

Health Economic Evaluation of Screening and Intervention Strategies for Chronic Kidney Disease in Hypertensive Population Based on Micro-simulation

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Abstract

Objective

Taking Shanghai as an example, the health economics evaluation of screening and intervention strategies for hypertension population provides quantitative basis for the selection of screening and intervention strategies for chronic kidney disease.

Method

Develop a microsimulation model for screening and intervention strategies for chronic kidney disease, and utilize SAS statistical software to simulate and analyze the cost and utility evolution of chronic kidney disease in hypertensive populations with and without screening and intervention strategies. Evaluate the screening strategies using cost-utility analysis.

Result

After 10 years of microsimulation, the annual per capita quality adjusted life year of the non-screened intervention strategy group in the hypertensive population aged 45 and above was 0.670, and the annual per capita screening and intervention cost was 42900 yuan; The per capita quality adjusted life year of the screening intervention strategy group is 0.692, and the annual per capita screening and intervention cost is 39600 yuan. Compared with the non-screened intervention strategy, the screened intervention strategy can save a total of 7.69 billion yuan over 10 years. The sensitivity analysis results indicate that all parameter adjustments did not have a substantial impact on the final cost-effectiveness analysis results.

Conclusion

The screening and intervention of chronic kidney disease for people over 45 years of age with diabetes, compared with those without screening and intervention, has lower annual per capita cost and higher annual per capita quality adjusted life years. Screening and intervention for this population can achieve better economic benefits.

1. Background

Chronic kidney disease (CKD) caused by various reasons has become a major public health problem endangering the health of our people. The complications caused by chronic kidney disease and end-stage kidney disease will cause significant decline in the quality of life, death and serious economic burden of patients. According to relevant statistical data, the global prevalence of chronic kidney disease is 10.1% -13.3%, and it is expected to become the fifth leading cause of death worldwide by 2040^[1].The

latest research results in 2023 show that the prevalence of chronic kidney disease in the Chinese population aged 18 and above is 8.2%, with over 82 million patients, but the awareness rate is only 10%^[2]. According to relevant reports, end-stage renal disease accounts for 1% of chronic diseases, but medical expenses account for 8% of chronic diseases, with an average annual treatment expenditure of about 100000 yuan per person^[3]. CKD has a insidious onset, and most patients with symptoms seek medical attention in the middle to late stages of the disease. When the disease progresses to the end stages of chronic kidney disease, it will seriously threaten the patient's life safety.

This study intends to build a micro-simulation model of screening intervention for high-risk groups of chronic kidney disease, take the registered residence population of Shanghai as an example, simulate the changes in the development of individual quality of life and intervention costs caused by different screening strategies in the future, use the cost-effectiveness analysis method to evaluate the screening strategies in health economics, and propose suggestions for screening strategies of chronic kidney disease.

2. Methods

2.1. Data Sources

2.1.1 Literature Collection

The probability of disease state transition and patient quality of life data related to the screening strategy for chronic kidney disease were collected through literature search. The results of chronic kidney disease state transition without screening intervention were mainly collected by searching relevant epidemiological literature in the population. Under the condition of screening intervention, the status of chronic kidney disease changes. Based on the results of relevant studies on the intervention effect of chronic kidney disease, it is planned to obtain the effect of (ACEI)/(ARB) relative to placebo or no treatment through relevant clinical trials and meta-analysis research literature^[4].

Population health microsimulation modeling frameworks such as POHEM provide standardized technical paradigms for constructing long-term disease evolution simulation models for chronic disease populations, which lays a methodological foundation for the micro-simulation design of this study^[5].

2.1.2 Survey Data Collection

The data on population morbidity and direct medical costs is sourced from the Chronic Kidney Disease Screening Survey Database. This database covers screening data of high-risk populations for chronic kidney disease in 27 community health service centers in Shanghai. The high-risk factors include hypertension, and the number of participants in screening is 104593. Among them, 28931 cases were known to have chronic kidney disease before screening, and the remaining 75662 cases did not show chronic kidney disease.

