Cost-effectiveness of population-based screening for chronic kidney disease among the general population and adults with diabetes in China: a modelling study

Fengyu Wen,[a,b] Jinwei Wang,[c,d,e,k] Chao Yang,[c,d,e,f,g,k] Fulin Wang,[a,b] Yan Li,[h,i,*] Luxia Zhang,[b,c,d,f,g,k,**] and José A. Pagán[j]

[a]Institute of Medical Technology, Peking University Health Science Center, Beijing, China
[b]National Institute of Health Data Science at Peking University, Beijing, China
[c]Renal Division, Department of Medicine, Peking University First Hospital, Beijing, China
[d]Peking University Institute of Nephrology, Beijing, China
[e]Research Units of Diagnosis and Treatment of Immune-mediated Kidney Diseases, Chinese Academy of Medical Sciences, Beijing, China
[f]Center for Digital Health and Artificial Intelligence, Peking University First Hospital, Beijing, China
[g]Advanced Institute of Information Technology, Peking University, Hangzhou, China
[h]School of Public Health, Shanghai Jiao Tong University School of Medicine, Shanghai, China
[i]Department of Population Health Science and Policy, Icahn School of Medicine at Mount Sinai, New York, NY, USA
[j]Department of Public Health Policy and Management, School of Global Public Health, New York University, New York, NY, USA
[k]State Key Laboratory of Vascular Homeostasis and Remodeling, Peking University, Beijing, China

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Summary

Background Despite the majority of patients with chronic kidney disease (CKD) live in low- and middle-income countries, most evidence on screening strategies is derived from high-income countries, where the contexts differ significantly. This study aims to assess the cost-effectiveness of population-based CKD screening strategies in both the general population and adults with diabetes in China.

Methods A validated microsimulation model of CKD was developed to evaluate the costs and health consequences of population-based CKD screening strategies from a societal perspective. A cohort of the population aged 45 years in China was simulated over their lifetime. Model parameters were estimated based on the existing literature and various data sources in China. Main outcomes included the averted number of cases with cardiovascular disease (CVD) and kidney failure with replacement therapy (KFRT) under the population-based screening strategy compared with usual care, and the incremental cost-effectiveness ratios (ICERs). CKD screening with different frequencies and for different age groups in both the general population and adults with diabetes were considered. One-way sensitivity analyses were performed to assess the robustness of the results.

Findings The ICER of annual screening starting at 45 years of age was $10,588 per quality-adjusted life year (QALY) for the general population and $9184 per QALY for adults with diabetes. Other screening strategies were also cost-effective compared to usual care, with ICERs less than three times the per-capita gross domestic product of China ($35,501). The most prominent absolute decrease in lifetime incidence of KFRT and CVD were also observed with the annual screening strategy in both the general population and in adults with diabetes. Specifically, the decreases were 1.88 and 8.55 per 1000 individuals for KFRT, and 35.07 and 19.92 per 1000 individuals for CVD, respectively.

Interpretation CKD screening in both the general population and adults with diabetes is cost-effective and could avert substantial numbers of KFRT and CVD cases in China.

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*Corresponding author. School of Public Health, Shanghai Jiao Tong University School of Medicine, 227 S. Chongqing Road, Shanghai 200025, China.
**Corresponding author. National Institute of Health Data Science at Peking University, 38 Xueyuan Road, Haidian District, Beijing 100191, China.
E-mail addresses: yanliacademic@gmail.com (Y. Li), zhanglx@bjmu.edu.cn (L. Zhang), wenfy1207@qq.com (F. Wen), gslzwjw@163.com (J. Wang), pkuyangchao@126.com (C. Yang), wangfulin0103@163.com (F. Wang), jose.pagan@nyu.edu (J.A. Pagán).

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Keywords: Cost-effectiveness analysis; CKD screening

Research in context

Evidence before this study

China accounts for more than one-sixth of the global chronic kidney disease (CKD) cases. However, awareness of CKD is low in China. Population-based CKD screening is crucial for early detection of CKD and prevention of its consequences, such as kidney failure and cardiovascular disease (CVD). We conducted a systematic literature search in PubMed and Web of Science from the inception of both databases until August 2024, using the search terms "cost-effectiveness" or "economic evaluation", "China" or "Chinese", "chronic kidney disease", "albuminuria", "screening", and "general population", to identify existing cost-effectiveness studies for CKD screening. We found no previous studies on cost-effectiveness of population-based screening for CKD in China. We also searched for studies on the cost-effectiveness of CKD screening in other countries using the same search terms, without "China" or "Chinese". These studies predominantly focus on high-income countries. Furthermore, the evidence supporting the cardiovascular benefits of population-based CKD screening is limited.

Added value of this study

To the best of our knowledge, this is the first study evaluating the cost-effectiveness of population-based CKD screening in China. We evaluated the cost-effectiveness of 15 screening strategies, combining three starting ages for screening (45 years, 55 years, and 65 years) and five screening frequencies (once per lifetime, once every 10 years, once every 5 years, once every 2 years, and annual screening). We found that annual screening starting at 45 years of age was the most cost-effective strategy for the general population, with an incremental cost-effectiveness ratio (ICER) of $10,588 per quality-adjusted life years (QALY), as well as for adults with diabetes, with an ICER of $9184 per QALY. Moreover, decreases in lifetime incidence of kidney failure with replacement therapy (KFRT) and CVD were observed with the CKD screening in both the general population and in adults with diabetes.

