Cost Effectiveness
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HPV vaccination strategy for 14-year-old females and economic returns for cervical cancer prevention in Wuxi City, China: a cost effectiveness analysis

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Abstract

Background Since December 2021, Wuxi, China has offered a two-dose human papillomavirus (HPV) vaccination to 14-year-old females for free. This study evaluated the costs and benefits of this vaccination scheduled in the Expanded Program on Immunization in Wuxi from the perspective of the cities' demographic characteristics, economic development, and policy support.

Methods The model-based economic evaluation used TreeAge Pro software to construct a decision tree-Markov model for the vaccination strategy in which 100,000 14-year-old females received two doses of bivalent HPV vaccine or no vaccination. Costs and effects of the strategy were assessed from a societal perspective through literature research and data obtained from the Wuxi Centre for Disease Control and Prevention. Univariate, multivariate, and probabilistic sensitivity analyses assessed the stability of the findings.

Results The cost of the bivalent HPV vaccine in Wuxi is 711.3 CNY. The two-dose of bivalent HPV vaccine for 100,000 14-year-old females would cost an additional 658,016 CNY compared to no vaccination, but would result in 1,960 Quality Adjustment Years of Life (QALYs). Using the per capita gross domestic product of 187,415 CNY in 2021 in Wuxi as the willingness-to-pay threshold, the vaccination strategy costs 3,357.37 CNY per QALY gained, which is much lower than the threshold, suggesting that it is a very cost-effective strategy. In addition, the vaccine strategy reduced the incidence of cervical cancer by 300 cases and cervical cancer deaths by 181 cases, representing a benefit-cost ratio of 2.86 (> 1) when health output outcomes were measured in monetary terms. These results suggested that the vaccination strategy was advantageous. Sensitivity analyses showed that changes in the parameters did not affect the conclusions and that the findings were robust.

Conclusions Compared to no vaccination, the delivery of two doses of bivalent HPV vaccine for 14-year-old females was a more highly cost-effective and optimal strategy.

Keywords Cost-effectiveness, HPV, Cervical cancer, Vaccination

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Background

Cervical cancer is the second most common malignant tumor of the female reproductive system worldwide [1]. According to data from the International Agency for Research on Cancer (IARC), there were approximately 604,127 new cases of cervical cancer and approximately 341,831 deaths from cervical cancer worldwide in 2020, accounting for 6.5% and 7.7% of global female new cases and deaths, respectively [2]. As the fourth most deadly cancer overall [3], cervical cancer is also a serious threat to the lives and health of Chinese women. Previous studies have confirmed that persistent infection with high risk human papillomavirus (HPV) is the main cause of cervical cancer [4, 5]. HPV types 16 and 18 account for approximately 70% of all cervical cancers [6]. Vaccination targeting high risk HPV can effectively prevent carcinogenic infections and precancerous lesions [7].

In 2020, the World Health Organisation (WHO) proposed the "Global Strategy to Eliminate Cervical Cancer", with the goal of achieving an HPV vaccination rate of 90% for females by 15-years-of-age by 2023 [8]. The prevalence of HPV infection varies according to the age group and sexual of the population. The prevalence of HPV infection can be as high as 20–40% among sexually active young women, with peak incidence occurring between the ages of 16 and 20 [9]. Various guidelines, including WHO, recommend that females aged 9–14 years be targeted for primary or routine vaccination because they are not yet sexually active [10]. According to WHO, as of November 2023, 140 countries have included HPV vaccines in their national immunization programs [11]. However, in many developing and low income countries, the coverage rate of HPV vaccination is still very low. In China, the HPV vaccination rate for women aged 9 to 45 years is less than 0.05%, with women aged 9 to 14 accounting for less than 5% of the vaccinated population [12]. At the 2020 "two sessions", several representative members submitted suggestions and proposals calling for the speedy implementation of the national plan for free HPV vaccination for eligible females in China. On December 31, 2019, China's first domestically produced HPV vaccine targeting HPV types 16 and 18 (Cecolin; Innovax, Xiamen, China) was approved by the China Food and Drug Administration [13]. The approval made it easier for adolescent females in China to receive this vaccine. In August 2020, Ordos City took the lead in providing free bivalent HPV vaccine to nearly 10,000 female students 13-years-of-age and older in primary and secondary schools in Zhungeer Banner. Subsequently, pilot projects have been undertaken in various cities.

