivity analyses were conducted using 1,000 Monte Carlo simulations.

Results Compared to no intervention, nephroprotection programs were found to be cost-effective, with a dominant incremental cost-effectiveness ratio (ICER). Furthermore, the sensitivity analysis results showed that having a nephroprotection program is a cost-effective strategy in 89.2% and dominant in 56.7% of the simulations.

Conclusions Nephroprotection programs result in better T2DM control and slower CKD progression, while also being lower in costs incurred during the year.

Keywords Cost-effectiveness analysis, Type 2 diabetes, Chronic kidney disease, Nephroprotection programs

Background

Diabetes mellitus (DM) is one of the major health problems in the world, according to the International Diabetes Federation (IDF), it is estimated that 537 million adults were living with diabetes in 2021, and this number is expected to increase to 783 million by 2045 [1–3] Concurrently, chronic kidney disease is one of the most prevalent conditions, affecting around 843.6 million people worldwide in 2017. It ranks among the leading causes of mortality and is a non-communicable disease that has been on the rise in the last two decades, especially among individuals with diabetes mellitus or hypertension [4].

In Colombia, the prevalence of DM was 3.11 cases per 100 inhabitants (1,576,508 prevalent cases of DM) in 2021, showing a 10.51% increase compared to 2020. The incidence rate was 3.46 per 1,000 inhabitants (176,766 incident cases of DM), showing a 3.25% increase from

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the previous period [5]. Additionally, for chronic kidney disease (CKD), a prevalence of 1.75 cases per 100 inhabitants (889,123 prevalent cases of CKD) was reported, while the incidence rate of CKD in 2021 remained at 3.05 per 1,000 (154,688 incident cases of CKD), consistent with the values from 2020. Notably, 15.20% (23,515) of incident CKD cases were attributed to DM [5].

The combination of factors such as age and conditions like hypertension (HTA) and diabetes (DM) can contribute to the onset of CKD [6]. The control criteria for type 2 diabetes mellitus, as defined by the Nephroprotection Consensus of the High-Cost Account (CAC) in 2020, involve maintaining a glycated hemoglobin (HbA1c) level below 7% (according to KDIGO and KDOQI guidelines) and avoiding an annual decline in estimated glomerular filtration rate (eGFR) of more than 5 ml/min/1.73 m^2 year [7]. It is crucial to consider DM as a precursor to CKD since, globally, as stated by the WHO, "Between 12 and 55% of people with diabetes have this condition, and its incidence is up to ten times higher in people with diabetes than in those without diabetes" [8].

Nephroprotection programs encompass measures aimed at preventing CKD development in populations at risk (primary nephroprotection), slowing the progression of renal damage (secondary nephroprotection), and limiting complications (tertiary nephroprotection) for patients on renal replacement therapy (RRT) [9]. It is essential to raise awareness and recognize the significance of the various measures within a nephroprotection program framework, these measures help mitigate CKD progression, lift the considerable financial burden on both the public and private sectors, and enhance the quality of life of these patients [10].

Considering the above, the aim of this research is to analyze whether nephroprotection programs, prove to be cost-effective compared to not implementing any program. This analysis will involve examining clinical outcome and total cost data reported to the High-Cost Diseases Fund (Cuenta de Alto Costo [CAC] in Spanish) from 2020 to 2023.

Methods

In the present research, we analyzed patients with type 2 diabetes mellitus (T2DM) within the chronic kidney disease (CKD) cohort of the High-Cost Diseases Fund (Cuenta de Alto Costo [CAC, in Spanish]) spanning the period from 2020 to 2023 from the health perspective of insurers in Colombia. Effectiveness was assessed based on the count of individuals who show controlled CKD progression. The reference period for this analysis is from July 1, 2020 to June 30, 2023, which will subsequently serve as a basis for the analysis of 10-year time horizon using the proposed Markov model.

The mandatory information report created by the Ministry of Health and Social Protection of Colombia in Resolution 2463 of 2014 [11] was used as the data source for the T2DM cohort. This report is submitted annually, covering the period from July 1 of the previous year to June 30 of the current year. In this context, the population with T2DM from 2020 to 2023, who remained in the same EPS (Health Promoting Entity) for all four periods (except for patients who passed away), was considered. Data from 2019 were incorporated solely to observe the annual estimate glomerular filtration rate (eGFR using CKD-EPI [Chronic Kidney Disease Epidemiology Collaboration] [12]) decline from 2019 to 2020. The database was structured as short longitudinal panel data.

For the cost-effectiveness analysis, the measure of effectiveness will be the proportion of controlled T2DM individuals. Two criteria were used to define a patient as "controlled":

- Reduced glomerular filtration rate (eGFR—CKD-EPI) $\leq$ 5 ml/min/1.73 $m.^2$
- Glycated hemoglobin (HbA1c) < 7%

In this instance, the perspective of the health insurer is taken to determine whether nephroprotection programs are cost-effective compared to not implementing such programs. The analysis focuses on the results at the national level in both the third party payer and state insured categories of the health system.

For the costs, the accumulated total cost of care up to the reporting date (July 1 of the year prior to June 30 of the reference year) is taken into account. The calculation excludes the 5th percentile (p5) because very low costs are observed, which can be attributed to the insurer's capitation scheme. The costs are adjusted to 2023 dollars ($USD) considering the annual reported inflation rate from the Central Bank of Colombia (Banco de la República [BanRep] in Spanish)[1]'s monetary policy reports [13]. And for the conversion from Colombian pesos to dollars (COP to USD) the nominal exchange rate was taken into account, using the average of the last quarter of 2023 of the Representative Market Rate (RMR, [TRM, in Spanish]) reported by the Banrep (RMR = $4071.19 COP per $1 dollar) [14].