Implications of all the available evidence

Our findings suggest that CKD screening in both the general population and adults with diabetes is cost-effective and could reduce the incidence of KFRT and CVD in China. Strengthening adherence to CKD screening and treatment is critical for population-based screening and CKD management. These findings provide useful insights that can inform CKD screening in China and other low- and middle-income countries with similar settings.

Introduction

Chronic kidney disease (CKD) is a major global health challenge. With an increasing trend in CKD prevalence since 1990, it was estimated that 850 million people worldwide were affected by CKD in 2017.[1] The majority of CKD cases occurred in low- and middle-income countries (LMICs), accounting for two-thirds of the global burden.[2] CKD, even at an early stage, can substantially increase the risk of cardiovascular disease (CVD), kidney failure, and mortality.[3–5] The disease has been the third fastest growing cause of death globally over the past three decades.[6] It is estimated that CKD will become the fifth leading cause of death by 2040, accounting for more than 1.18 million deaths annually.[7]

Early intervention effectively slows CKD progression and reduces the risk of CVD, kidney failure, and all-cause mortality.[8,9] However, CKD does not present apparent symptoms at an early stage, often leading to underdiagnosis and low awareness rate.[10] Even high-risk patients, such as those with hypertension and diabetes, often remain undiagnosed until a substantial decline in kidney function or the onset of multiple complications. CKD awareness has been estimated to be about 19.2% globally.[11] In LMICs, the awareness rate has been estimated to be even lower (6% and 10% in general and high-risk cohorts, respectively).[10] Therefore, population-based CKD screening is crucial for early detection and effective prevention of more severe consequences, especially in LMICs with a high burden of CKD.

Despite the importance of population-based CKD screening programs, they are often not available in LMICs.[10] One reason is that evidence on the cost-effectiveness of CKD screening is predominantly focused on high-income countries (HICs), and the recommendations in the *Kidney Disease: Improving Global Outcomes* (KDIGO) guidelines have limited applicability to the implementation of CKD screening programs in LMICs.[10,12–15] There are several limitations in existing cost-effectiveness studies of CKD screening in HICs, such as the omission of CVD outcomes and the use of imprecise disease parameters in models.[11] Moreover, the conclusions drawn from previous studies in HICs may not be directly applicable to LMICs.[16–18] The target population and frequency of CKD screening should be tailored based on regional income levels and disease profiles, which is crucial to ensure that screening programs are both cost-effective and actionable.[19]

China, as an LMIC, accounts for more than one-sixth of the global CKD cases, with diabetes being the leading risk factor of CKD.[20,21] However, awareness about CKD was only 10%, and there is a lack of studies on the cost-effectiveness of CKD screening in China.[22] In this study, we aimed to evaluate the cost-effectiveness of population-based screening for CKD in the general population as well as adults with diabetes in China. Our study would fill the research gap regarding the cost-effectiveness of CKD screening in LMICs. The findings not only provide evidence to support policy-making in China but also contribute to guiding similar research efforts in other LMICs, thereby fostering greater global attention to CKD prevention and management.

Methods

Model overview

We developed a microsimulation model of CKD that integrates CKD progressions and CVD events over the lifetime. Unlike a Markov cohort model, which assumes homogeneous transitions across populations, a microsimulation model allows for the simulation of individual patient trajectories, capturing the impact of patient history—such as prior CVD events—on the risk of subsequent events. This approach enables a more nuanced and accurate representation of disease progression and its interplay with comorbidities, providing greater flexibility and precision in modeling complex, personalized health outcomes.[23] From a societal perspective, we assessed the cost-effectiveness of different population-based screening strategies compared with usual care in China. A half-cycle correction was applied. The model was constructed using TreeAge Pro 2021, and the analysis was reported in line with the Consolidated Health Economic Evaluation Reporting Standards 2022 (CHEERS 2022) guidelines.[24]

We simulated the onset, progression, and treatment of CKD in a cohort of 100,000 individuals 45 years of age. This age is a threshold for a higher prevalence of chronic disease and mortality, and it is also the starting age for CKD screening in previous studies.[14,25,26] The model employed a one-year time cycle and included nine mutually exclusive health states (Supplementary Fig. S1): stage 1–2, 3, and 4–5 CKD (both treated and untreated), dialysis, kidney transplantation, and death. Stages 1–2, 3, and 4–5 CKD were defined by an estimated glomerular filtration rate (eGFR) ≥ 60 mL/min/1.73 m^2, 30–59 mL/min/1.73 m^2, and < 30 mL/min/1.73 m^2, respectively. Although patients with an eGFR ≥ 60 mL/min/1.73 m^2 but a urine albumin-creatinine ratio (UACR) ≥ 30 mg/g were categorized as being in the stage 1–2 state, they had an increased risk of CVD and death compared with those without CKD. CKD progression included an increase in albuminuria and a decline in eGFR. We simulated kidney damage by first specifying the prevalence of micro- and macroalbuminuria at age 45 years, followed by incorporating the annual incidence of microalbuminuria and progression rate from microalbuminuria to macroalbuminuria. The incidence and progression rates were stratified by age, diabetes, and hypertension. As a measure of kidney function, an initial eGFR was assigned to each individual and reduced annually. Dialysis was initiated when a patient's eGFR fell below a threshold. In China, the average duration of dialysis before kidney transplantation was 25.7 months in 2019.[27] We assumed that patients underwent at least one year of dialysis before receiving a kidney transplant. Kidney failure with replacement therapy (KFRT) was defined as the initiation of dialysis or transplant.