Evaluation of health economics is one of the important scientific basis for decisions concerning vaccine immunization planning. WHO suggests that public health service decision-makers should perform targeted health economics evaluations based on the specific situation of the applied population before incorporating HPV vaccines into immunization planning, and make scientific decisions with full consideration of cost benefits [14]. Quadrivalent and nine-valent HPV vaccine was launched in China in 2017 and 2018, respectively. However, the supply of the vaccines has been insufficient, with waiting times of months or even years for vaccination appointments, with insufficient vaccine for free mass vaccination. In addition, quadrivalent and nine-valent HPV vaccines require three doses and are more expensive than bivalent HPV vaccine. Free mass vaccination will impose greater financial pressure on the government. The launch of domestic bivalent HPV vaccines has reduced the cost of vaccination. Based on these facts, we evaluated mass vaccination with bivalent vaccine in this study. Both before and after the domestic bivalent HPV vaccine was launched, many domestic and foreign studies evaluated the health economics of HPV vaccination. Although vaccine price is an important influencing factor, most research results indicate that HPV vaccination is a cost-effective prevention strategy [15, 16]. In China's immunization program, all HPV vaccine costs are covered by the National Health Commission. The cost of cervical cancer screening is also reimbursed by the Chinese government. However, due to differences in regional populations, policies, and economic development, health decision-making should be evaluated based on specific application populations to make scientific judgments.

In the present study, a Markov model was used to simulate the lifelong cohort of 14-year-old females in Wuxi from the perspectives of population characteristics, economic development, and policy support. The aim was to explore the cost-effective situation of HPV vaccination strategies based on the regional characteristics of Wuxi, and provide scientific basis for the health decision-making of incorporating HPV vaccines into the cities' immunization planning projects.

Methods

Study design

In the model-based economic evaluation, TreeAge Pro software was used to construct a decision tree-Markov model to compare the vaccination strategy of two doses of bivalent HPV vaccine for 100,000 14-year-old females with no vaccination. Costs and effects were evaluated from a social perspective.

Model building

The decision tree model was constructed to inform vaccine immunization decision-making based on HPV vaccination or no vaccination. Based on the natural development process of cervical cancer caused by HPV infection, a decision tree-Markov model was constructed to simulate all states and natural death processes after HPV infection by combining all natural outcomes and death process of the disease. The preliminary Markov model framework is shown in Fig. 1.

LSIL: low level squamous intraepithelial lesions, HSIL: high level squamous intraepithelial lesions.

We assumed that 14-year-old females in China had not yet had sexual relations and had not yet been exposed to the risk of HPV infection. We simulated a cohort of 100,000 14-year-old females, with an average life expectancy of 82.74 years for women reported in the seventh population census of Wuxi City as the endpoint, running 68 cycles with a 1-year cycle. The model included eight different health states: health, HPV infection, low level squamous intraepithelial lesions (LSIL), high level squamous intraepithelial lesions (HSIL), cervical cancer, cervical cancer cured, death from cervical cancer, and death from other causes [17]. Within each cycle, different health states can transition according to a certain probability, and each health state has a certain cost and utility value. Arrows represent the progression, reversal, and maintenance of the status quo between different health states within a cycle. Patients who progress to cancer have irreversible conditions. At the same time, differences in disease outcomes and incidence rates are considered at different age stages in the model.

Cost parameters

The cost of vaccination includes the cost of purchasing the vaccine (vaccine price), and labor and material resources consumed in vaccine transportation, storage, and vaccination (vaccine management cost). This data was directly obtained from the Immune Planning Department of the Wuxi Center for Disease Control and Prevention, and all the HPV vaccine cost will be covered by National Health Commission of China.

The treatment costs related to diseases included direct and indirect economic costs. Direct economic costs included direct medical expenses composed of examination fees, treatment fees, medical expenses, hospitalization fees, rehabilitation medical service fees, and direct non-medical expenses incurred during the medical treatment process, such as transportation and accommodation fees. Direct medical costs were obtained by the Wuxi Centre for Disease Prevention and Control through the calculation of cost lists provided by the big data platform of Wuxi Unified Information Centre. This platform provides information on the costs spent on outpatient and