The cost data mainly comes from the collected management data of chronic kidney disease prevention and treatment in Jing'an District, Shanghai, which includes the medical consumption data of some chronic kidney disease patients who visited outpatient clinics at various levels of hospitals from 2018 to 2020.

2.2 Research Methods

2.2.1 micro-simulation model

Micro-simulation technology is an effective tool for analyzing and evaluating the long-term effects of prevention and control strategies. The model fully considers the heterogeneity of micro individuals and constructs simulation models based on the state of micro individuals in various systems of real society, that is, constructing the main evolution patterns of individuals in the model; Using computer technology to simulate the changes in micro individual related characteristic indicators caused by changes in relevant policy parameters and micro individual characteristics, that is, obtaining simulation results through the operation of the model; Analyze the impact of policies on populations through statistical analysis, inference, analysis, and synthesis of characteristic indicators.

This study combines screening and intervention strategies for hypertensive individuals with chronic kidney disease and the evolution of chronic kidney disease status to construct a micro simulation model. Simulation analysis was conducted in four modules (Fig. 1), including micro database construction module, screening strategy module, intervention strategy module, and annual adjustment and result analysis module. SAS statistical software was used for simulation analysis ^[6, 7, 8].

Micro database construction module: Based on the distribution of hypertension population related to the incidence of chronic kidney disease and the distribution of chronic kidney disease in hypertension population, combined with the age and gender composition distribution of the population in a certain area, estimate the number of people affected by age and disease stages in a certain area in the starting year, and form a micro data file.

Screening strategy module: refers to the micro database of newly screened individuals in a certain area, including high-risk factor types, disease stages, health utility, medical consumption, and other information, formed under the influence of screening strategies.

Intervention strategy module: refers to the process of disease state transition in newly screened individuals with or without intervention strategies, simulating the occurrence and development of chronic kidney disease in individuals under intervention strategies ^[9].

Annual Adjustment and Results Analysis Module: Make necessary adjustments and prepare data files for the next year's simulation, and summarize the simulation results after the simulation is completed. This module adjusts the micro database of newly screened patients based on their mortality events.

After completing the simulation, the model outputs the simulation results and conducts a comprehensive analysis of them.

2.2.2 Screening and intervention strategy

The screening strategy is to screen and intervene in hypertensive individuals aged 45 and above, or to not screen and intervene.

Intervention strategies include: Relevant research results have shown that angiotensin-converting enzyme inhibitors (ACEIs)/angiotensin II receptor blockers (ARBs) can reduce urinary protein levels ^[4]. This study used this strategy as an intervention measure to investigate the cost and disease state transition patterns.

2.2.3 Cost-utility analysis

Based on the micro-simulation model, the direct medical burden (cost) and quality adjusted life years (utility) under different screening intervention strategies are summarized and output. The cost-effectiveness analysis method is used to evaluate the health economics of various chronic kidney disease screening intervention strategies and propose the selection of prevention and treatment strategies in different contexts.

3. Results

3.1 Construction results of microdata files for chronic kidney disease

This study combines the screening results of chronic kidney disease with the estimated number of newly screened patients to construct an initial microdata file for the screened chronic kidney disease patients, which is also the starting file for the simulation. Construction process:

(1) It is assumed that the distribution of high risk population of hypertension related to chronic kidney disease among registered residence population in Shanghai is consistent with that of hypertension population participating in screening. The results showed that the patients participating in the screening followed a normal distribution by age, with a mean of 71.45 years and a standard deviation of 8.18 years. Therefore, according to the number of high-risk groups of 10% of the registered residence population with chronic kidney disease, micro data with age characteristics of high-risk groups with chronic kidney disease of registered residence population in Shanghai were randomly generated based on this distribution, with the minimum age of 45 years and above.