In this model, diabetes and hypertension were risk factors for greater annual reductions in eGFR, faster progression of albuminuria, and increased mortality rates. The initial prevalence of diabetes and hypertension in 45-year-old individuals and subsequent annual incidence rates were assigned. The model included CVD as an outcome because it is an important complication of CKD. We assumed that patients may experience multiple CVD events during their lifetime. Once a patient was identified as having a baseline history of CVD or had experienced a new CVD event, the probability of experiencing subsequent CVD events increased in future cycles. The occurrence of CVD was influenced by age, CKD, hypertension, and diabetes. CVD is defined as coronary heart disease, heart failure, ischemic stroke, and peripheral arterial disease. Patients in every health state could die, with the probability determined by age, CKD, diabetes, hypertension, and CVD.

We calculated the prevalence of CKD, albuminuria, diabetes, hypertension, CVD, and life expectancy under usual care. We then validated the model against the corresponding indicators from several national studies.[28,29] In addition, the incidence of dialysis was also validated by comparing the parameters of different age groups with those in previous studies, since lifetime incidences were reported in this study.

Screening and treatment

We simulated the process from entry into a screening program to initiation of treatment (Supplementary Fig. S2). The screening included simultaneous testing of UACR and serum creatinine to calculate eGFR. If the test results showed an abnormality (UACR ≥ 30 mg/g or eGFR < 60 mL/min/1.73 m^2), the person was advised to seek a clinical evaluation by a nephrologist. If a diagnosis was confirmed, treatment was recommended. We collected data on the sensitivity and specificity of UACR and GFR tests from previous studies (Table 1). In cases of false positive results, individuals were still

Parameter	Base case value	Source
Adherence		[22,30–32]
Screening	0.93	
Clinical evaluation	0.85	
Treatment after diagnosis	0.80	
UACR test		[33]
Sensitivity	0.87	
Specificity	0.88	
GFR test		[15,34,35]
Sensitivity		
GFR 60-30	0.60	
GFR < 30	0.95	
Specificity	0.91	
Screening and evaluation costs per person, $		Supplement S2[a]
Screening	16	
Clinical evaluation		
No biopsy	37	
Biopsy	1423	
Annual costs per person, $		Supplement S2[b]
G1–G2 & albuminuria	1974	
G3	2967	
G4–G5	4995	
Dialysis	12,986	
DM	313	
CVD	588	
Transplant first year	20,718	
Transplant >1 year	2762	
Utility decrease		C-STRIDE,[36–38]
G3	0.02	
G4	0.07	
G5	0.11	
Dialysis	0.23	
Transplant	0.18	
CVD	0.06	
DM	0.03	
Treatment effect, hazards ratio		[39,40]
Mortality	0.93	
CVD events	0.73	
GFR reduction	0.64	
Albuminuria progression	0.45	

C-STRIDE: The Chinese Cohort Study of Chronic Kidney Disease. UACR: urine albumin-creatinine ratio. GFR: glomerular filtration rate. DM: diabetes mellitus. CVD: cardiovascular disease. [a]Screening and evaluation costs were obtained from medical service prices in several provinces and from data at Peking University First Hospital. The detailed calculation was listed in Supplement S2. [b]Annual treatment costs were obtained from the China Kidney Disease Network (CK-NET)-Yinzhou Study, the China Health and Retirement Longitudinal Study (CHARLS), CK-NET 2016 Annual Data Report.[30,41–43] The detailed calculation was listed in Supplement S2.

Table 1: **Key parameters used in the model.**

advised to undergo a clinical evaluation, but they ultimately would not be diagnosed. We assumed that these individuals might still participate in subsequent screenings. The model included adherence rates for screening, clinical evaluation, and treatment to better capture the reality.

According to the American Diabetes Association and KDIGO guidelines, screening for CKD with eGFR and UACR testing is recommended for adults with diabetes.[44] Besides, the primary cause of CKD in China shifted from glomerulonephritis to diabetes around 2011, and the proportion of diabetes-related CKD has continued to rise since then.[41,45] Therefore, screening for CKD among adults with diabetes was also considered in our analyses.

Usual care included annual incidental testing, the probabilities of which were stratified by diabetes and hypertension. We estimated these probabilities from the China Health and Retirement Longitudinal Study (CHARLS) 2015.[42] We defined 15 screening strategies, which included three starting ages for screening (45 years, 55 years, and 65 years) and five screening frequencies (once per lifetime, once every 10 years, once every 5 years, once every 2 years, and annual screening). We assumed that individuals aged 75 years and older would not receive screening.