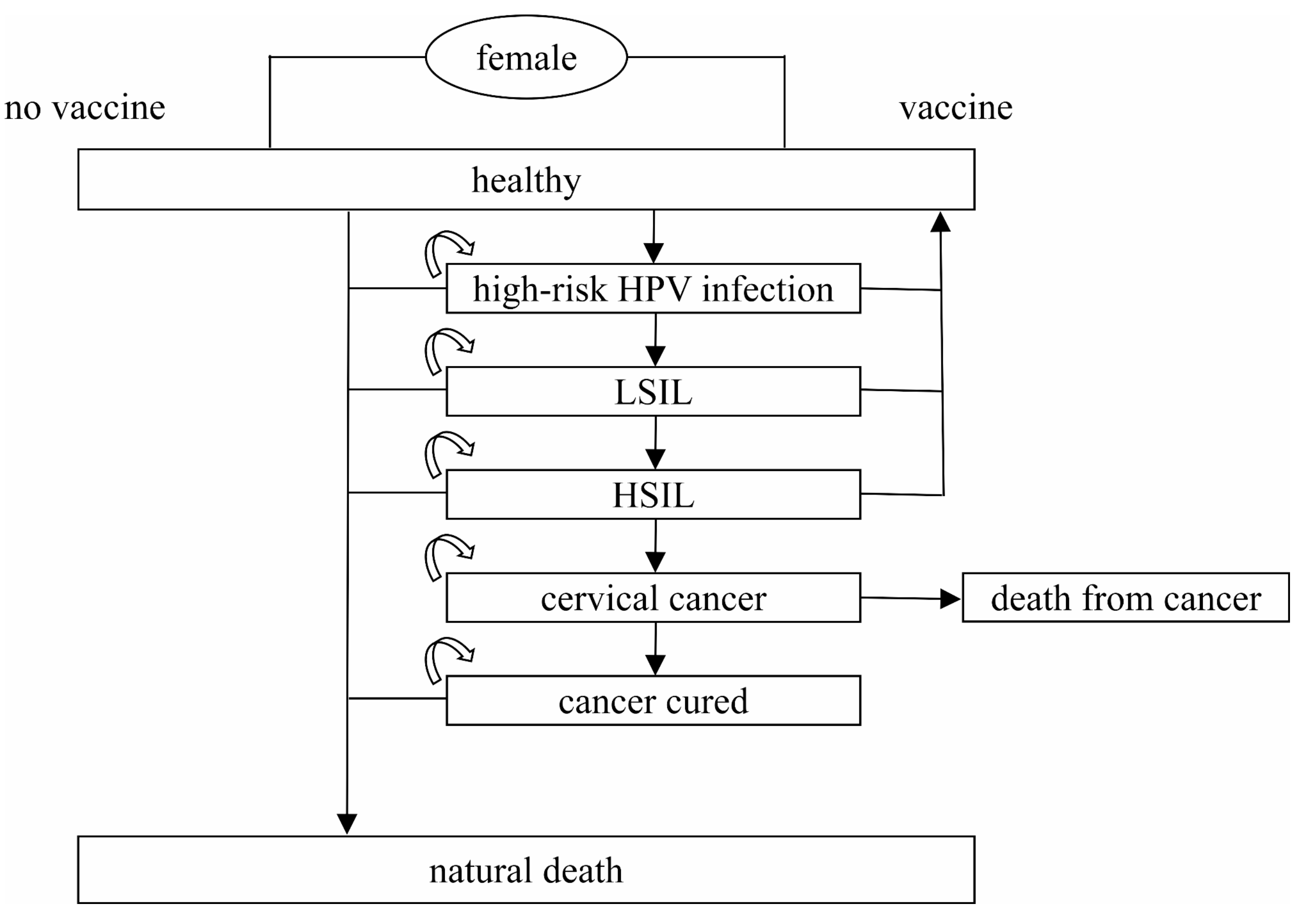

Fig. 1 Markov model framework diagram

inpatient visits by patients treated at hospitals in Wuxi for LSIL, HSIL, and cervical cancer, respectively, from 2018 to 2022. The identification information was based on ID. First, hospitalization and outpatient expenses incurred by all patients due to a certain disease status within 1 year were calculated. The average was determined to obtain the direct medical expenses for a certain disease status within a cycle (i.e., one year). These costs were the sum of what patients pay for themselves and what they are reimbursed by health insurance. The cervical cancer inpatient cost list has 1,437 records and the cervical cancer outpatient cost list has 2,494 records; the HSIL inpatient cost list has 2,126 records and the HSIL outpatient cost list has 785 records; and the LSIL outpatient cost list has 15 records.

Literature data [18] have indicated ratio of 0.150 and 0.087 of direct medical expenses to direct non-medical expenses for LSIL and HSIL patients, and cervical cancer patients, respectively. This information can be used to calculate direct non-medical expenses.

Indirect economic costs included the loss of labor value that include patient care by family members and personal labor loss. The human capital method measured the effective labor value lost due to illness and the labor time lost due to disease treatment was converted into a monetary value based on the per capita disposable income of permanent residents in Wuxi (55,053 CNY in 2021). Indirect cost was calculated as lost time in days multiplied by per capita disposable income, with the value then divided by 365. Due to the mild adverse reactions caused by vaccination, mostly local pain, the treatment cost for adverse reactions was not calculated.

Health utility

The health utility value is the weight of quality of life used to calculate quality adjusted life years (QALYs). The calculation considered the length of life and quality of life. A health utility value was assigned to each health state in the model, ranging from 0 to 1, with complete health defined as 1 and death defined as 0. The higher the value, the higher the quality of life. Table 1 presents the relevant parameters and literature references.

