10.18686/mhr.v2i2.4131

Effectiveness and Cost-Effectiveness Analysis of Influenza Vaccination Among the Adolescents in the United States

Zirui Liu

High School Affiliated to Renmin University of China Beijing 100086

Abstract: Influenza is a common respiratory virus that could cause death. Vaccination of influenza was recommended in many countries to reduce the heavy disease burden in every flu season. In this study, we applied a simulation model to estimate the economic outcomes of influenza vaccination among adolescents in the United States in 2024. In this study, we use the competing choice method to compare the cost-effectiveness of vaccination and no vaccination. We divide the cohort group into the younger age group (10-14) and the elder age group (15-19). We use the estimation of net cost and net quality-adjusted life years (QALYs) to calculate the incremental cost-effectiveness ratios (ICER) of influenza vaccination in three different coverage of 50%, 80%, and 100% in 2024. The result shows the highest cost-effectiveness for 80% coverage and younger age group, and the largest health benefit for 100% coverage among adolescents from 10 to 19 in the US in 2024.

Keywords: Influenza; Vaccination; Cost-effectiveness analysis; Adolescents

Introduction

Influenza is one of the most common infectious diseases around the world. As a virulent and contagious respiratory virus, it affects the human respiratory system such as the nose, throat, and lungs. Although most people believe that influenza can be recovered on their own, sometimes it can be deadly. In this flu season in the US, 2023, the Centers for Disease Control and Prevention (CDC) estimates the influenza in-season burden that there are 7. 1 to 14 million flu illnesses, 73000 to 150000 hospitalizations, and 4500 to 13000 deaths. Moreover, between 2010 and 2022, CDC estimates that flu has resulted in 9. 4 million to 41 million illnesses, 100000 to 710000 hospitalizations, and 4900 to 52000 deaths annually. Due to the heavy disease burden, the CDC states that the best way to reduce the risk of flu and its potentially serious consequences is by getting vaccinated each year. Especially for the high-risk groups which are young children under age 12 or live or work with many other residents, vaccination is essential for them to prevent the infection. During the last 4 flu seasons, the influenza vaccination rate among US adolescents shows a declining trend, from 53. 1% in 2019 to 45. 9% in 2022. To discover the reason why the vaccination rate is around half of the population, this study conducts the method to gain the effectiveness and cost-effectiveness of different coverage of influenza vaccination.

According to previous studies, there is a consensus that influenza vaccination is either cost-saving or cost-effective for children. However, there are some gaps in current research. For example, some studies generalized the results from a wide range of regions and age groups, which regional factors, such as the differences between healthcare systems, economic structures, and influenza prevalence may constrain. Some reviews are based on outdated data, which may create calculating errors. Also, the age groups that previous researchers have chosen are focused most on elder people and very young children. To fill these gaps, this paper will focus on the age group from 10 to 19 in the United States by using the most recent data based on the relative conclusions to develop new discussions of the cost-effectiveness analysis of influenza vaccination among adolescents in the US.

Method

Overview

In this study, we estimate the effect and cost-effectiveness of influenza vaccination for the population of adolescents from age 10 to 19 in the United States. A simulation model is constructed for using the competing choice analysis to estimate the health and economic outcomes of different coverage of influenza vaccination for the US cohorts. To estimate the cost-effectiveness of influenza vaccination more accurately, this study applied the epidemiologic and vaccine effectiveness data from last winter (2022-2023) to the model structure. Outcomes from the model include the net cost and net quality-adjusted life years (QALYs) gained of vaccination and no vaccination, and the incremental cost-effectiveness ratio (ICER) in dollars per QALYs gained.