For patients who followed medical advice, we assumed that they would receive treatment with ACE inhibitors (ACEIs) or angiotensin receptor blockers (ARBs), as recommended by KDIGO guidelines.[46] The benefits of treatment included slowing the progression of CKD by reducing the rate of eGFR decline and the progression of albuminuria, as well as reducing mortality and risk for CVD. All treatment effects were based on conservative estimates derived from systematic reviews and randomized controlled trials (RCTs).[39,40]

Data collection

We collected data to parameterize CKD progression, utility, cost, and other parameters from the literature, as well as from regional and national databases of the Chinese population. The baseline distribution of eGFR (at 45 years) and prevalence of micro- and macroalbuminuria, stratified by diabetes, were estimated based on a nation-wide survey with a representative sample of Chinese general population.[30] Annual eGFR declines were derived from several studies specific to China, the above-mentioned national survey, and a follow-up cohort in Peking University First Hospital. Similar to previous studies, we assumed that eGFR declines did not change through CKD stages for persons with no hypertension, no diabetes, and no increased albuminuria.[47,48] Due to the lack of evidence on the transition probabilities for the progression of albuminuria (A1 to A2 and A2 to A3) in the Chinese population, we used quadratic programming to estimate these probabilities, which predicted the prevalence derived from the national survey data.[30,48,49] Age-specific mortality was obtained from the 2021 National Cause of Death Surveillance Dataset.[50]

Costs and utilities

Since this study was conducted from a societal perspective, we included direct screening, medical, and indirect costs. Direct medical costs included the costs of evaluation and treatment and were estimated using data from the Chinese Electronic Health Records Research in the China Kidney Disease Network (CK-NET)-Yinzhou Study and CHARLS.[42,43] The annual medical costs for dialysis were obtained from CK-NET 2016 Annual Data Report, which provided a comprehensive overview of the burden of kidney disease in China, based on a national surveillance system.[41] The indirect costs included costs of hired nurse, transportation, food and accommodation of patients and their relatives, which were estimated from CHARLS. The other indirect costs included income losses of patients, relatives, and screening recipients based on time spent and per capita daily income in China, which was obtained from China Statistical Yearbook 2022.[51] We assumed that patients with undetected CKD incurred costs for diabetes and CVD, but not for CKD.[13] Patients with more advanced eGFR stages detected incurred larger costs. All costs in the model have been converted to United States (US) dollars (CNY$1 = US$0.1381, in 2024). The detailed cost estimation is described in the Supplement S2.

To determine health-related quality of life (HRQOL), we estimated stage-specific utility values based on published studies of Chinese patients with CKD and questionnaire data from the Chinese Cohort Study of Chronic Kidney Disease (C-STRIDE).[36,37,52] For a given CKD stage, we assumed that there were no differences in utility according to albuminuria status, detection, or treatment status.

Cost-effectiveness analysis

We calculated the ICER for each screening strategy vs. usual care. Total life years (LY), lifetime incidence of KFRT, and CVD were also calculated. As recommended by the World Health Organization (WHO),[53] screening strategies with an ICER less than, between one and three times, and more than three times the gross domestic product (GDP) per capita were considered as highly cost-effective, cost-effective, and not cost-effective, respectively. The willingness-to-pay (WTP) threshold was set as three times GDP per capita ($35,501, for China in 2022). Costs and quality-adjusted life-years (QALYs) were discounted at 3% annually.[54,55]

Sensitivity analysis

To evaluate how uncertainties in model input influence ICERs, we performed one-way and probabilistic sensitivity analysis. In one-way sensitivity analysis, each parameter was varied by 20% around its base case value, with all other parameters held constant (see Supplement S2 for details). The results were presented as tornado diagrams with the width of the bars indicating the influence on ICERs. Probabilistic sensitivity analysis was conducted using 1000 Monte Carlo simulations. The cost-effectiveness acceptability curves were plotted to display the probability of strategies being cost-effective at different WTP thresholds. Specifically, for each WTP value, the net monetary benefit (NMB) was calculated for each strategy, and the proportion of simulations in which each strategy achieved the highest NMB was recorded. The NMB was defined as effectiveness × willingness-to-pay − cost. The beta distribution was assigned to transition probabilities and quality of life utility values, the gamma distribution was assigned to costs, and the log-normal distribution was used for the treatment effects (Supplementary Table S2). To provide evidence for decision-makers with different priorities, in addition to the societal perspective, we also evaluated the cost-effectiveness of screening from the healthcare sector perspective (see Supplement S2 and S5 for details).

Role of the funding source

The funders of the study had no role in the study design, data collection, data analysis, data interpretation, writing of the report, or decision to publish.

Results

Model validation

The model projected outcomes closely matched the estimates from national studies. Under usual care, the incidence of KFRT between the model and the annual data report from the CK-NET was estimated to be 286 vs. 296 per million population.[41] The estimated life expectancy at 45 years based on the model was 37.9 years, which was similar to the reported average life expectancy in China (36.7 years).[56] The model estimated prevalence for stage 3–5 and albuminuria lay between the prevalence values from two national surveys.[22,30] The estimated prevalence of hypertension, diabetes, and CVD was also in line with those reported from the previous studies.[28,29] The detailed results of internal and external validation are provided in Supplement S3.

Effectiveness

Under usual care, the lifetime incidence of KFRT in the general population aged 45 was estimated to be 1.05%. The incidence rates of both CVD and KFRT decreased under all screening strategies. Compared with adults with diabetes, the general population was estimated to have larger reductions in the incidence of CVD, but smaller reductions in the incidence of KFRT (Table 2, Fig. 1, Supplement S4). Specifically, annual CKD screening starting at age 45 could reduce the CVD incidence rate by 35.07 per 1000 individuals in the general population, and by 19.92 per 1000 individuals in adults with diabetes. In terms of the reductions of KFRT incidence with annual screening for 45-year-olds, we estimated a 1.88 per 1000 reduction in the general population, and a larger 8.55 per 1000 reduction in adults with diabetes.