To conduct the cost-effectiveness health economic evaluation (HEE), a simple Markov model is chosen using the "heemod" package in R [15, 16]. The Markov model comprises 3 states: 1) Controlled, 2) Uncontrolled, and 3) Death. The model starts with a population with T2DM in

[1] Bank of the Republic (Banco de la República [BanRep] in Spanish) is the central bank of Colombia and monetary authority of the country.

2020, which could be in any of the 3 states. The aim is to observe how the states of the patients change in 2021, 2022 and 2023. Based on this, the transition probability matrix is estimated for patients who were not in nephroprotection programs. The relative risk of having uncontrolled DM was calculated for individuals exposed to nephroprotection programs, allowing the estimation of the transition probability matrix with nephroprotection. Univariate and multivariate sensitivity analyses were performed using the same R package mentioned above.

The baseline characteristics of the populations with and without neproprotection are shown (Table 1 and Table 2). A total of 298,402 adults with type 2 diabetes mellitus were analyzed; most patients were female and lived in the Central region. The minority of patients are under nephroprotection, constituting 11.24% of the total

Table 1 Baseline characteristics of study participants without Nephroprotection

Population/year	2020 (n = 264,861)	2021 (n = 264,861)	2022 (n = 264,861)	2023 (n = 264,861)
Age				
Mean Age (sd)	64.93 (11.23)	65.91 (11.22)	66.85 (11.18)	67.78 (11.14)
Age group (%)				
30 to34	1,577 (0.60%)	1,159 (0.39%)	821 (0.31%)	515 (0.19%)
35 to39	3,632 (1.37%)	3,068 (1.03%)	2,583 (0.98%)	2,201 (0.83%)
40 to44	6,723 (2.54%)	6,112 (2.05%)	5,475 (2.07%)	4,872 (1.84%)
45 to49	12,079 (4.56%)	10,499 (3.52%)	9,297 (3.51%)	8,355 (3.15%)
50 to54	22,357 (8.44%)	20,068 (6.73%)	17,942 (6.77%)	15,893 (6.00%)
55 to59	34,761 (13.12%)	32,475 (10.88%)	30,148 (11.38%)	27,601 (10.42%)
60 to64	43,220 (16.32%)	42,076 (14.10%)	40,566 (15.32%)	39,112 (14.77%)
65 to69	45,643 (17.23%)	45,765 (15.34%)	45,845 (17.31%)	45,483 (17.17%)
70 to74	39,197 (14.80%)	41,286 (13.84%)	42,659 (16.11%)	44,033 (16.62%)
75 to79	28,663 (10.82%)	30,365 (10.18%)	32,717 (12.35%)	34,962 (13.20%)
80 or More	27,009 (10.20%)	31,988 (10.72%)	36,808 (13.90%)	41,834 (15.79%)
Sex (%)				
Women	159,638 (60.27%)	159,645 (53.50%)	159,642 (60.27%)	159,631 (60.27%)
Men	105,223 (39.73%)	105,216 (35.26%)	105,219 (39.73%)	105,230 (39.73%)
Race (%)				
Other	261,272 (98.64%)	261,839 (87.75%)	261,793 (98.84%)	261,694 (98.80%)
Black	3,589 (1.36%)	3,022 (1.01%)	3,068 (1.16%)	3,167 (1.20%)
Stage CKD (%)				
Without CKD	92,407 (34.89%)	93,893 (31.47%)	83,638 (31.58%)	90,060 (34.00%)
G1	5,281 (1.99%)	4,972 (1.67%)	5,101 (1.93%)	4,797 (1.81%)
G2	126,901 (47.91%)	122,634 (41.10%)	126,529 (47.77%)	121,290 (45.79%)
G3a	28,512 (10.76%)	29,598 (11.17%)	32,987 (12.45%)	31,829 (12.02%)
G3b	9,670 (3.65%)	10,952 (4.13%)	12,969 (4.90%)	12,864 (4.86%)
G4	2,090 (0.79%)	2,812 (0.94%)	3,637 (1.37%)	4,021 (1.52%)
State (%)				
Controlled	65,487 (24.73%)	67,966 (22.78%)	57,368 (21.66%)	49,770 (18.79%)
Death	5,863 (2.21%)	14,993 (5.02%)	18,883 (7.13%)	21,756 (8.21%)
Uncontrolled	193,511 (73.06%)	181,902 (60.96%)	188,610 (71.21%)	193,335 (72.99%)
Region (%)				
Amazonía/Orinoquía	1,244 (0.47%)	1,223 (0.41%)	1,180 (0.45%)	1,191 (0.45%)
Bogotá D.C	53,324 (20.13%)	53,301 (17.86%)	52,296 (19.74%)	51,780 (19.55%)
Caribbean	68,937 (26.03%)	68,883 (23.08%)	69,046 (26.07%)	69,022 (26.06%)
Central	69,187 (26.12%)	69,186 (23.19%)	69,454 (26.22%)	69,622 (26.29%)
Eastern	34,406 (12.99%)	34,478 (11.55%)	35,085 (13.25%)	35,428 (13.38%)
Pacific	37,763 (14.26%)	37,790 (12.66%)	37,800 (14.27%)	37,818 (14.28%)