Model Structure

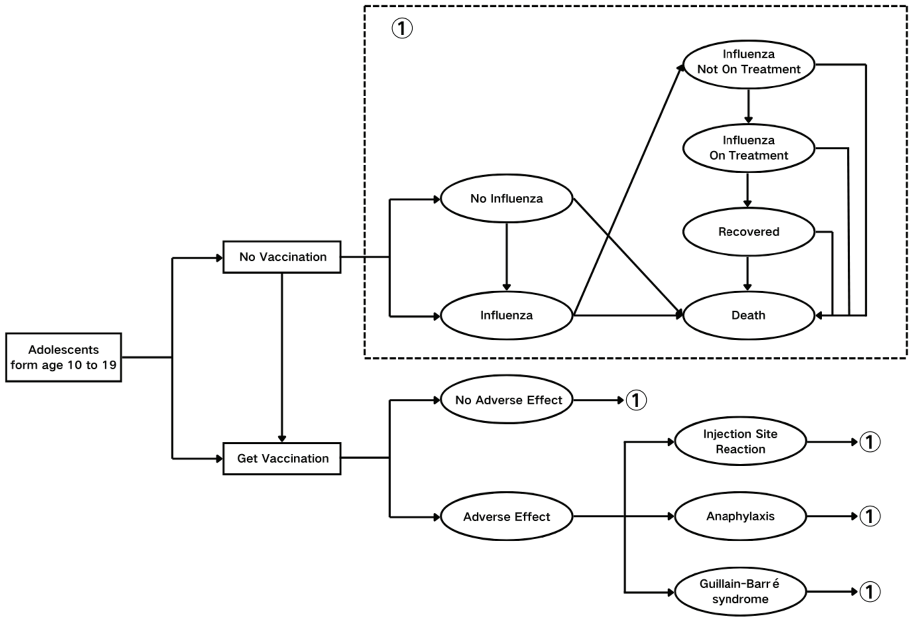

Fig. 1. Influenza cost-effectiveness cohort simulation model

The model structure contains two components: a decision tree capturing outcomes relating to vaccination and a Markov model simulating the lifetime progression of the cohort of US adolescents. The entire model structure is shown in Figure 1.

Decision Tree

This study modeled the two strategies of vaccination and no vaccination of the cohort groups. To be detailed, cohorts were the adolescents from age 10 to 19 in the United States, stratified by age: 10-14 years and 15- 19 years. There are two groups of people which are adolescents from age 10 to 19 with no influenza vaccination and adolescents with influenza vaccination during the last 12 months.

Markov Model

The Markov model simulates the outcomes in long-term related to whether the cohorts received influenza vaccination, including getting or not getting the influenza infection, having or not having the adverse effects led by the influenza vaccination, and finally the mortality from influenza or influenza vaccination and other causes. According to the data sources, the decreased influenza infection rate, the increased influenza mortality rate, and the decreased vaccination effectiveness in elder age groups, we divide the cohorts into groups of two age groups which are 10-14 years and 15-19 years.

For each case that received influenza vaccination, we modeled the primary outcomes of having and not having adverse effects. For the case of adverse effects, we use the three dominant consequences: injection site reaction, anaphylaxis, and Guillain-Barré syndrome to model the rate of adverse effects and the cost of treatments of these adverse effects.

Model Data

In this study, we selected the parameters shown in Table 1 from related medical literature. This study estimates the probability and cost of adverse effects of vaccination by adding the probabilities and costs of three main types of adverse effects together, which are the injection site reaction, anaphylaxis, and Guillain-Barré syndrome. Considering from a healthcare perspective, we use the sum of the costs of influenza outpatient visits and hospitalizations to calculate the cost of influenza treatment. We also add the costs of IIV or LAIV vaccine per dose, the administration costs, and the parent time costs to form the total cost of vaccination. Moreover, we use the coverage of 50%, 80%, and 100% to calculate cost-effectiveness. We use the discounting rate of 3% in the calculation.

Table 1. Parameter table of the influenza cost-effectiveness model

Variable	Base Case	Range of Sensitivity Analysis
Influenza Vaccination Coverage in 2022-2023		
Children under the age 18 years	0. 459	0. 444-0. 474
Probability of Adverse Effect of Vaccination		
Injection Site Reaction	0. 0003	0-0. 001

Variable	Base Case	Range of Sensitivity Analysis
Anaphylaxis	0. 00000025	0-0. 00000025
Guillain-Barré syndrome	0. 0000016	0-0. 000010
Vaccination-related Adverse Effect Costs		
Injection Site Reaction	$61	$30-683
Anaphylaxis	$2700	$52-13754
Guillain-Barré syndrome	$23360	$6700-78900
Influenza Infection Rates		
5-17years	0. 096	0. 029-0. 193
18-49years	0. 071	0. 022-0. 144
Influenza Vaccine Effectiveness		
5-11years	0. 44	0. 33-0. 53
12-17years	0. 42	0. 28-0. 54
18-49years	0. 35	0. 24-0. 45
Influenza-attributable Deaths(per 100000 Population)		
5-17years	0. 173	0. 000-1. 373
18-49years	0. 285	0. 027-1. 199
Influenza-related Medical Costs		
Ⅰ Outpatient visit		
5-17years	$208	$28-758
18-49years	$293	$23-1295
Ⅱ Hospitalization		
5-17years	$16644	$1816-66009
18-49years	$25113	$2287-1060
Vaccination Costs		
Per Dose IIV	$6. 86	
Per Dose LAIV	$12. 89	$10-25
Administration Costs	$25	$10-40
Parent Time Costs	$32	$0-$64
Quality Adjustments		
Influenza illness	0. 0082	0. 0075-0. 0090
Hospitalizations	0. 0165	0. 0151-0. 0180
Anaphylaxis	0. 0137	0. 0135-0. 0139
Guillain-Barré syndrome	0. 0198	0. 0181-0. 0217