(2) According to the prevalence rate in the screening data of chronic kidney disease patients and the proportion of newly screened patients, combined with the micro data of registered residence population in Shanghai with age characteristics, a micro database of newly screened patients with age and chronic

kidney disease stage characteristics was randomly generated. Table 1 shows the screening of chronic kidney disease patients in diabetes population of registered residence population in Shanghai.

Table 1
Summary of Micro-Simulation Model Parameters

Parameter	Base case value	Source
Screening situation		
Hypertension prevalence rate		
18–44	R = 13.33%	Shanghai Statistical Yearbook (2021)
45–59	R = 37.80%	
60-	R = 59.20%	
Screening results of CKD hypertensive population		
Detection rate	R = 23.13%	Shanghai screening data
Proportion of new screenings	R = 25.85%	
Estimated prevalence of hypertension in Shanghai population(ten thousand)		
45–64	173.23	Statistical analysis results
65-	226.73	
total	399.96	
Estimation results of CKD screening for hypertensive population in Shanghai(ten thousand)		
Number of patients	92.51	Statistical analysis results
Known number of patients	68.60	
Newly screened number of patients	23.91	
Disease state transition probability		
Before Intervention		
CKD Mortality Rate	R = 2.04%	Wen et al.,2008
Incidence rate of end-stage renal disease	R = 7.87%	Deng et al.2022
End-Stage Renal Disease Mortality Rate	R = 3.38%	Shanghai Dialysis Annual Registration Report
After Intervention		
CKD Mortality Rate	R = 1.55%	Wen et al.,2008

Parameter	Base case value	Source
Incidence rate of end-stage renal disease	R = 6.64%	Deng et al. 2022
End-Stage Renal Disease Mortality Rate	R = 3.38%	Shanghai Dialysis Annual Registration Report
Cost		
Screening cost per person	12	Field investigation
Stages I-IV	4,159	
Stage V	107,209	
Quality-Adjusted of Life Years		
CKD	0.81	Saito et al. 2008
ESRD	0.658	Kondo et al. 2012

3.2 Model parameter acquisition results

3.2.1 Disease state transition parameters

The probability of state transition or event occurrence is usually not directly obtained in literature, and is usually calculated based on the event occurrence rate, which is used to calculate the probability of state transition or event occurrence. This study estimates the incidence of corresponding disease events based on the observation period of the queue and the occurrence of results. The parameter results are shown in Table 1.

3.2.2 Utility parameters

The health utility in the model is measured using Quality Adjusted Life Year (QALY), with a complete health QALY value of 1 and a death QALY value of 0. The disease status data of chronic kidney disease was obtained through relevant research literature searches. A Japanese analysis shows that the quality adjusted life years for stages 1–4 of chronic kidney disease are approximately 0.81. The quality adjusted life years for end-stage renal disease were obtained from the CRIC study, which showed a value of 0.658.

3.2.3 Cost data

Table 1 shows the outpatient medical expenses of patients with chronic kidney disease. From the data results, it can be seen that the outpatient medical expenses of end-stage patients are much higher than those of early-stage patients. The community screening for chronic kidney disease is mainly judged through urine routine and blood creatinine test, so the screening cost is mainly composed of these two parts. The two costs are determined based on the medical service prices in Shanghai, which are 4 yuan and 8 yuan respectively.

3.3 Economic evaluation results of screening strategies for chronic kidney disease

According to Table 2, the simulation summary results of the cost and effectiveness of the annual screening intervention strategy from 2024 to 2033 show that if a comprehensive screening intervention is conducted on the population aged 45 and above with hypertension, the average quality adjusted life year per person per year for the population screened and intervened is 0.692, and for the population not screened and intervened, the average quality adjusted life year per person per year is 0.670; The annual per capita cost for the population screened and intervened is 39600 yuan, while the annual per capita cost for the population not screened and intervened is 42900 yuan. Meanwhile, based on the 10-year simulation results of the population, if screening and intervention are carried out for hypertensive individuals, a total of 7.69 billion yuan in expenses can be saved during the 10-year period. Screening and intervention for chronic kidney disease in individuals aged 45 and above with hypertension can yield significant economic benefits.