Table 2 Baseline characteristics of study participants with Nephroprotection

Population/year	2020 (n = 33,541)	2021 (n = 33,541)	2022 (n = 33,541)	2023 (n = 33,541)
Mean Age (sd)	63.89 (11.36)	64.86 (11.34)	65.8 (11.3)	66.72 (11.25)
Age group (%)				
20 to24	45 (0.13%)	40 (0.12%)	28 (0.08%)	16 (0.05%)
25 to29	107 (0.32%)	91 (0.27%)	86 (0.26%)	78 (0.23%)
30 to34	218 (0.65%)	179 (0.53%)	144 (0.43%)	116 (0.35%)
35 to39	487 (1.45%)	414 (1.23%)	356 (1.06%)	313 (0.93%)
40 to44	881 (2.63%)	799 (2.38%)	724 (2.16%)	630 (1.88%)
45 to49	1,673 (4.99%)	1,477 (4.40%)	1,289 (3.84%)	1,158 (3.45%)
50 to54	3,069 (9.15%)	2,788 (8.31%)	2,514 (7.50%)	2,202 (6.57%)
55 to59	4,687 (13.97%)	4,355 (12.98%)	4,007 (11.95%)	3,746 (11.17%)
60 to64	5,811 (17.33%)	5,684 (16.95%)	5,534 (16.50%)	5,308 (15.83%)
65 to69	5,805 (17.31%)	5,910 (17.62%)	6,024 (17.96%)	6,013 (17.93%)
70 to74	4,718 (14.07%)	4,978 (14.84%)	5,168 (15.41%)	5,475 (16.32%)
75 to79	3,248 (9.68%)	3,507 (10.46%)	3,794 (11.31%)	4,064 (12.12%)
80 or More	2,792 (8.32%)	3,319 (9.90%)	3,873 (11.55%)	4,422 (13.18%)
Sex (%)				
Women	19,033 (56.75%)	19,033 (56.75%)	19,035 (56.75%)	19,039 (56.76%)
Men	14,508 (43.25%)	14,508 (43.25%)	14,506 (43.25%)	14,502 (43.24%)
Race (%)				
Other	32,992 (98.36%)	33,260 (99.16%)	33,261 (99.17%)	33,256 (99.15%)
Black	549 (1.64%)	281 (0.84%)	280 (0.83%)	285 (0.85%)
Stage CKD (%)				
Without CKD	12,773 (38.08%)	12,137 (36.19%)	11,644 (34.72%)	11,871 (35.39%)
G1	673 (2.01%)	658 (1.96%)	690 (2.06%)	643 (1.92%)
G2	14,759 (44.00%)	14,748 (43.97%)	14,849 (44.27%)	14,400 (42.93%)
G3a	3,539 (10.55%)	3,802 (11.34%)	3,883 (11.58%)	3,948 (11.77%)
G3b	1,419 (4.23%)	1,670 (4.98%)	1,884 (5.62%)	1,942 (5.79%)
G4	378 (1.13%)	526 (1.57%)	591 (1.76%)	737 (2.20%)
State (%)				
Controlled	8,321 (24.81%)	8,109 (24.18%)	7,306 (21.78%)	6,745 (20.11%)
Death	765 (2.28%)	2,094 (6.24%)	2,638 (7.87%)	3,034 (9.05%)
Uncontrolled	24,455 (72.91%)	23,338 (69.58%)	23,597 (70.35%)	23,762 (70.84%)
Region (%)				
Amazonía/Orinoquía	655 (1.95%)	655 (1.95%)	651 (1.94%)	651 (1.94%)
Bogotá D.C	7,147 (21.31%)	7,389 (22.03%)	7,149 (21.31%)	7,031 (20.96%)
Caribbean	3,920 (11.69%)	3,832 (11.42%)	3,927 (11.71%)	3,926 (11.71%)
Central	7,934 (23.65%)	7,927 (23.63%)	7,967 (23.75%)	7,978 (23.79%)
Eastern	4,954 (14.77%)	4,818 (14.36%)	4,933 (14.71%)	5,045 (15.04%)
Pacific	8,931 (26.63%)	8,920 (26.59%)	8,914 (26.58%)	8,910 (26.56%)

model population, while the population without nephroprotection accounts for 88.76%. Furthermore, most patients, both with and without nephroprotection, are in the uncontrolled state (for more detailed information about data processing, refer to Appendix 1).

Table 3 displays the parameters estimated from our data sources that will be included in the analysis. The reference point for the estimated relative risk (RR) is based on the comparison of the controlled state vs the uncontrolled state and death when considering the nephroprotection program. The sensitivity range is set to the 95% confidence interval. A discount rate of 5% is defined, and sensitivity analysis is performed ranging from 3 to 7%, following the recommendation of the

Table 3 Parameters of markov model

Parameters	Value	Sensitivity range	Distribution	Source
Relative Risk	0. 9,931,201	0.989711—0.996541	Beta	
Discount Rate	0.05	0.03–0.07	Beta	IETS (17)
Effect Controlled	1.0	1.0		
Effect Uncontrolled	0.0	0.0		
Effect Death	0.0	0.0		
Cost of Controlled*	423.87 (939.17)	72.59—492.44	Gamma	
Cost of Uncontrolled With Nephroprotection*	515.25 (1,293.73)	58.45—608.90	Gamma	
Cost of Uncontrolled Without Nephroprotection*	521.01 (1,032.85)	79.24—659.07	Gamma	
N	1,000			

* The standard deviation (SD) of total annual costs are shown in parentheses ()

IETS economic evaluation manual for Colombia [17]. Regarding effectiveness, the proportion of controlled individuals without and with nephroprotection from 2020 to 2023 was taken into account. The sensitivity range encompasses the lowest and highest values over the four years. Additionally, a parameter was defined to take the value of 1 only if an individual is in the controlled state. This parameter is used to count individuals under control in the developed Markov model in R. For the annual total costs of controlled and uncontrolled taking into account whether with or without nephroprotection for uncontrolled measures, which were adjusted for inflation to last quarter 2023 COP prices and average of the last quarter of 2023 nominal exchange rate (RMR), the average over the four years was used, and for the sensitivity analysis we used the first and third quartiles of the cost distribution. The willingness-to-pay (WTP) threshold value was US$4,487.5 [18].