References: Buchy (2020), CDC (2023), Kim DeLuca (2023), NHIS (2023), Prosser (2006), Stratton (2012).

Statistical Analysis

We calculate the net cost and net QALYs by the parameters table and the model structure. We conduct a competing choice analysis for the cost-effectiveness analysis. We estimate the difference between the costs and QALYs of 50%, 80%, and 100% coverage and that of no vaccination (0% coverage) as the net costs and net QALYs of each strategy. We calculate the ICER by dividing the net costs by the net QALYs. Then, labeling the ICERs of 50%, 80%, and 100% coverage of influenza vaccination for the two age groups under the three strategies.

Results

Table 2. 100% coverage of influenza vaccination

Age	Death averted	Infection Averted	Net Costs (in billion)	Net QALYs (in million)	ICER
10-14 years	44987. 8 (14972, 153307)	1038242351 (370011623, 2164887716)	1752 (1564, 1955)	26. 9 (7. 6, 58. 9)	85489 (30407, 221392)
15-19 years	42204. 5 (17118, 80266)	915247277 (276639085, 1861313679)	1613 (1421, 1813)	16. 8 (4. 6, 39. 3)	131510 (41316, 364898)

Table 3. 80% coverage of influenza vaccination

Age	Death averted	Infection Averted	Net Costs (in billion)	Net QALYs (in million)	ICER
10-14 years	40489 (1339, 137976)	934418116 (333010461, 1948398944)	1401. 281 (1251. 257, 1564. 151)	24. 2 (6. 8, 52. 8)	75991 (27028, 196792)
15-19 years	37140 (15064, 70634)	805417604 (243442395, 1637956037)	1290. 204 (1137. 191, 1450. 121)	14. 8 (4. 2, 34. 6)	119555 (37551, 339073)

Table 4. 50% coverage of influenza vaccination

Age	Death averted	Infection Averted	Net Costs (in billion)	Net QALYs (in million)	ICER
10-14 years	15745. 7 (521, 53657)	363384823 (129504068, 757710700)	875. 8 (782. 0, 977. 6)	9. 7 (2. 9, 21. 2)	117324. 13 (40766. 38, 310276. 96)
15-19 years	13506 (5478, 25685)	201354401 (60860599, 409489009)	806. 4 (710. 7, 906. 3)	5. 4 (1. 4, 12. 6)	205997. 85 (63179. 54, 609271. 21)

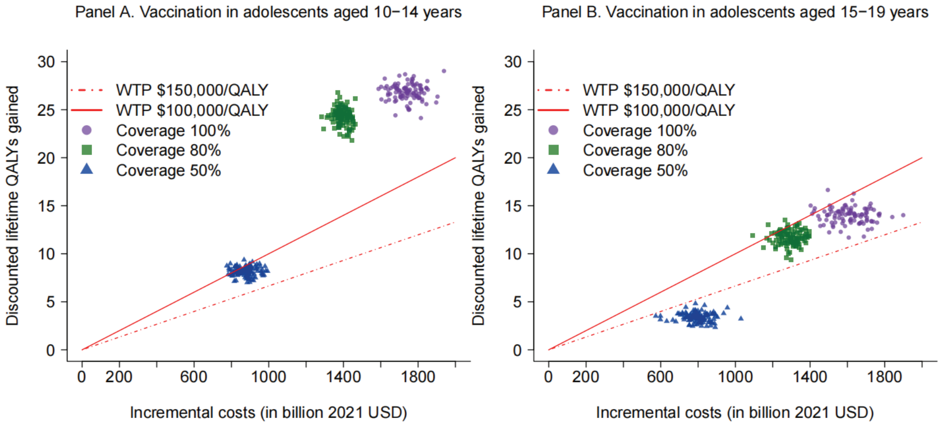

Fig. 2. Cost-effectiveness of different coverage of influenza vaccination

Health and Economic Outcomes

According to the estimations, influenza in-season vaccination increased the net costs and contributed to gains in QALYs. The larger the coverage of influenza vaccination, the greater the number of influenza infections and deaths averted. For the elder age group of the age 10 to 14, the number of averted infections and deaths also increase. For the three strategies, the net cost and net QALYs change as the same trend as averted deaths and infections.