Table 2
Micro-simulation results of cost utility of two strategies

Strategy Name	Total cost (trillion yuan)		Difference in total cost(trillion yuan)	Annual average cost per person(ten thousand Yuan)	Annual per capita effectiveness (QALYs)
Non-intervention	1011.95	76.90		4.29	0.670
Intervention	935.05	—		3.96	0.692

3.4 Sensitivity analysis results

The parameters that affect the simulation analysis results include the probability of chronic kidney disease metastasis, mortality probability, cost, and utility. Adjust the above parameters and conduct a single factor sensitivity analysis. The simulation results indicate that all parameter adjustments did not have a substantial impact on the final cost-effectiveness analysis results, and there is a cost-effectiveness advantage in screening and intervening in chronic kidney disease for hypertensive individuals aged 45 and above. The factors that have the greatest impact on cost and utility outcomes are the adjustment of cost and utility parameters.

The single-factor sensitivity analysis results under various parameter fluctuation scenarios are summarized in Table 3 here.

Table 3
Cost utility sensitivity analysis results of two strategies

Cost utility sensitivity analysis results of two strategies			
Strategy Name	Annual average cost per person(ten thousand Yuan)	Annual average cost per person(ten thousand Yuan)	Scheme selection
The probability of disease metastasis increases by 20%			
Non-intervention	4.87	0.662	Intervention strategy
Intervention	4.57	0.682	
The probability of disease metastasis reduces by 20%			
Non-intervention	3.51	0.680	Intervention strategy
Intervention	3.40	0.700	
The probability of disease death reduces by 20%			
Non-intervention	4.21	0.659	Intervention strategy
Intervention	3.92	0.682	
The probability of disease death increases by 20%			
Non-intervention	4.34	0.681	Intervention strategy
Intervention	4.02	0.701	
Screening intervention costs increase by 20%			
Non-intervention	5.14	0.670	Intervention strategy
Intervention	4.75	0.692	
Screening intervention costs reduce by 20%			
Non-intervention	3.43	0.670	Intervention strategy
Intervention	3.17	0.692	
Utility value increase by 20%			
Non-intervention	4.29	0.804	Intervention strategy
Intervention	3.96	0.830	
Utility value reduce by 20%			

Strategy Name	Annual average cost per person(ten thousand Yuan)	Annual average cost per person(ten thousand Yuan)	Scheme selection
Non-intervention	4.29	0.536	Intervention strategy
Intervention	3.96	0.553	

4. Discussion

Chronic kidney disease (CKD) is a highly prevalent condition that contributes to a substantially increased burden of cardiovascular diseases, other morbidities, and mortality^[11]. Estimates of CKD prevalence from large screenings of nationally representative samples were reported in only a few countries, including Australia, the US, Canada, Korea, and China, and ranged from 7.2% to 13.4%^[11–15].

In 2017, 1.2 million people died of CKD globally, and the mortality rate of CKD increased 41.4% between 1999 and 2017. The global prevalence of CKD in 2017 was estimated at 9.1%, though the quality of the data used for prevalence estimation varied greatly with regions. A previous survey of 47 204 participants in China reported a CKD prevalence of 10.8%, The latest research results in 2023 show that the prevalence of chronic kidney disease in the Chinese population aged 18 and above is 8.2%.

Chronic kidney disease is a controllable and preventable disease. If early screening and intervention are carried out for high-risk populations of chronic kidney disease, the occurrence of complications can be effectively reduced, the incidence of end-stage renal disease can be lowered, and the economic burden of the disease can be reduced. A study on the cost of chronic kidney disease patients in stages 3–5 in the UK found that more than half of the total expenditure on chronic kidney disease is for medical expenses related to kidney replacement therapy and cardiac complications, which is a huge expense. However, the target audience of chronic kidney disease patients is only 2%. The results indicate that the approach that conforms to health economics principles is to do a good job in primary prevention of chronic kidney disease^[16]. Many studies show that the risk factors of chronic kidney disease in China include diabetes, hypertension, obesity and other chronic diseases. The above diseases may develop into chronic kidney disease in about 10 years. Therefore, we can make full use of this time gap, move forward the threshold of disease management, effectively implement chronic disease management measures, reduce risk factor exposure, and do a good job in primary prevention of chronic kidney disease. The Chinese government has listed end-stage renal disease as a special protection disease, significantly improving the treatment rate of end-stage renal disease patients. However, insufficient preventive investment is a challenge faced by chronic kidney disease prevention and control.