In Figs. 1 and 2, the transition of the population without and with nephroprotection over the three available years (2020, 2021, 2022 and 2023) is depicted. These figures show that the population without nephroprotection began with 24,7% of the population in a controlled state in 2020, which decreased to 18.8% by 2023. The percentage of the population that died started at 2.2% in 2020 and increased to 8.2% by 2023. Furthermore, 73.1% of the population was not controlled in 2020, decreasing to 73.0% by 2023. In contrast, the group with nephroprotection began with 24,8% of the population in a controlled state in 2020, which decreased to 20,1% in 2023, mortality rates for this group began at 2.3% in 2020 and increased to 9.0% by 2023, the uncontrolled population in this group accounted for 72.9% in 2020, decreasing

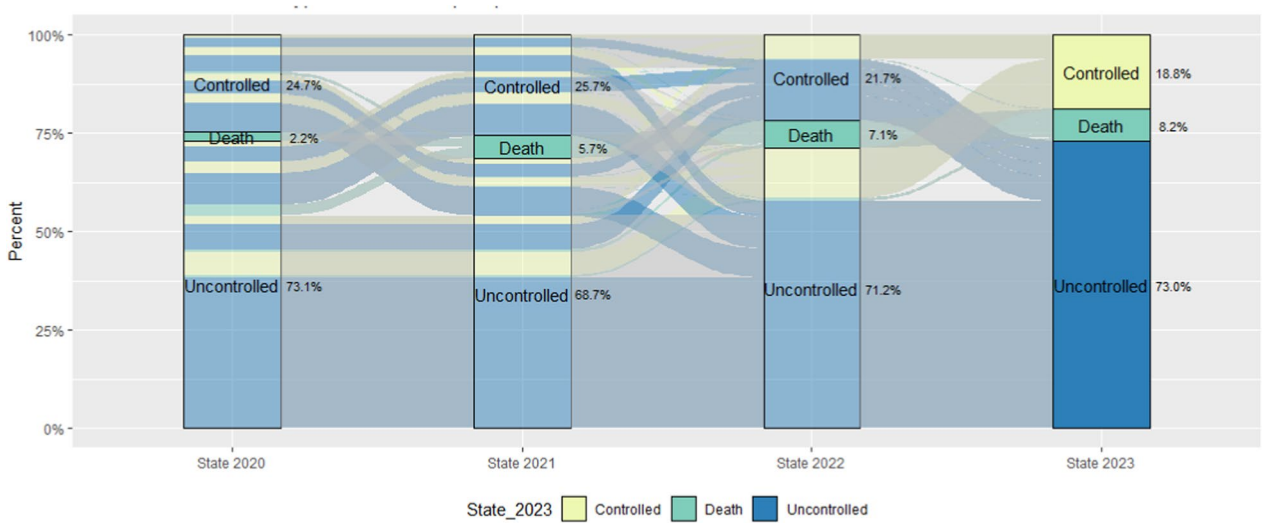

Fig. 1 Alluvial plot of diabetes Type 2 without nephroprotection

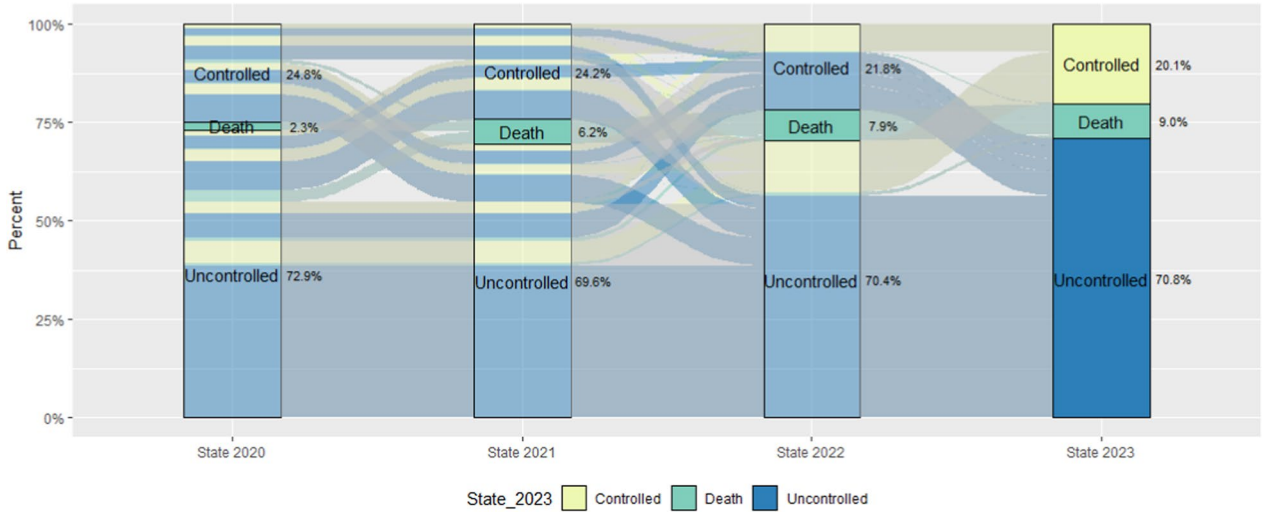

Fig. 2 Alluvial plot of diabetes Type 2 with nephroprotection

to 70.0% by 2023. Overall, these figures show that during the period from 2020 to 2023, patients enrolled in nephroprotection programs did not show much difference in the control rate compared to those who did not participate in nephroprotection programs. On average for the 4 years, 22.72% of patients were controlled with nephroprotection and 22.71% without nephroprotection program. (for more detailed transition information, please refer to Appendix 2).

Figure 3 presents two histograms for patients with and without nephroprotection. Given the presence of very high costs, the cost distribution analysis will only consider costs up to $1,000. In the histogram on the left, it is evident that the costs without nephroprotection have a positive skewness and a positive kurtosis over the four years. This indicates that most of the costs are concentrated in the lower values. In the histogram on the right, it can be seen that costs with nephroprotection also show a positive skewness.