Discount rate

The progression of HPV infection to cervical cancer takes a decade several decades, and the time value of currencies in different years often varies. Thus, scientific comparison and evaluation requires the conversion of the costs and benefits of different future times to the current value at the same time point, which is done to discount the costs and benefits. In this study, we calculated costs and benefits using an annual discount rate of 3% in accordance with WHO recommendations [19] and performed sensitivity analyses over a range of 0-5%.

Transition probability

We assumed that all of these 100,000 14-year-old females were healthy at the time of entry into the cohort in one-year cycles, and that the age of the females increased as the cycles cycled, so that at each cycle study subjects would be at age-specific risk of HPV infection and might continue to maintain this risk or progress to other stages or subside in the next cycle. HSIL patients may develop cervical cancer and ultimately die or recover. Among them, every person in each cycle may die from reasons other than cervical cancer. The transfer probability parameters for the natural development of cervical cancer were obtained from literature data. The age specific mortality rate of women in Wuxi City in 2022 was provided by the Wuxi Center for Disease Control and Prevention. The cure rate of cervical cancer was calculated based on the 5 year relative survival rate of cervical cancer, cure rate = 1- (1–5 year survival rate) $^{1/5}$. The specific parameters are shown in Table 1.

Model analysis

Model analyses were conducted to obtain the additional QALYs that could be gained, the number of cervical cancer cases and cervical cancer deaths that would be reduced, and the additional costs that would need to be incurred by an HPV vaccination strategy compared with no vaccination. Use the incremental cost-effectiveness ratio (ICER, the ratio of the increased cost to the additional QALY gained) was used to evaluate the cost-effectiveness of the strategy.

WHO proposes to categorize the results of the assessment according to the per capita gross domestic product (GDP) of the country concerned as follows: below per capita GDP are classified as "highly cost-effective"; between 1 and 3 times per capita GDP are classified as "cost-effective"; and exceeding three times per capita GDP are classified as "low cost-effectiveness" [31]. We used the 2021 per capita GDP of Wuxi (187,415 CNY) as the willingness-to-pay threshold (WTP). If the ICER was lower than the WTP, it was considered to be cost-effective.

We then calculated the net present value and benefit-cost ratio (BCR) of the HPV vaccine regimen, and generally considered options with a cost-benefit ratio greater than 1.

Sensitivity analysis

Due to the large number of parameters in the model and the uncertainty of their values, sensitivity analysis was conducted to change the values of certain parameters in the model and analyze the impact of parameter fluctuations on the stability of simulation results. If the fluctuation of a model parameter over a range of values led to a change in the conclusions of the study, it indicated

Table 1 Model parameters

Variable	Age	Value	Range	Reference
Transition probability				
HPV infection rate	12–24	0.1728		[20]
	25–29	0.1363		
	30–34	0.1429		
	35–39	0.1818		
	40–44	0.188		
	45–49	0.1962		
	50–59	0.1648		
HPV to Health	15-	0.6		[21]
	20-	0.6		
	25-	0.35		
	30-	0.3		
	81	0		
HPV to LSIL		0.16	-20%-+20%	[22]
LSIL to Health		0.23	-20%-+20%	[23]
LSIL to HPV		0.23	-20%-+20%	
LSIL to HSIL		0.026	-20%-+20%	[24]
HSIL to Health		0.315	-20%-+20%	[23]
HSIL to Cervical Cancer		0.12	-20%-+20%	[25]
Cervical Cancer mortality rate	30–34	0.2381		[26]
	35–39	0.2381		
	40–44	0.2675		
	45–49	0.2675		
	50–54	0.331		
	55–59	0.331		
5-year survival rate of Cervical Cancer		0.6169		Wuxi Center for Disease Control and Prevention
Cure rate of Cervical Cancer		0.1746	-20%-+20%	1- (1–5 year survival rate) $^{1/5}$
Female population mortality rate (1/100000)	0-	171.95		Wuxi Center for Disease Control and Prevention
	1-	16.59		
	5-	7.57		
	10-	14.65		
	15-	25.87		
	20-	12.95		
	25-	21.91		
	30-	15.81		
	35-	32.00		
	40-	59.27		
	45-	88.96		
	50-	144.18		
	55-	236.99		
	60-	332.68		
	65-	604.83		
	70-	1115.65		
	75-	2354.48		
	80-	5268.63		
	85+	15649.06		
LSIL treatment rate		0.3	-20%-+20%	[27]
LSIL cure rate		1		
HSIL treatment rate		0.7	-20%-+20%	
HSIL cure rate		0.9	-20%-+20%	
Vaccine efficiency		0.7678	-20%-+20%	A×B+(1-A)×C
A: Proportion of 16/18 types		0.6900		
B: Protection for 16/18 models		0.9780		[28]