To show the trend more specifically, we chose the death averted by the influenza vaccination as an example. It is first that the 100% coverage of vaccination prevents 44987. 8 deaths with a confidence interval of (14972, 153307) for 10 to 14 years old and 42204. 5 deaths with a confidence interval of (17118, 80266) for 15 to 19 years old. Then, the 80% coverage of vaccination prevents 40489 deaths with a confidence interval of (1339, 37976) for 10 to 14 years old and 37140 deaths with a confidence interval of (15064, 70634) for 15 to 19 years old. Lastly, the 50% coverage of vaccination prevents 15745. 7 deaths with a confidence interval of (521, 53657) for 10 to 14 years old and 13506 deaths with a confidence interval of (5468, 25685) for 15 to 19 years old. And other results are shown in Tables 2, 3, and 4.

Cost-effectiveness Analysis Outcomes

We can arrange the ICER of different coverage of vaccination by 80%, 100%, and 50% in an increasing order. For the coverage of 80%, the cost-effectiveness is 75991 per one QALY for 10 to 14 years old with a confidence interval of (27028, 196792) and $119555 per one QALY for 15 to 19 years old with a confidence interval of (37551, 339073). The cost-effective for 100% coverage of vaccination is $85489 per one QALY for 10 to 14 years old with a confidence interval of (30407, 221392) and $131510 per one QALY for 15 to 19 years old with a confidence interval of (41316, 364898). The cost-effective for 50% coverage of vaccination is $117324. 13 per one QALY for 10 to 14 years old with a confidence interval of (40766. 38, 310276. 96) and $205997. 85 per one QALY for 15 to 19 years old with a confidence interval of (63179. 54, 609271. 21) (Table 2, 3, and 4).

Discussion

We use the simulation model to conduct the calculation of the cost-effectiveness of influenza vaccination for the population of all adolescents from ages 10 to 19 in the US. Firstly, we found that for each coverage, the ICERs of the younger group (10-14) are all greater than that of the elder group (15-19), suggesting that the influenza vaccination is more cost-effective for younger adolescents when the coverage is

50%, 80%, and 100%. Also, the death and infection averted are larger for younger age groups so influenza vaccination could produce more health benefits for younger adolescents. Secondly, the ICERs of the 100% vaccination coverage for the younger group and the 80% vaccination coverage for the younger group are less than 100000. Since these two strategies have ICERs that are less than the willingness to pay (WTP) of $100000, we can conclude that people will strongly purchase them. Nevertheless, the ICERs of 100% coverage for the elder group and 80% for the elder group are relatively low, so these two strategies are relatively more cost-effective. Thirdly, the 100% coverage of influenza vaccination has the largest infection and death averted, leading to the largest health benefits among all the strategies. Although the influenza vaccination rate among US adolescents is about 50%, the results clearly show that this strategy is less cost-effective than higher proportions of vaccination. (Tables 2, 3, and 4)

In Figure 2, the incremental cost is labeled on the x-axis and the discounting lifetime QALYs gain is labeled on the y-axis. Since the ICER is the ratio of net cost and net QALYs gained, in this figure, the steeper the slope of the line connected between the origin and the dots, the higher the ICER the strategy has. Therefore, the steeper slope would cause a more cost-effective strategy. One finding is that comparing panels A and B, the younger age group has a slope generally larger than the elder group. The strategies of 80% and 100% coverage for all the adolescents in the group have ICERs lower than WTP of $150000, representing the relatively cost-effective strategies. Another thing is that for both age groups, the slope of the line connected between the origin and the dots of 80% influenza vaccination coverage for younger adolescents is steeper and dominated the other two strategies, which suggests that the cost-effectiveness becomes higher when the coverage increasing from 50% to 80% but lower when the coverage increasing from 80% to 100. Our supposition is that this is because of vaccination shield among adolescents.