Subsequently, Figs. 4 and 5 display the results of the transition probability matrix considering the behavior of patients from 2020 to 2023, differentiating between those who are in a nephroprotection program and those who are not. The relative risk (RR) is 0.9931201 and is

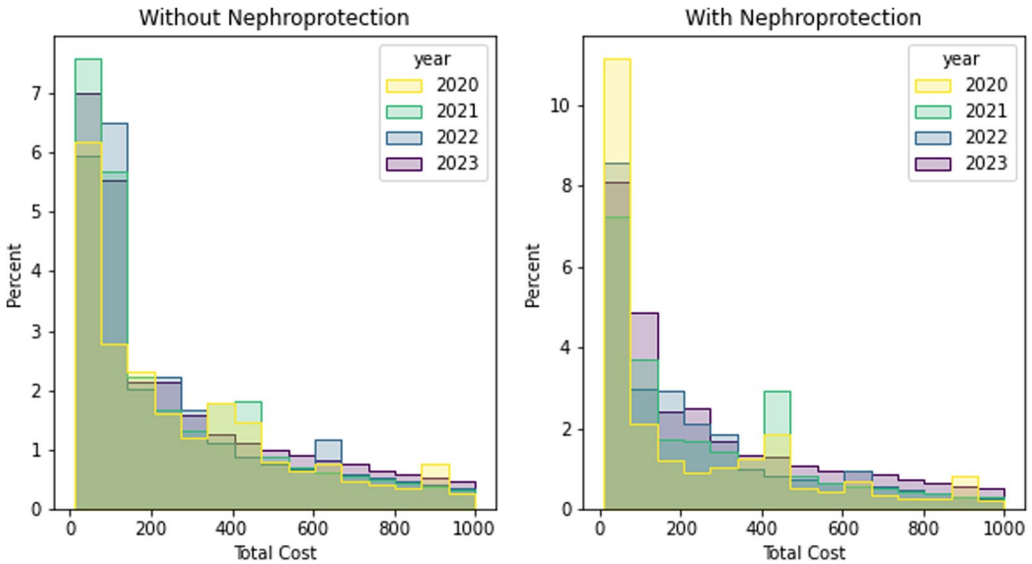

Fig. 3 Histogram of total cost

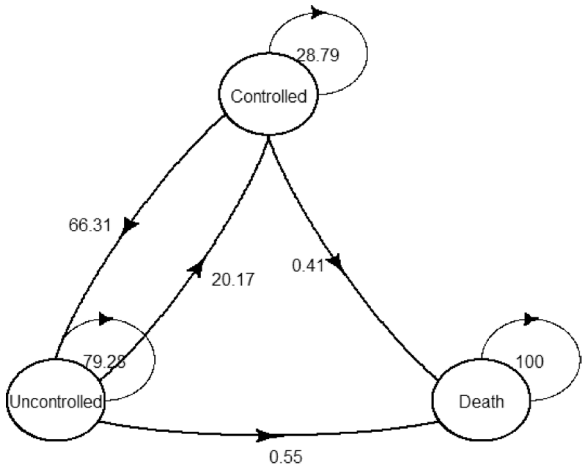

Fig. 4 Markov chain without nephroprotection

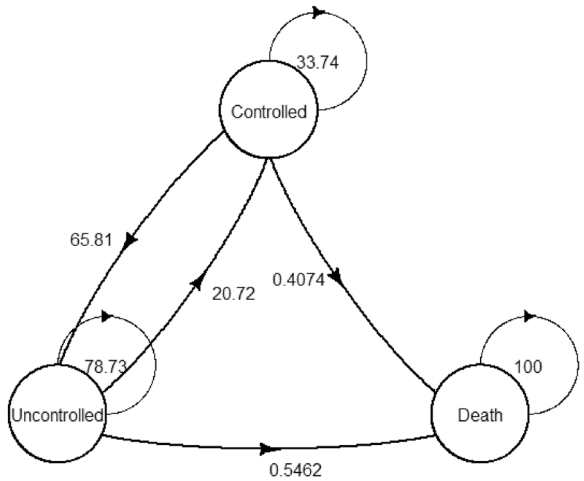

Fig. 5 Markov chain With nephroprotection

incorporated into the probabilities for patients with nephroprotection. Being in a program reduces the probability of being in the non-control state or dying (with death being an absorbing state in the model). Therefore, those with nephroprotection show a lower risk of being uncontrolled, implying higher effectiveness when nephroprotection programs are in place (for more detail of the transition probability matrix, please refer to Appendix 3).

Results

Figure 6 shows the simulations performed over a 10-year period using the Markov model. In both the group of 1,000 individuals with and without nephroprotection programs, the first panel on the left shows a decrease in the controlled population that tends to be stable from year 3. In contrast, the uncontrolled population shows a somewhat strong initial increase, but tends to decrease in year 3 and mortality always has a moderate increasing trend. On the other hand, the centre panel shows that the number of controlled individuals is slightly higher in the group with a nephroprotection program, while mortality and the number of uncontrolled individuals are slightly higher in the group without a nephroprotection program, although the difference is very small. Finally, in the right-hand panel, the count of individuals with efficiency defined as control is moderately higher in the population with nephroprotection program and the cost of the population without a nephroprotection program is higher, but the difference is not substantial compared to being in a nephroprotection program.

Table 4 illustrates that patients with T2DM who are in nephroprotection programs incurred an average annual total cost of $386,448.20 while patients without nephroprotection had an average annual total cost of $389,992, resulting in an incremental cost of -$3,544. This suggests that not having nephroprotection is more expensive. Additionally, the proportion of controlled patients in nephroprotection programs was 283.20 out of 1,000 people, whereas in the group without nephroprotection, it was 277.69. This presents an incremental effect of 5.51 indicating that nephroprotection is more effective. Considering these findings, an Incremental Cost-Effectiveness Ratio (ICER) of -$643.51 is presented for individuals under control of HbA1c and non-progression of CKD. This indicates that nephroprotection programs are a dominant strategy (for the estimated ICER from R and used in the Markov model, please refer to Appendix 4).