Table 1 (continued)

Variable	Age	Value	Range	Reference
C: Protection for non-16/18 types		0.3000		[24]
Health utility				
Health		1		
HPV infection		1		
LSIL		0.9965	-20%-+20%	[29]
HSIL		0.984	-20%-+20%	
Cervical Cancer		0.693	-20%-+20%	
Rehabilitation of Cervical Cancer		0.87	-20%-+20%	[30]
Cost parameters				
LSIL economic burden		858.79	-20%-+20%	Wuxi Center for Disease Control and Prevention
HSIL economic burden		12312.51	-20%-+20%	
Cervical Cancer economic burden		45926.29	-20%-+20%	
Vaccine costs		711.3	-20%-+20%	

Table 2 Cost- effectiveness analysis of HPV vaccination strategy

Strategy	Effectiveness (QALY)	Incremental Effectiveness (QALY)	Cost (CNY)	Incremental Cost (CNY)	Incremental Cost-Effectiveness Ratio (CNY/QALY)
HPV vaccination strategy	2,874,934	1,960	90,651,368	6,580,016	3357.37
non-HPV vaccination strategy	2,872,974	-	84,071,352	-	-

Table 3 The health outcomes of HPV vaccination strategy

Strategy	Number of cases of cervical cancer	Number of deaths from cervical cancer	Life years
HPV vaccination strategy	91	55	2,875,130
non-HPV vaccination strategy	391	236	2,873,818
D-value	300	181	1,312

that the simulation results were unstable; If the simulation results were not affected by parameter fluctuations, it indicated that the simulation results had stability and high credibility. In the tornado diagrams and one-factor sensitivity analyses, we adjusted all parameters except the time-dependent variables and used a 20% fluctuation in the parameters as a range of values.

Probability sensitivity analysis refers to a sensitivity analysis method that introduces random elements in the analysis process, that is, the parameters are regarded as random variables that can take any value within their range. If the model is run repeatedly, the results may vary. We set the cost parameters to follow a Gamma distribution, and the transfer probability parameters to follow a Beta distribution. We then conducted second-order Monte Carlo simulation, and the results of probability sensitivity analysis are presented in the form of cost-effectiveness acceptability curve and scatter plots.

Results

Cost-effectiveness analysis

As shown in Table 2, the results of the model simulation showed that compared with no vaccination, 100,000 14-year-old females vaccinated with the HPV vaccine were able to gain an additional 1,960 QALYs and needed to pay an additional cost of 658,016CNY, which resulted in an ICER of 3,357.37CNY, which was much lower than the WTP (per capita GDP of Wuxi City in 2021 of 187,415 CNY), suggesting that the strategy was highly cost-effective.

As shown in Table 3, assuming 100,000 14-year-old female children enter this cohort, with cervical cancer mortality rate as the outcome indicator, the strategy of not receiving HPV vaccine will ultimately result in 236 deaths from cervical cancer, while the strategy of receiving HPV vaccine will result in 55 deaths from cervical cancer. Therefore, compared to not receiving the vaccine, vaccination will reduce 181 deaths from cervical cancer. When the incidence rate of cervical cancer is taken as the outcome indicator, 391 cases of cervical cancer will eventually occur if the strategy of not vaccinating HPV vaccine is selected, while 91 cases of cervical cancer will occur if the strategy of vaccinating HPV vaccine is selected. The HPV vaccination will reduce the incidence of 300 cases of cervical cancer. The vaccination strategy also provides an additional 1,312 life years.

We expressed the outputs of health outcomes in monetary terms. The direct benefit refers to the medical expenses saved by cervical cancer patients due to reduced vaccination (reduced number of cases × per capita medical cost for cervical cancer). The indirect benefit is due to the contribution of life years saved by vaccination to production (life years saved × per capita GDP). Taking 100,000 people entering the intervention as an example, the number of cervical cancer cases can be reduced by