This study analyzed whether to screen and intervene in hypertensive populations associated with chronic kidney disease. By constructing a microsimulation model combined with health economics evaluation methods to analyze screening and intervention strategies, the following findings were made:

(1) Screening and intervention for chronic kidney disease in individuals aged 45 and above with hypertension results in lower annual per capita costs and higher annual per capita quality adjusted life years compared to those without screening and intervention. Over a period of 10 years, 768 million yuan in costs can be saved, with an average annual cost savings of 76 million yuan. The economic benefits are significant. Simultaneously adjusting for sensitive factors did not have a substantial impact on the simulation results.

(2) Microscopic simulation model is an effective tool for analyzing and evaluating the long-term effects of prevention and control strategies. Based on fully considering the heterogeneity of microscopic individuals, a population disease microscopic database and a microscopic simulation model of disease occurrence and development are constructed. According to the micro individual disease state transition rules under different prevention and control strategies, as well as the micro individual medical consumption rules under different disease states, the evolution law of chronic disease burden in specific populations is explored, and the effectiveness of disease prevention and control strategies is analyzed and evaluated. This solves the difficult problems faced by the evaluation of prevention and control strategies in the real world.

Markov model is another mainstream technical route for cost-effectiveness evaluation of long-term CKD screening strategies, which can realize dynamic tracking of disease progression and economic loss changes of high-risk groups, and its modeling ideas provide supplementary reference for the design of micro-simulation framework in this paper ^[20].

According to relevant foreign studies, the American diabetes Association supports screening among individuals with diabetes, the National Kidney Foundation and the Society of Nephrologists support screening among individuals with diabetes and hypertension, and further recommends screening among African Americans, elderly people over 60 years of age, and individuals with a family history of kidney failure ^[17]. Japanese scholars conducted research using cost-effectiveness analysis methods, and the results showed that conducting urine routine and blood creatinine surveys on the general population in Japan has economic value ^[18]. Studies in Taiwan and Canada found that it is more cost-effective to screen proteinuria and glomerular filtration rate for people with hypertension, diabetes, and people aged 60 years and over compared with population census ^[19]. The results of this study further confirm the cost-effectiveness advantage of screening interventions for hypertensive populations in China.

In summary, based on the micro simulation results of the screening and intervention strategy for chronic kidney disease in Shanghai, it is recommended to combine the concept of integrated prevention and treatment of chronic diseases, continue to explore the construction of the screening and prevention system for chronic kidney disease in Shanghai, strengthen inter institutional coordination, effectively implement key measures for the three-level prevention and treatment network of chronic kidney disease, and carry out chronic kidney disease screening and intervention for hypertensive populations. This can effectively reduce the number of end-stage patients, reduce the treatment and intervention costs for end-stage kidney disease patients, and improve the quality of life of the population.

Abbreviations

CKD: Chronic Kidney Disease

ACEI: Angiotensin-converting Enzyme Inhibitor

ARB: Angiotensin II Receptor Blocker

CRIC: Chronic Renal Insufficiency Cohort

QALYs: Quality-adjusted life years

Declarations

Ethical Considerations

The implementation of the project was approved by the Ethics Committee of the Naval Medical University. [and its supplementary information files].

Consent to participate

The ethics committee waived the requirement for informed consent.

Data Availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Clinical trial number

Not applicable

Consent for Publication

Not applicable

Competing interests

The authors declare that they have no competing interests.