In Fig. 7, a cost-effectiveness plane after 1,000 iterations with Monte Carlo simulations in the Markov model is shown. In this analysis, the strategy of having a nephroprotection program is mostly dominant, as it showcases lower costs and higher effectiveness. On the other hand, having nephroprotection is a cost-effective strategy in 89.2% and dominant in 56.7% of Monte Carlo simulations. (for more details on the equations and approach of the Cost-Effectiveness model and Markov model, please refer to appendix 5).

In Fig. 8, the most sensitive variables in terms of costs are the cost of uncontrolled patients, followed by the cost of controlled patients, discount rate, and relative risk (RR). Similarly, Fig. 9 illustrates that in terms of effectiveness, the most sensitive variables is the RR. Finally, in Fig. 10, regarding ICER, the most sensitive variable is the cost of uncontrolled patients, followed by the RR, cost of controlled patients and discount rate.

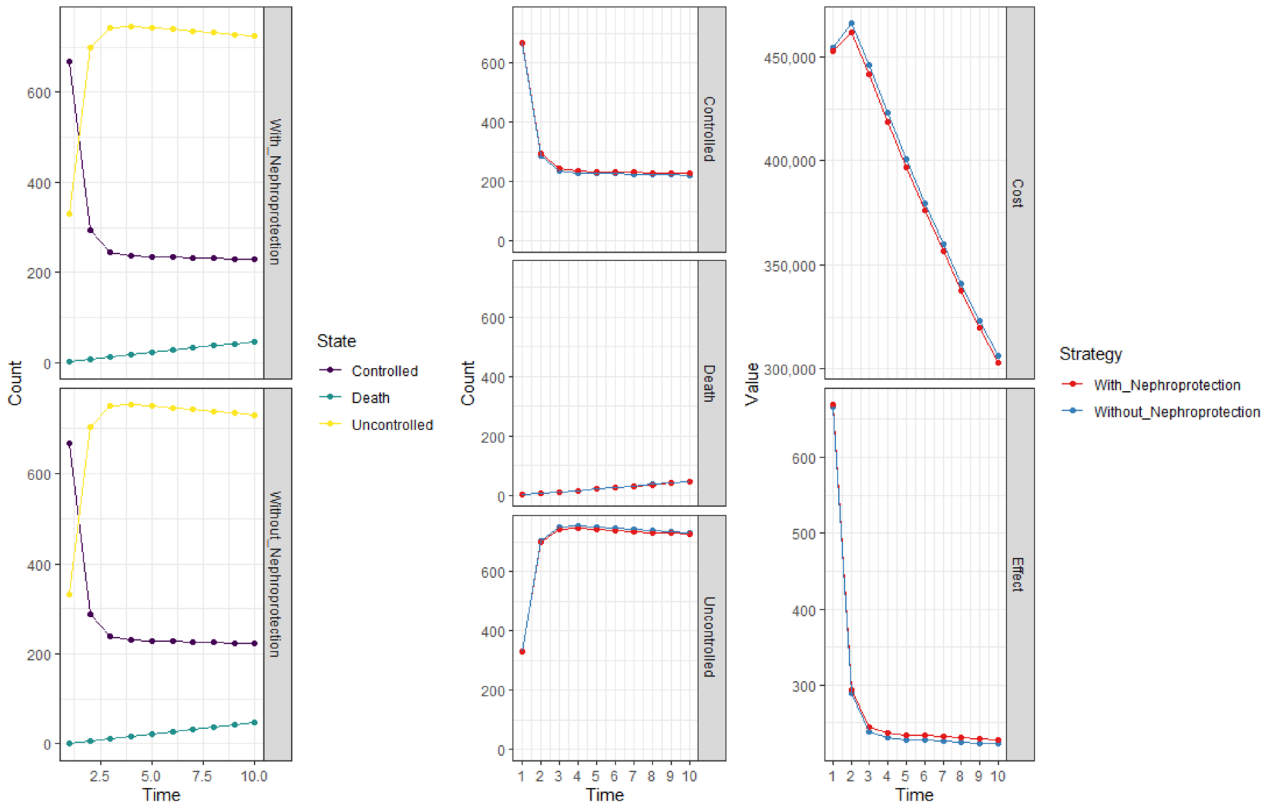

Fig. 6 Simulations of counts by state, strategy and value by strategy

Table 4 Incremental cost-effectiveness ratio (ICER)

Interventions	Total Cost ($USD 2023)	Effect (controlled patients)	CER [C/E]	ICER [ΔC/ΔE]
Without Nephroprotection	$ 389,992.00	277.69	$ 1,404	
With Nephroprotection	$ 386,448.20	283.20	$ 1,365	Dominant

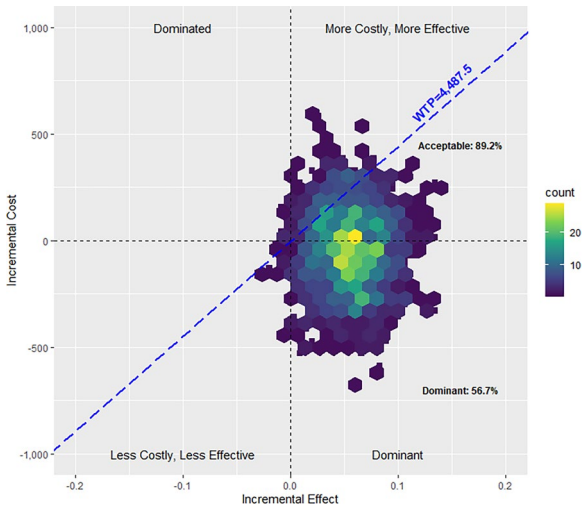

Fig. 7 Cost-effectives plane with nephroprotection

Discussion

The deterministic ICER shows that being in nephroprotection programs is cost-effective, defining effectiveness as control of T2DM with HbA1c levels equal to or less than 7% and a eGFR loss of less than 5 ml/min/1.72 m^2. This indicates that implementing a nephroprotection program, irrespective of the program level and CKD stage, for T2DM patients, results in lower costs and a higher proportion of controlled at-risk population compared to not having a program. These findings are supported by the Markov model in Fig. 6, which display the behavior of the three defined states (control, uncontrolled, and death) along with cost and effectiveness values. These figures show superior outcomes in the population with nephroprotection. Lastly, Fig. 7 demonstrates that the strategy of having any