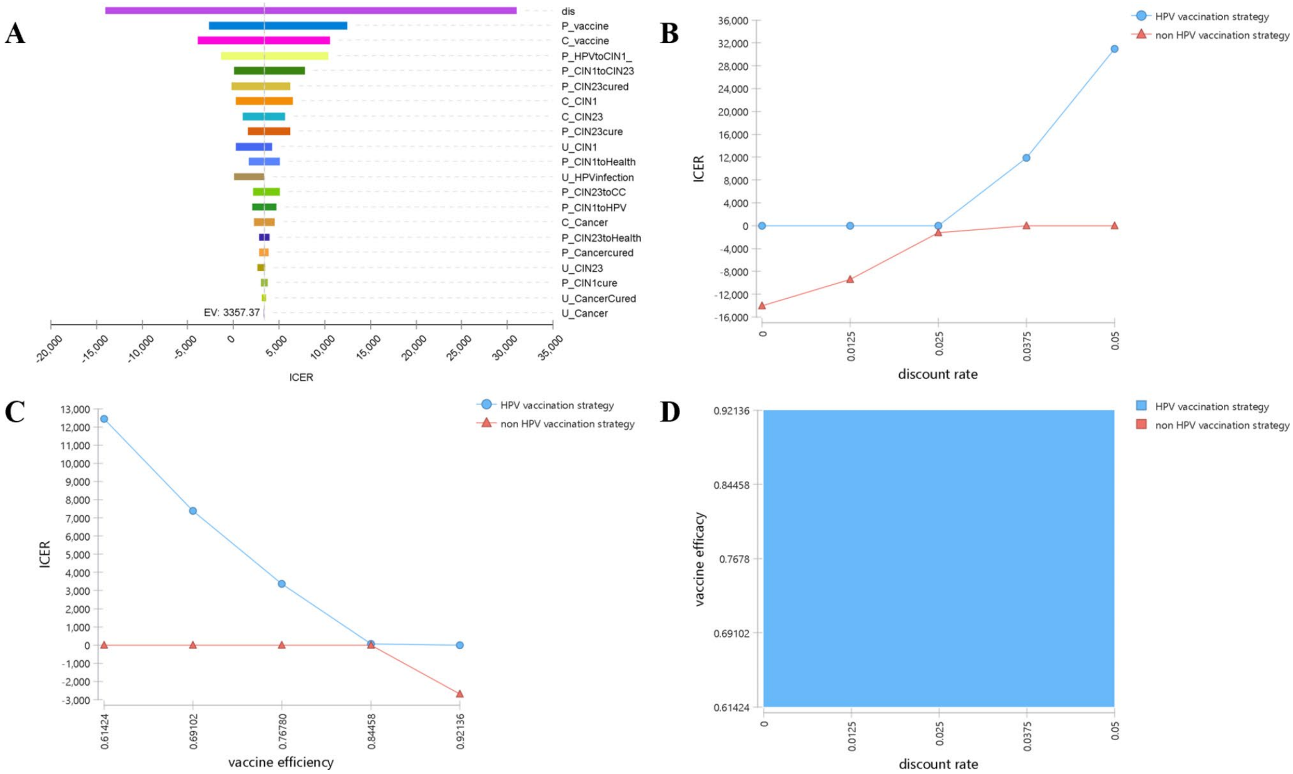

Fig. 2 **A:** Tornado diagram for sensitivity analysis. **B:** Visualization of discount rate single factor sensitivity analysis. **C:** Visualization of vaccine efficacy single factor sensitivity analysis. **D:** Sensitivity analysis of two factors

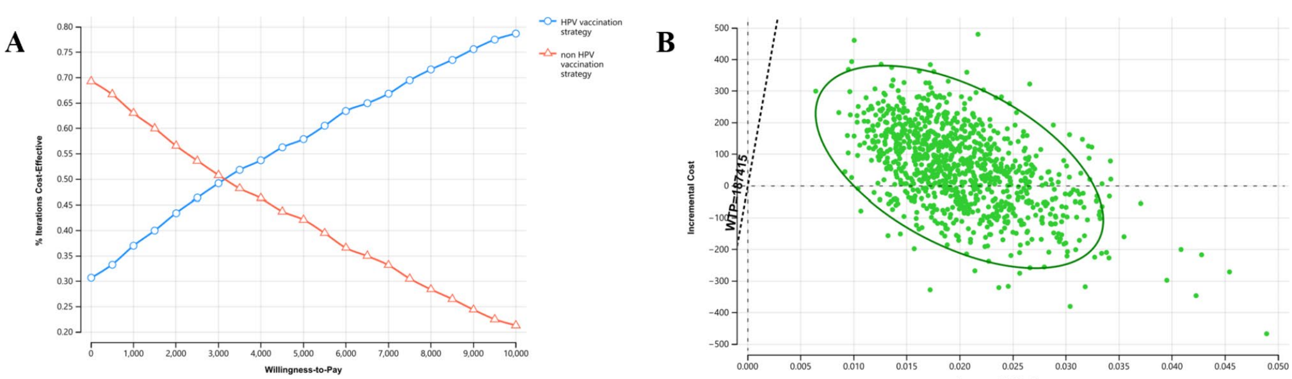

Fig. 3 **A:** Cost-effectiveness acceptability curve. **B:** Scatter plot

300, while the increased life year is 1,312, Table 3). So the direct benefit that can be gained from the vaccination strategy is 300×45,926.29 = 13,777,887 CNY, and the indirect benefit gained is 1,312×187,415 = 245,888,480 CNY, for a total benefit of 259,666,367 CNY.