Limitations

One of the study's limitations is that more factors affect the probability and cost of influenza treatments, and vaccination adverse effects. Also, different outcomes may occur when the cohort groups are infected by different types of influenza virus or take different brands of vaccination. Therefore, this paper only discusses the general cost-effectiveness of influenza vaccination among both type a and b viruses and all types of vaccines. Moreover, the result only shows the most cost-effective influenza vaccination coverage among 50%, 80%, and 100% coverage. For further research and discussion, the cost-effectiveness of other coverage rates could be established, and the coverage that leads to the highest cost-effectiveness should be found.

Conclusions

This study focuses on the cost-effectiveness of influenza vaccination among US adolescents in 2024 since influenza causes a heavy burden around the world in every flu season. In summary, the paper highlights that the 80% coverage of influenza vaccination among US adolescents is the most cost-effective strategy, and the 100% coverage of influenza vaccination produces the largest health benefits among US adolescents. Although 100% influenza vaccination coverage is not the most cost-effective strategy, it is recommended for most of the developed countries especially the US which puts large investments in the healthcare system.

References

[1] Babazadeh, A. *et al.* (2019) 'Influenza vaccination and Guillain–barré syndrome: Reality or fear', *Journal of Translational Internal Medicine*, 7(4), pp. 137–142. doi:10. 2478/jtim-2019-0028.

[2] Buchy, P. and Badur, S. (2020) 'Who and when to vaccinate against influenza', *International Journal of Infectious Diseases*, 93, pp. 375–387. doi:10. 1016/j. ijid. 2020. 02. 040.

[3] Cheng, Y. *et al.* (2020) 'Effects of influenza vaccination on the risk of cardiovascular and respiratory diseases and all-cause mortality', *Ageing Research Reviews*, 62, p. 101124. doi:10. 1016/j. arr. 2020. 101124.

[4] *FASTSTATS - Influenza* (2023) *Centers for Disease Control and Prevention*. Available at: https://www. cdc. gov/nchs/fastats/flu. htm (Accessed: 30 January 2024).

[5] Kim DeLuca, E. *et al.* (2023) 'Cost-effectiveness of routine annual influenza vaccination by age and risk status', *Vaccine*, 41(29), pp. 4239–4248. doi:10. 1016/j. vaccine. 2023. 04. 069.

[6] *NHIS - Summary Health Statistics - Children* (2018) *Centers for Disease Control and Prevention*. Available at: https://www. cdc. gov/ nchs/nhis/KIDS/www/index. htm (Accessed: 30 January 2024).

[7] Osterholm, M. T. *et al.* (2012) 'Efficacy and effectiveness of influenza vaccines: A systematic review and meta-analysis', *The Lancet Infectious Diseases*, 12(1), pp. 36–44. doi:10. 1016/s1473-3099(11)70295-x.

[8] Peasah, S. K. *et al.* (2013) 'Influenza cost and cost-effectiveness studies globally – A Review', *Vaccine*, 31(46), pp. 5339–5348. doi:10. 1016/j. vaccine. 2013. 09. 013.

[9] Pelton, S. I. , Mould-Quevedo, J. F. and Nguyen, V. H. (2023) 'Modelling the population-level benefits and cost-effectiveness of cell-based quadrivalent influenza vaccine for children and adolescents aged 6 months to 17 years in the US', *Expert Review of Vaccines*, 23(1), pp. 82–87. doi:10. 1080/14760584. 2023. 2295014.

[10] Prosser, L. A. *et al.* (2006) 'Health benefits, risks, and cost-effectiveness of influenza vaccination of children', *Emerging Infectious Diseases*, 12(10), pp. 1548–1558. doi:10. 3201/eid1210. 051015.

[11] Schiller, J. S. and Norris, T. (2023) 'Early Release of Selected Estimates Based on Data From the 2022 National Health Interview Survey', *U. S. Department of Health and Human Services*, Centers for Diseases Control and Prevention(National Center for Health Statistics), pp. 1–2.

[12] Smith, K. J. *et al.* (2016) 'Cost effectiveness of influenza vaccine choices in children aged 2–8 years in the U. S. ', *American Journal of Preventive Medicine*, 50(5), pp. 600–608. doi:10. 1016/j. amepre. 2015. 12. 010.

[13] Stratton, K. R. (2012) *Adverse effects of vaccines evidence and causality*. Washington, D. C. : National Academies Press.

[14] Wang, Q. *et al.* (2023) 'Cost-effectiveness of seasonal influenza vaccination of children in China: A modeling analysis', *Infectious Diseases of Poverty*, 12(1). doi:10. 1186/s40249-023-01144-6.