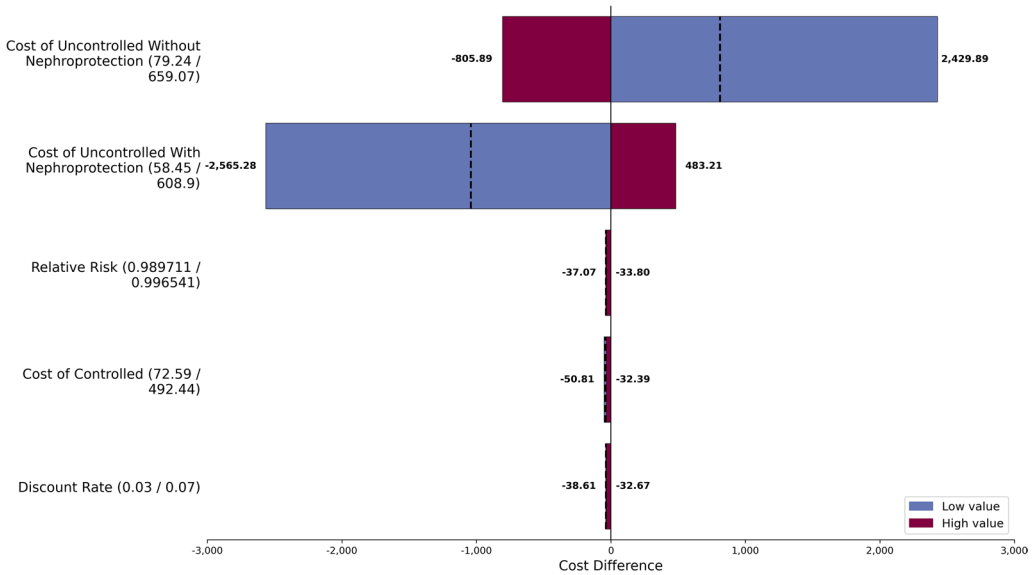

Fig. 8 Tornado diagram of incremental cost

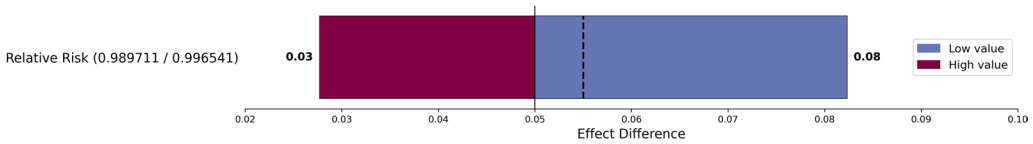

Fig. 9 Tornado diagram of incremental effect

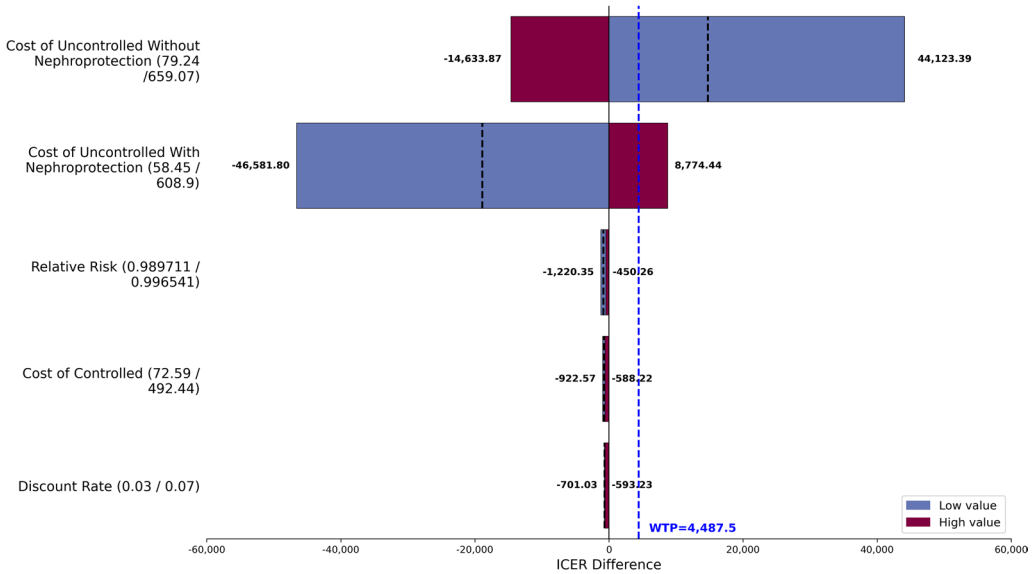

Fig. 10 Tornado diagram of ICER

nephroprotection program is cost-effective in 89.2% and dominant in 56.7% This is mainly due to the fact that in most cases it is below the WTP of $4,487.5 per controlled person and slightly more than half of the cases have positive incremental effectiveness and negative incremental costs.