The cost of vaccination for 100,000 people is 90,651,368 CNY. The BCR of the vaccination strategy is 259,666,367/90,651,368 = 2.86. The value of the BCR > 1 indicates that the strategy is advantageous and has a cost-benefit advantage.

Multifactor sensitivity analysis

A deterministic sensitivity analysis was performed, with fluctuation range for parameters such as transfer probability and cost set in the model. The changes in results caused by each parameter within the fluctuation range were analyzed. Sensitivity analysis of multiple factors was performed using a tornado diagram, as shown in Fig. 2A. Among the included parameters, the discount rate (dis) is the most influential parameter on the results, followed by the vaccine efficacy (P_vaccine).

Single factor sensitivity analysis

We conducted a single factor sensitivity analysis on the discount rate parameter, as shown in Supplementary Table 1. The visualization analysis of single factor sensitivity analysis is shown in Fig. 2B, which displays the changing trend of ICER with parameter changes. When the discount rate changed in the range of 0.0 to 0.05, the ICER of the HPV vaccination strategy was always higher, indicating that the strategy was always the dominant strategy.

Single factor sensitivity analysis was also performed on the parameter of vaccine efficacy (Supplementary Table 2). Figure 2C shows the trend of sensitivity analysis of vaccine efficacy. When the vaccine efficacy varied within the range of 0.61424 to 0.92136, the ICER of the HPV vaccination strategy was always higher, indicating that the strategy was always an advantage strategy.

Sensitivity analysis of two factors

Discount rate and vaccine efficacy were the two parameters with the greatest impact in the tornado diagram in a two factor sensitivity analysis (Fig. 2D). Regardless of how these two parameters change within the range, when the WTP was 187,415 CNY, the HPV vaccination strategy was more cost-effective.

Probability sensitivity analysis

Probability sensitivity analysis can reflect both the changes in results when different parameters change simultaneously and the comprehensive impact of parameters on simulation results. The data are usually represented by a visualized ICER scatter plot that is divided into four quadrants, with the horizontal and vertical coordinates representing incremental effectiveness (QALYs) and incremental costs, respectively. The incremental utility value of the first quadrant was positive and the incremental cost was also positive, therefore it was considered as the advantage quadrant. The incremental utility value in the second quadrant was negative, while the incremental cost was positive, therefore it was considered an absolute disadvantage quadrant. The incremental cost in the third quadrant was negative, and the incremental utility value was also negative, indicating that the new intervention had a worse effect. The incremental cost of the fourth quadrant was negative, while the incremental utility value was positive, indicating that the new intervention measures had better effect and lower cost, which was termed the absolute advantage quadrant. The WTP threshold line was combined with the ICER scatter plot to select an advantageous strategy with higher cost-effectiveness value. The ICER scatter plot was divided into two parts using the WTP threshold line. When the ICER was located below the WTP threshold line indicated that the intervention has cost-effectiveness dvalue. An ICER above the WTP threshold line indicated that the strategy did not have cost-effectiveness value.

It can be seen from Fig. 3B that the ICER scatter plot was mainly distributed in the first and fourth quadrants, that is, the dominant and absolute advantage quadrant, respectively. Based on the WTP threshold line (dashed line on the left) in the figure, the ICER scatter point was located below the threshold line, indicating that the HPV vaccination strategy had a more cost-effective advantage than no vaccination strategy. The probability sensitivity analysis results showed that the model analysis results were relatively stable.

Discussion

This study conducted a health economic evaluation of the inclusion of HPV vaccine in the immunization plan of Wuxi based on the population characteristics, economic development, and policy support. Compared to non-vaccination, the two-dose strategy of bivalent HPV vaccine for 14-year-old females was more cost-effective and is an optimal strategy. The sensitivity analysis revealed that when parameters changed, the results were still robust.