Screening for CKD increased QALYs compared with usual care. As the starting age increased and the frequency decreased, the health benefits of CKD screening

	Lifetime incidence of CVD			Lifetime incidence of KFRT		
	Events per 1000 individuals	Absolute decrease	Relative decrease (%)	Events per 1000 individuals	Absolute decrease	Relative decrease (%)
General population						
Usual care	429.65			10.54		
Once	426.00	3.65	0.85	9.96	0.58	5.50
Every 10 years	421.13	8.52	1.98	9.46	1.08	10.25
Every 5 years	413.34	16.31	3.80	9.16	1.38	13.09
Every 2 years	401.28	28.37	6.60	8.89	1.65	15.65
Annually	394.58	35.07	8.16	8.66	1.88	17.84
Adults with diabetes						
Usual care	376.14			58.09		
Once	372.35	3.79	1.01	55.90	2.19	3.77
Every 10 years	370.44	5.70	1.52	53.79	4.30	7.40
Every 5 years	366.41	9.73	2.59	52.02	6.07	10.45
Every 2 years	359.87	16.27	4.33	50.54	7.55	13.00
Annually	356.22	19.92	5.30	49.54	8.55	14.72

CVD: cardiovascular disease. KFRT: kidney failure with replacement therapy. Onset of CVD and KFRT before age 45 was excluded. All screening scenarios were compared with usual care.

Table 2: **Benefits of CKD screening for cardiovascular disease and kidney failure with replacement therapy in the general population and adults with diabetes aged 45 years.**

diminished. For the general population aged 45 years, gains in QALYs were estimated to be the highest with annual screening (0.213 QALYs per person), followed by every two years (0.169 QALYs per person), and the least with one-off screening (0.038 QALYs per person). Compared with annual screening starting at age 45, those starting at ages 55 and 65 years had comparatively smaller effects (Table 3). For adults with diabetes, a similar pattern was observed: the earliest and most intensive screening (annual screening starting at age 45) yielded the highest QALY gain of 0.275, while the latest one-off screening starting at age 65 yielded the lowest QALY gain of 0.014.

Given that China has a 547.5 million population between the ages of 45 and 75, annual CKD screening starting at age 45 would prevent more than 19.2 million CVD cases and 1.0 million KFRT cases compared with usual care, with a relative reduction of 8.16% and 17.84%, respectively. Moreover, approximately 327.4 million life-years and 116.6 million QALYs would be gained under this strategy.

Costs and cost-effectiveness

Screening for CKD could result in a healthcare cost increase of $453 to $2256 for the general population, and $321 to $2526 for adults with diabetes (Table 3).

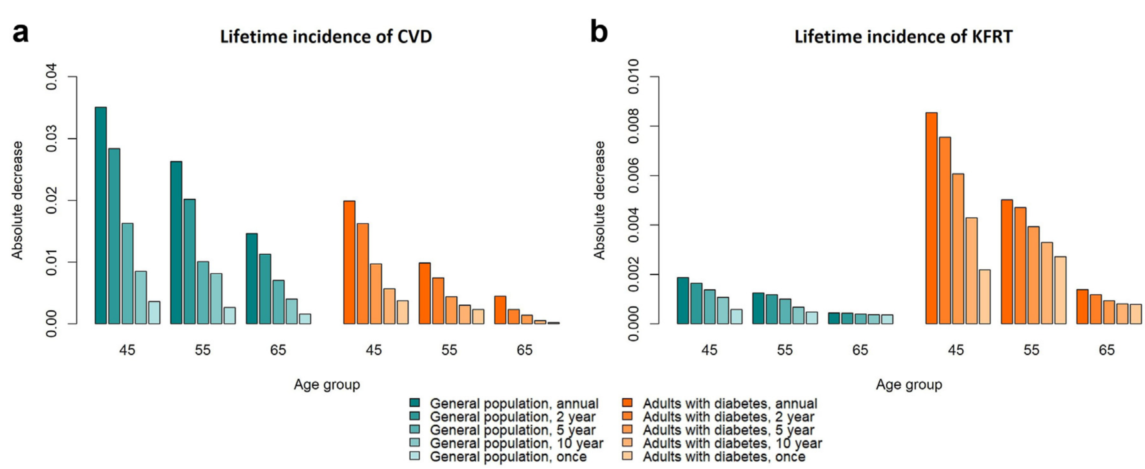

Fig. 1: **Absolute decreases in lifetime incidence of CVD (a) and KFRT (b) from CKD screening at 45 years of age in comparison with usual care.** CVD: cardiovascular disease. KFRT: kidney failure with replacement therapy.