It's important to note that other studies, such as Saldarriaga EM et al. [19], have shown that nephroprotection

is also a dominant strategy in Lima, Peru, considering effectiveness as quality-adjusted life years (QALYs) and using costs provided by one payer over a year, incorporating dialysis before mortality as states in the Markov model. Additionally, the research conducted by Guarin N et al. [20] in Colombia from 2010 to 2013 with a cohort of 17,000 patients presenting CKD, DM, and hypertension, which used QALYs and analyzed between basic and advanced nephroprotection programs, concluded that nephroprotection programs are cost-effective. Furthermore, the literature review by Abuabara-Franco E et al. concluded that nephroprotection programs are important and can have a positive impact on both years of life and quality of life, considering the implications of requiring dialysis [21]. These programs substantially reduce the financial burden associated with high costs incurred in renal replacement therapy (RRT) and non-dialytic medical treatment [21]. As a result, nephroprotection measures can prove to be cost-effective.

On the other hand, it is important to detail the limitations of this research. For starters, due to the general costs incurred by insurers annually, there is uncertainty regarding the specific healthcare technologies used. This leads to a significant heterogeneity in cost behavior, as can be seen in the distribution of the first 1,000 dollars in Fig. 3. Approximately 10.93% of the data presents costs above USD $1,000. This wide range of costs, both extremely high and very low, is considered in the Markov model. However, the presence of very low costs, especially in the 5 th percentile, with values around USD $0.25 to USD $0.49, is a reason for concern. To mitigate this, the decision was made to exclude these very low-cost outliers from the analysis.

Furthermore, regarding the nephroprotection intervention, it's common that the risk factors for CKD progression are not promptly addressed and lead to irreversible pathologic progression, as such early enrollment of patients in these programs improves patients well-being and adherence to interventions [22]. In consequence, it's crucial to consider the specific nature of the program. In this research, the focus is on whether there's entry into some form of nephroprotection program, without delving into the specific type and level of the program as described in other studies [9, 10, 21]. Different program levels have distinct objectives based on the degree of progression of chronic kidney disease (CKD). Additionally, this study takes a general approach, assuming the presence of a diagnosis of type 2 diabetes (T2DM) and progression to CKD, without specifying the CKD stage. The exclusion criteria only involve patients in renal replacement therapy (RRT) or non-dialytic medical treatment and CKD in stage G5. This generalization introduces uncertainty regarding the type of nephroprotection program and the CKD stage. The effectiveness is measured solely based on the achievement of HbA1c and eGFR with goals as defined by the CAC and clinical experts' nephroprotection consensus [7]. Lastly, the analysis was restricted to a 4-year period for the calculation of transition probability matrices, considering annual periodicity. This is because, in years before 2020, diagnostic information for DM was reported without differentiating the type of diabetes.

While this research benefits from utilizing nationwide data over a four-year period, taking into account the limitations mentioned earlier, it's advisable for future investigations to consider more detailed data. This could involve differentiating between types of nephroprotection programs and the specific healthcare technologies associated with annual costs. By doing so, a more comprehensive understanding of the cohort data used in constructing the Markov model can be achieved, thus enhancing the model's robustness. Additionally, distinguishing between various stages of chronic kidney disease (CKD) would provide insights into the outcomes based on the specific CKD stage, allowing for a more nuanced analysis of implications in line with disease progression.

Conclusions

The nephroprotection programs in general, without considering the level, for patients with type 2 diabetes (T2DM) in the period from 2020 to 2023 in Colombia, prove to be cost-effective, presenting an a dominant ICER. This calculation takes into account the total costs incurred in the year and considers as effectiveness the control of HbA1c at or below 7% and a decrease in eGFR of less than 5. This highlights the importance of these programs aimed at preventing, controlling, and limiting the impact caused by the progression of CKD, as well as the financial burden that arises when a patient undergoes non-dialytic medical treatment or RRT. Despite the limitations of not having certainty about the type of nephroprotection program and the discrimination of CKD stages, the Markov model and Monte Carlo simulations demonstrate that nephroprotection programs are cost-effective compared to not implementing any program. Moreover, the model reveals that the costs of patients who are not under control, followed by the costs of controlled patients and the effectiveness of controlled patients, are the most sensitive parameters of the model in terms of the ICER. This emphasizes that the costs of individuals not under control have the greatest financial impact on the cost-effectiveness of implementing a nephroprotection program.

Abbreviations

DM	Diabetes mellitus
HTA	Hypertension

IDF	International diabetes federation
T2DM	Type 2 diabetes mellitus
eGFR	Estimated glomerular filtration rate
CKD	Chronic kidney disease
CKD-EPI	Chronic kidney disease epidemiology collaboration
HbA1c	Glycated hemoglobin
SD	Standard deviation
RRT	Renal replacement therapy
CAC	High-cost diseases fund (Cuenta de Alto Costo in Spanish)
BanRep	Bank of the Republic (Banco de la República in Spanish)
RMR	Representative market rate (Tasa Representativa del Mercando in Spanish)
HEE	Health economic evaluation
RR	Relative risk
ICER	Incremental cost-effectiveness ratio
QALYs	Quality-adjusted life years

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12962-025-00618-8.

Additional file 1.

Additional file 2.

Additional file 3.

Additional file 4.

Additional file 5.

Additional file 6.

Additional file 7.

Additional file 8.

Additional file 9.

Additional file 10.

Additional file 11.

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C.A.G.R: Conceptualization, Methodology, Formal analysis, Visualization, Writing—original draft, Writing—review & editing. S.A.C.M: Conceptualization, Methodology, Formal analysis, Visualization, Writing—original draft, Writing—review & editing. L.A.S.V: Conceptualization, Methodology, review & editing, Supervision. L.A.A.M: Conceptualization, review & editing, Supervision. All authors read and approved the final manuscript.

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Availability of data and materials
The data that support the findings of this study are available from High Cost Diseases Fund (Cuenta de Alto Costo [CAC] in Spanish), but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are however available from on reasonable request via email to the coauthor: Luis Alberto Soler-Vanoy: lsoler@cuentadealtocosto.org.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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