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Authors' Contributions

YL, XL contributed equally to this work. YL obtained the funding. YL, XL conceived and designed the experiments. YL, GD performed the experiments, analyzed the data, and contributed reagents/materials/analysis tools. YL, XL drafted the manuscript. All authors participated in discussion, revision, and approval of the final manuscript.

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Figures

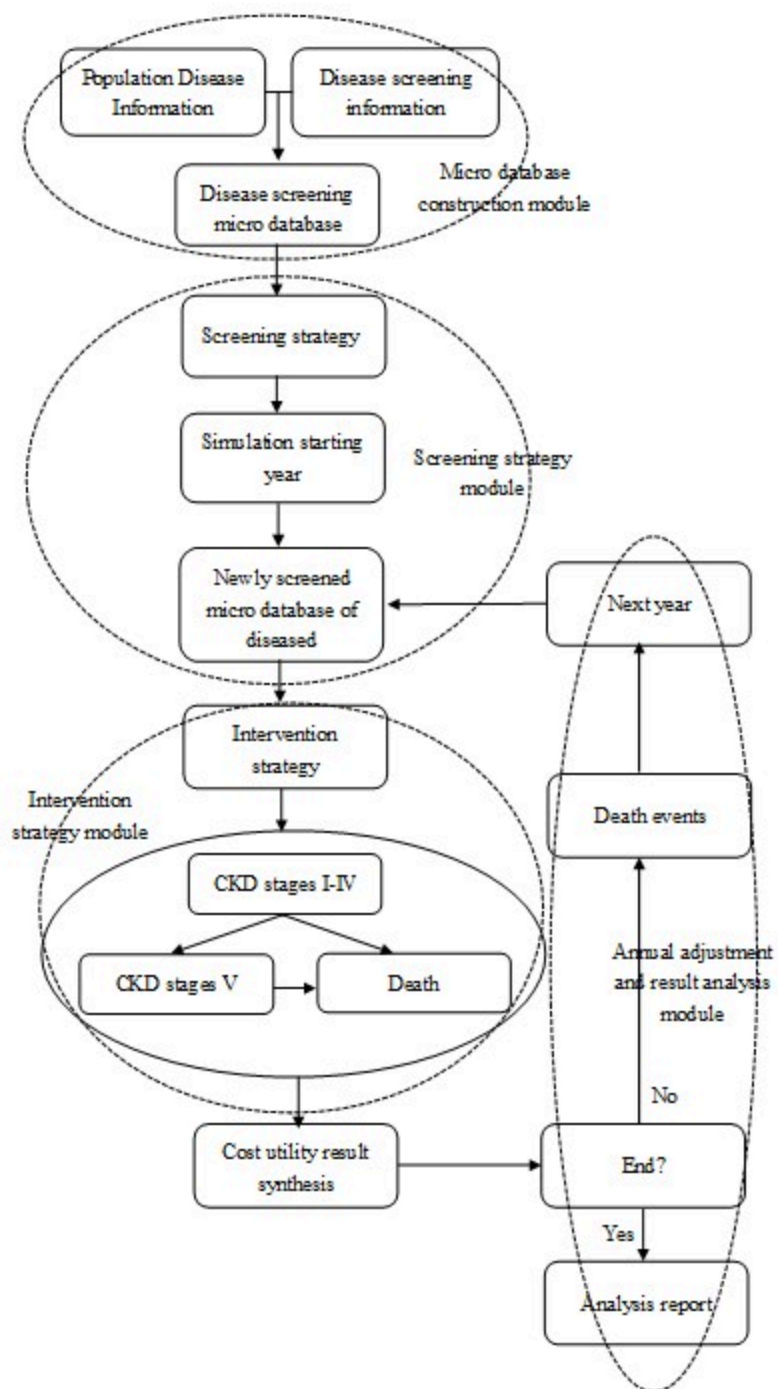


Figure 1

Micro-simulation Model Framework for Health Economics Evaluation of CKD Screening Intervention