	General population						Adults with diabetes					
	Life years	QALYs	Incremental QALYs	Costs, $	Incremental costs, $	ICERs, $	Life Years	QALYs	Incremental QALYs	Costs, $	Incremental costs, $	ICERs, $
45-year-old												
Usual care	37.861	21.644		7532			32.860	19.160		19,897		
Once	37.954	21.682	0.038	8252	720	18,980	32.965	19.209	0.050	20,766	869	17,545
Every 10 years	38.097	21.726	0.082	8812	1281	15,541	33.084	19.253	0.093	21,240	1343	14,421
Every 5 years	38.175	21.756	0.112	9227	1695	15,160	33.177	19.293	0.133	21,672	1775	13,319
Every 2 years	38.328	21.813	0.169	9637	2105	12,452	33.329	19.354	0.194	22,229	2332	12,028
Annually	38.459	21.857	0.213	9788	2256	10,588	33.529	19.435	0.275	22,423	2526	9184
55-year-old												
Usual care	28.024	18.164		8273			23.109	15.239		20,214		
Once	28.087	18.195	0.031	8852	579	18,421	23.168	15.269	0.031	20,684	470	15,286
Every 10 years	28.128	18.213	0.049	9188	915	18,607	23.207	15.286	0.048	20,938	723	15,137
Every 5 years	28.205	18.245	0.081	9499	1226	15,191	23.235	15.301	0.063	21,209	995	15,859
Every 2 years	28.284	18.280	0.116	9889	1616	13,881	23.356	15.358	0.119	21,657	1443	12,105
Annually	28.350	18.305	0.141	10,123	1850	13,081	23.384	15.371	0.132	21,843	1629	12,316
65-year-old												
Usual care	18.500	13.265		7537			14.100	10.197		16,789		
Once	18.541	13.290	0.025	7990	453	17,977	14.122	10.211	0.014	17,110	321	23,413
Every 10 years	18.565	13.301	0.037	8152	615	16,861	14.125	10.212	0.014	17,222	433	29,895
Every 5 years	18.586	13.313	0.048	8329	792	16,620	14.146	10.223	0.026	17,366	577	21,875
Every 2 years	18.645	13.345	0.080	8614	1077	13,431	14.213	10.262	0.065	17,656	868	13,283
Annually	18.709	13.378	0.113	8832	1295	11,463	14.219	10.265	0.068	17,825	1036	15,252

QALYs: quality-adjusted life-years. ICERs: incremental cost-effectiveness ratios. All screening scenarios were compared with usual care.

Table 3: **Cost-effectiveness of CKD screening in the general population and adults with diabetes.**

Among all screening strategies for the general population, annual screening at age 45 was the most cost-effective, with an incremental cost of $2256 and an ICER of $10,588 per QALY gained. For adults with diabetes, this strategy was also the most cost-effective, with an incremental cost of $2526 and an ICER of $9184 per QALY gained. Moreover, the ICERs of annual screening at age 45 for both the general population and adults with diabetes were less than one time GDP per capita ($11,834), indicating that this strategy would be highly cost-effective. Despite the differences in ICERs across different screening strategies, all the screening strategies were less than three times GDP per capita ($35,501) and, thus, were considered cost-effective.

Sensitivity analysis

In the one-way sensitivity analysis, we found that variations in the parameters did not significantly alter the results (Supplement S6). As Fig. 2 shows, when the treatment adherence increased by 20%, the ICER for annual screening starting at age 45 would decrease to $9159 per QALY for the general population and $7459 per QALY for adults with diabetes. In comparison, when the adherence rate decreased by 20%, the ICER would increase to $12,293 per QALY and $10,354 per QALY for the general population and adults with diabetes, respectively.

For the general population and adults with diabetes, annual screening was most likely to be the most cost-effective strategy among all screening frequencies when the WTP ranged from $11,834 to $35,501 (one to three times GDP per capita, Supplement S7). At a WTP threshold of one time GDP per capita, the probability of cost-effectiveness for annual screening starting at age 45 years was 45% in the general population and 89% in the population with diabetes. From the healthcare sector perspective, consistent with the findings from the societal perspective, annual screening starting at age 45 remained the most cost-effective strategy for both the general population and adults with diabetes, with ICERs of $9162 and $7759 per QALY gained, respectively (Supplement S5).

Discussion

To the best of our knowledge, this is the first study comprehensively evaluating the cost-effectiveness of population-based CKD screening strategies in China. Our study found that annual CKD screening starting at age 45 was the most cost-effective approach, leading to substantial decreases in the incidence of KFRT and CVD both in the general population and among adults with diabetes. These findings have significant implications for clinical care and public health policy in China,