Many studies have explored the cost-effectiveness of HPV vaccination strategies based on the policies and development situations of different countries. A study in the United States analyzed the cost-effectiveness of increasing HPV vaccination. In the study, to estimate the value of HPV vaccine coverage interventions [32], the researchers developed a zonal dynamic model of HPV infection, transmission, and progression to cancer in heterosexual patients, and compared the costs and benefits of implementing three evidence-based interventions across the state to improve HPV vaccination coverage and non-intervention (normal vaccination). The results indicated higher benefits compared to costs regardless of which intervention measures were used to increase HPV vaccination, the benefits [32]. The ICER for the most cost-effective intervention was $1,538/QALY. Another study involved a meta regression analysis of the cost-effectiveness of HPV vaccination in 195 countries [33]. Due to potential heterogeneity, there was significant uncertainty in predicting the ICER in some countries. However, the results supported the introduction and expansion of HPV vaccination, especially in many countries eligible for Gavi, Vaccine Alliance, and Pan American Health Organization (PAHO) subsidised vaccines [33]. In South Korea, adding two dose of HPV vaccine to cervical cancer screening was a cost-effective option compared to conducting cervical cancer screening alone [34]. A 2017 health economics evaluation of bivalent HPV vaccination strategies based on dynamic models found that vaccination and screening for appropriate age groups was a cost-effective prevention strategy [35]. There are various methods for evaluating health economics; the main research methods in foreign countries are static proportional, Markov, and propagation dynamics models; WHO and PAHO have also developed the PRIME and CERVIVAC models, which can more conveniently and quickly conduct economic evaluations of HPV vaccines for regional adaptation adjustments. The economic evaluation research methods for HPV vaccines in China are relatively single, mostly using Markov or dynamic queue models. However, the research results are relatively consistent, and it is generally believed that HPV vaccination strategies are cost-effective [17, 36, 37]. A 2022 study used the PRIME static proportional outcome model recommended by WHO to evaluate the possible costs and social and economic benefits of adopting various HPV vaccination strategies in 31 Chinese Mainland provinces. Compared with no HPV vaccination, HPV vaccination could reduce the incidence rate of cervical cancer in women of all ages. Incorporating HPV vaccination into immunization plans was cost-effective at the national level and in most provinces [38]. A study described that for men who have sex with men with a high-risk of HPV infection, receiving domestic bivalent HPV vaccines provides a more cost-effective option for preventing anal cancer and is a "very cost-effective" strategy [39]. In a study similar to ours, an ICER of 6,124 CNY for three doses of bivalent HPV vaccination in urban areas was reported [28].

In the present study, the two parameters with the greatest impact on the model results were the discount rate and vaccine efficacy. However, within the range of parameter changes, the results still showed that the HPV vaccination strategy was more cost-effective.

The advantages of this study included the application of vaccine cost information, disease cost information, and some epidemiological data based on the population characteristics of Wuxi City provided by Wuxi Disease Control and Prevention. Due to differences in the speed of economic development between regions, significant differences in economic levels, and varying levels of healthcare, fitting results using models with different parameters could also result in significant differences. Therefore, this model was more suitable for the actual situation of Wuxi City and could obtain more realistic simulation results. Deterministic and probabilistic sensitivity analyses of the parameters in the model were also performed to make the results of the study more stable and credible. In addition, when constructing the Markov model, we classified cervical intraepithelial lesions before progression to cervical cancer according to The 5th edition of WHO classification of the female genital tumors [40] in two grades: LSIL, including cervical intraepithelial neoplasia (CIN 1), and HSIL, including CIN2 and CIN3. The model was more scientific and reasonable.

There were several limitations of the study. We only considered the effectiveness of the HPV vaccine in preventing cervical cancer. We did not consider its protective effect on other HPV related cancers, such as vaginal cancer and head and neck cancer. Thus, we may have underestimated the effectiveness of the vaccine. In addition, most of the transfer probability parameters in the model came from the published studies involving people from elsewhere than China. Thus, these parameters may deviation somewhat from the data of the Chinese population. However, we performed a sensitivity analysis on the probability parameters of the model, and within a certain range of changes, the research results did not change.

Conclusion

Compared to the strategy of not receiving HPV vaccine, the use of two doses of bivalent HPV vaccine for 14-year-old females was more cost-effective. The research results provided scientific basis for adjusting immunization planning projects, optimizing HPV vaccination strategies, and making health decision-making in Wuxi City. The results also have important theoretical and practical application value for preventing the occurrence and development of cervical cancer and improving quality of life.

Abbreviations

IARC	International Agency for Research on Cancer
HPV	High-risk human papillomavirus
LSIL	Low-level squamous intraepithelial lesions
HSIL	High-level squamous intraepithelial lesions
QALYs	Quality adjusted life years
ICER	Incremental cost-effectiveness ratio
BCR	Benefit-cost ratio
WTP	Willingness-to-pay threshold

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12962-024-00574-9.

Supplementary Material 1

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Author contributions

JJ and ZF collected the data and carried out the analyses. HX and WX validated the data. All authors contributed in interpreting the results and writing the manuscript. All authors read and approved the final manuscript.

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Data availability

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

Declarations

Ethics approval and consent to participate
This study only involved the collection of population monitoring data, outpatient and inpatient cost data, and did not involve the collection of personal information and samples. After review and confirmation by the Ethics Committee of Wuxi Center for Disease Control and Prevention, this study meets the conditions of exemption from ethical review.

Competing interests
The authors declare no competing interests.

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