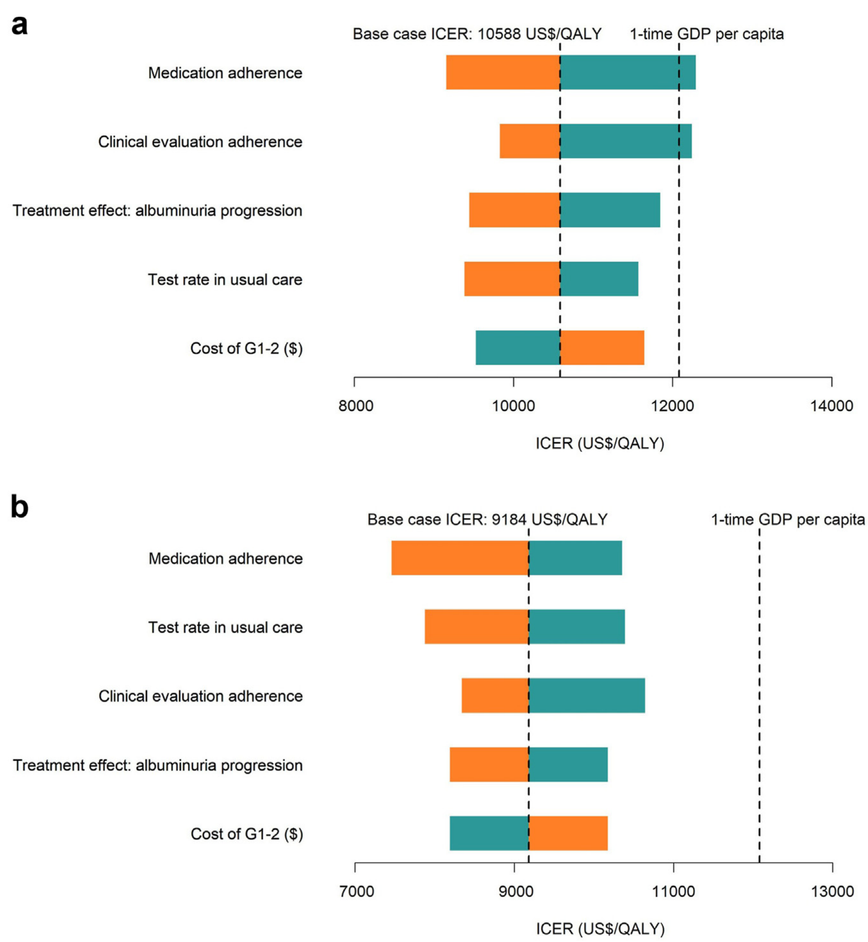

Fig. 2: **One-way sensitivity analysis.** The top five parameters that had the greatest impact on the ICER of annual screening for 45-year-old general population (a) and adults with diabetes (b) compared with usual care. The orange bars represent the ICER obtained with the highest variable input, while the teal green bars represent the ICER obtained with the lowest variable input. ICER: incremental cost-effectiveness ratio. QALY: quality-adjusted life-year. GDP: gross domestic product.

especially regarding the implementation of early detection and intervention strategies for CKD.

While existing CKD microsimulation models provide valuable insights, most are designed based on populations in HICs and may not be directly applicable to LMICs.[14,16–18] Firstly, there are notable disparities in the burden of CKD and KFRT between HICs and LMICs, which can significantly influence model parameters and outcomes.[57,58] For instance, the prevalence of CKD in China is substantially lower than in the US (8.2% vs. 14.9%).[22,59] Furthermore, the distribution of eGFR categories varied between China and US, partly influenced by the diversity of potential risk factors associated with CKD.[60] Similarly, in this model, the prevalence of eGFR < 60 mL/min/1.73 m^2 among the general population aged 45–75 years was estimated to range from 1.04% to 9.12%, which is markedly lower than the 3.19% to 16.85% estimated by a CKD model in the US.[48] Moreover, the incidence of dialysis in China is lower than in the US (116.1 vs. 374.1 per million population), aligning with this model's lower estimated lifetime incidence of KFRT compared to US-based models (1.05% vs. 2.36%).[13,41,57] Secondly, differences exist in the incidence rates of CKD complications. Two CKD cohort studies with similar designs, conducted in China and the US, respectively, demonstrated that the incidence rates of both kidney failure and CVD in the US-based Chronic Renal Insufficiency Cohort (CRIC) were approximately twice as high as those observed in the China-based C-STRIDE study.[61,62] Finally, CKD models are developed to inform health policy decisions, but key factors such as healthcare costs and affordability vary widely between countries, influencing the cost-effectiveness of screening and intervention strategies.[58] As a result, there is a clear need for a CKD progression model specifically tailored to the Chinese population, addressing local disease prevalence, healthcare resources, and policy priorities to ensure its relevance and utility.

Previous studies have assessed the cost-effectiveness of CKD screening for individuals with CKD risk factors.[63] For example, Boulware et al. and Hoerger et al. found that screening for proteinuria or albuminuria was cost-effective among patients with hypertension or diabetes in the US.[47,48] Moreover, screening for eGFR has been widely demonstrated to meet cost-effectiveness thresholds in Canada, Japan, and Korea.[15,64,65] However, evidence is limited in LMICs.[10] Srisubat et al. found that annual microalbuminuria screening was cost-effective in adults with diabetes in Thailand.[66] Cha'on et al. found that community-based screening of both albuminuria and eGFR was also cost-effective in rural population in the Northeast Thailand.[67] Although these two studies focused on LMICs, they either lacked an analysis of the general population or did not explore different screening strategies, such as different age groups and screening frequencies. These limitations not only affect the effectiveness of screening but also limit its practical implementation. Given financial constraints in LMICs, it is particularly crucial to develop tailored screening strategies according to the specific circumstances of each country.[68,69] Our study not only emphasized the potential benefit of CKD screening in China but also provides some insights that can inform CKD screening in other LMICs.

Two previous studies found that population-based CKD screening followed by treatment with ACEIs or ARBs in the general population was not cost-effective[63,68]; yet, our study found it was cost-effective in the Chinese population. There are several possible explanations on the difference in the findings. First, individuals with early CKD, characterized by moderately increased albuminuria or mildly decreased kidney function, are at substantial risk of CVD.[10] This highlights the broader clinical importance of CKD screening, not only for addressing kidney-related outcomes but also for its potential to improve cardiovascular health. Unlike most previous studies that primarily focused on CKD-related cost savings and health benefits,[13,64] our study also considered the prevention of CVD by early CKD detection and treatment. This expanded focus underscores the potential for greater overall health benefits and further enhances the cost-effectiveness of screening in the general population. Second, factors such as cheaper labor and widespread primary healthcare,[70,71] which reduce the costs of screening, enhance its cost-effectiveness. Third, our study evaluated the combined screening of albuminuria and serum creatinine, which was more likely to identify early CKD patients compared to single tests.[13,64] Last but not least, cost-effectiveness is directly related to willingness to pay. In HICs, higher economic conditions allow for higher WTP thresholds. In our study, the WTP threshold was set at three times the GDP per capita ($35,501), lower than the thresholds used in HICs like Japan ($70,093) and the US ($100,000).[13,72]

Our findings provide insights into both the benefits and cost-effectiveness of CKD screening in adults with diabetes. Our study demonstrated that CKD screening of the population 45 years of age and older can reduce the incidence of KFRT, with greater reductions in adults with diabetes than in the general population, which is consistent with previous studies.[48,73] In contrast to the well-documented benefits of CKD screening in KFRT, few studies reported CVD benefits for the general population, and none for adults with diabetes.[15,65] A recent study in the Netherlands found that home-based screening in the general population could reduce the lifetime incidence of non-fatal myocardial infarction and non-fatal stroke by 5.1% and 4.1%, respectively, which were in line with our results.[14] However, benefits among adults with diabetes were not considered in that study. Additionally, our study found that the reduction in CVD incidence in adults with diabetes was lower compared with the general population. This may be attributed to the fact that diabetes is itself a major risk factor for CVD and, thus, adults with diabetes have a higher baseline prevalence of CVD prior to CKD screening.[29] However, considering the much higher risk of CVD death for adults with diabetes compared to adults without diabetes,[74] CKD screening remains essential for improving CVD-related health outcomes in this population. Regarding cost-effectiveness, our study found that the ICERs of screening at age 45 and 55 were lower in adults with diabetes than in the general population, consistent with previous studies in the US and Korea.[15,48] Surprisingly, screening starting at age 65 resulted in higher ICERs in adults with diabetes compared with the general population. One possible explanation is that delayed management is associated with increased morbidity and mortality. Consequently, the improvement in QALY was relatively small. This finding underscored the importance of early screening, particularly for adults with diabetes, to enable timely interventions that achieve better health outcomes and economic benefits.

Sensitivity analysis showed that both screening and treatment adherence were key factors in the ICER of screening. Higher adherence enhanced the cost-effectiveness screening, in line with previous studies.[12,64] Globally, improving screening adherence among CKD patients remains a challenging public health issue.[75] In China, suboptimal screening adherence among patients with CKD, as evidenced by community screenings, nationwide surveys, and surveillance data, indicated room for improvement.[22,30,76–78] Similarly, treatment adherence is crucial in CKD management. Primary healthcare is considered an important factor influencing treatment adherence. A study showed that 40% of the improvement in hypertension control under China's Basic Public Health Service program can be attributed to increased adherence to hypertension treatment.[79] Additionally, mobile health and physician-pharmacist collaborative clinics are potentially effective strategies to improve treatment adherence.[80,81]

Our study also has several limitations. First, while most parameters were derived from the literature and national or regional databases specific to China, some treatment parameters lacked direct evidence from China and relied on data from RCTs or meta-analyses from other countries. However, the estimates were conservative, which may have led to an underestimation of cost-effectiveness. Second, like all simulation models, our CKD model is a simplification of the real world and, thus, includes assumptions that may not be fully supported based on existing data. For example, we assumed that patients underwent at least one year of dialysis before receiving a kidney transplant and individuals aged 75 years and older would not receive screening. Although these assumptions align with other published modeling studies in the literature, they may inevitably result in model misspecification bias. We have conducted extensive model validation to ensure that the modeling results are reasonable and a variety of sensitivity analyses to account for uncertainty caused by the assumptions. Third, our study did not account for dynamic factors of screening, such as the impact of false positives on patient adherence to subsequent screening. Fourth, utility values were not stratified by age. However, sensitivity analyses indicated that the results were robust. Fifth, our study did not consider CKD screening among patients with hypertension or other high-risk populations. Finally, we assumed that patients were treated with ACEIs or ARBs rather than other kidney- and cardio-protective medications such as glucagon-like peptide-1 receptor agonists, sodium-glucose cotransporter 2 (SGLT2) inhibitors, or mineralocorticoid receptor antagonists. The assumption may be justifiable because only ACEIs and ARBs are widely used in China due to their safety, efficacy, and relatively low costs. Future research is needed to include novel treatments (e.g., SGLT2 inhibitors) into the cost-effectiveness analysis as well as considering the impact of population heterogeneity (e.g., urbanization and obesity) on CKD progression and more screening strategies, such as point-of-care screening for UACR or serum creatinine and screening among younger or other high-risk populations.

In conclusion, our study demonstrated that CKD screening in the general population and adults with diabetes was cost-effective and could reduce the incidence of KFRT and CVD in China. We noted that improving adherence to CKD screening and treatment is critical in population-based screening and CKD management. Our study provided useful insights for health policies and guidelines related to CKD in China and other LMICs.

Contributors

FYW, LZ and YL conceived the study idea and designed the analyses plan. LZ and YL obtained the research funding. FYW, FLW, and JW contributed to the data curation and the statistical analyses. FYW, JP, LZ, and YL contributed to the interpretation of the data. FYW and LZ wrote the initial version of the manuscript. FYW, JW, CY, JP, LZ and YL revised the manuscript. All authors had full access to all the data in the study and FYW and LZ had final responsibility for the decision to submit for publication.

Data sharing statement

The parameters that we used in our model are available on reasonable request from the corresponding author.

Declaration of interests

Authors declare no conflict of interest.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.lanwpc.2025.101493.

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