The impact of accelerated COVID-19 bivalent booster vaccination on US pediatric health outcomes and school absenteeism

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Key Points

Question: Could accelerated COVID-19 bivalent booster uptake in the US have decreased outcomes of pediatric hospitalizations and student absenteeism among children?

Findings: In this simulation model of COVID-19 transmission, booster campaigns achieving an uptake similar to seasonal influenza vaccination could have prevented over 10,000 pediatric hospitalizations and 5.4 million days of school absenteeism from the beginning of October 2022 to the end of March 2023 in the entire US population.

Meaning: Although COVID-19 prevention often focuses on older populations, the benefits of booster campaigns for children are still substantial.

Abstract

Importance: Adverse outcomes of COVID-19 for the pediatric population include disease and hospitalization, leading to school absenteeism. Booster vaccination for eligible individuals across all ages may promote health and school attendance.

Objective: To quantify the benefits of accelerating bivalent COVID-19 booster uptake across the general population in reducing pediatric hospitalizations and school absenteeism.

Design: A simulation model of COVID-19 transmission fitted to reported incidence data from October 2020 to September 30, 2022, with outcomes simulated from October 1, 2022 to March 31, 2023

Setting: United States (US)

Participants: Entire age-stratified US population in the transmission model; children under the age of 18 for outcomes

Interventions: Accelerated bivalent COVID-19 booster campaigns to achieve either half or similar age-specific uptake observed for 2020-21 seasonal influenza vaccination among the eligible population across all age groups

Main Outcomes and Measures: Hospitalizations, intensive care admissions, isolation days of symptomatic infection, and days of school absenteeism for children aged 5-17 averted by accelerated bivalent booster campaigns

Results: A bivalent booster campaign achieving age-specific coverage similar to influenza vaccination could have averted a total of 5,448,694 (95% Credible Interval [CrI]: 4,936,933 - 5,957,507) days of school absenteeism due to COVID-19 illness. In addition, the campaign could have prevented 10,019 (95% CrI: 8,756 - 11,278) hospitalizations among the pediatric population, of which 2,645 (95% CrI: 2,152 - 3,147) were estimated to require intensive care. Even a less ambitious campaign with only 50% age-specific uptake of influenza vaccination among eligible individuals could have averted 2,875,926 (95% CrI: 2,524,351 - 3,332,783) days of school absenteeism and 5,791 (95% CrI: 4,391 - 6,932) hospitalizations among children aged 0 to 17 years, of which 1,397 (95% CrI: 846 - 1,948) were estimated to require intensive care.

Conclusions and Relevance: In this decision analytic model study, increasing uptake of bivalent booster vaccination among eligible age groups was shown to provide substantial benefits to the pediatric population, keeping children out of hospitals and in schools.

Introduction

COVID-19 substantially disrupted many elements of normal life, with notable consequences for children. As of March 6, 2023, the pandemic has been responsible for over 185,000 hospitalizations and 1700 deaths in the pediatric population.[1,2] Among interventions implemented, school closure was the most consistently applied measure globally in 2020, affecting more than 90% of the world's students.[3] In subsequent academic years, students have faced challenges including illness-driven absenteeism, pandemic-driven instability in their personal lives, outbreak-driven school closures, and transition to virtual or hybrid learning formats. The repercussions of this upheaval are evident in reports of lower test scores among children educated during the COVID-19 pandemic compared to their pre-pandemic counterparts.[4] Preventing severe illness among children and maintaining high levels of school attendance must be important goals for policymakers.

Vaccines are among the most important tools available to combat COVID-19. While waning protection and immune escape have posed substantial challenges to control,[5] a bivalent COVID-19 booster vaccine is available which specifically targets some of the highly transmissible Omicron subvariants.[6] We hypothesized that vaccination campaigns achieving high booster coverage among eligible individuals could have markedly reduced severe disease and deaths across all ages as well as preventing school absenteeism and consequent educational disruption. Using a simulation model, we evaluate the benefits which would have accrued to the pediatric population by improving bivalent booster coverage among both children and adults. We quantified not only the booster campaign impact on hospitalizations but also on pediatric isolation days and school absenteeism, demonstrating the importance of vaccination uptake for maintaining in-person education.

Methods

Ethics

We used publicly available data for COVID-19 reported infections, hospitalizations and deaths for this modelling study (eMethods in the supplement).[7] Because data were not collected specifically for this decision analytical model study and no identifiable personal data were used, specific ethical approval and informed consent were not required in accordance with York University research ethics guidelines for program evaluation activities relying on secondary use of anonymous data. We followed the CHEERS reporting guideline for decision analytic models and simulated modelling studies.[8]

Study design and population

We used a simulation model to project COVID-19 health outcomes for the US population under a range of bivalent booster uptake scenarios from the beginning of October 2022. These include a baseline scenario matching daily vaccination rates, and two counterfactuals of bivalent booster with (i) a campaign that achieved a coverage equivalent to half of the age-specific influenza vaccine uptake in 2020-2021 season,[9] and (ii) a campaign that mimicked the same age-specific influenza vaccine coverage for eligible individuals aged 5 years and older by the end of 2022. Outside the three-month duration of counterfactual campaigns, the daily rates of vaccination remained the same as the baseline. We focused specifically on the pediatric

outcomes projected by this model, including isolation days, school absenteeism, and hospitalizations.

Simulation modelling framework

We adapted our age-stratified, agent-based model of COVID-19 to account for the waning of naturally acquired or vaccine-elicited immunity (eMethods).[10–15] The population was stratified into 10 age groups of 0 to 4, 5 to 10, 11-13, 14-17, 18 to 20, 21 to 29, 30 to 39, 40 to 49, 50 to 64, and 65+ years based on the US demographics.[16] The model incorporated age-specific risk of hospitalizations, deaths, and contact patterns (eTable 1, eMethods in the Supplement).[17,18] For the transmission dynamics, we considered the spread of five SARS-CoV-2 variants, including Iota, Alpha, Gamma, Delta, and Omicron, in addition to the original Wuhan-Hu-I pandemic strain (eMethods in the Supplement). Parameterization of the transmission dynamics was based on the most recent estimates (eTable 2 in the Supplement).

The model was calibrated by fitting to the reported incidence of COVID-19 between October 2020 and February 28, 2022 (Figure 1, eMethods in the Supplement).[7] The fitted model was then simulated forward to the end of March 2023 under the baseline and counterfactual scenarios of booster vaccination campaigns. Since the model calibration and fitting was based on the reported COVID-19 cases (and not the actual number of infections), the projected outcomes correspond to reported cases under the counterfactual scenarios.

Vaccination scenarios simulated

In counterfactual scenarios, the average daily number of vaccine doses was maintained the same as the baseline through September 30, 2022 before the start of accelerated booster vaccination campaigns. These campaigns were implemented between October 1 to December 31, 2022, during which the booster uptake of eligible individuals reached either half (Scenario 1) or the same level (Scenario 2) as the age-specific influenza vaccination coverage in the 2020-21 season. We considered the coverage in different age groups as the benchmark for booster campaigns, corresponding to 59%, 51%, 38%, 54%, and 75% in age groups 5 to 11, 12 to 17, 18 to 49, 50 to 64, and 65+ years.[19] As we expected diminishing marginal gains for increasing booster uptake when high coverage has already been achieved, the second counterfactual provides an exploration of whether an ambitious campaign, compared to the reported bivalent booster coverage of 23.3% of eligible individuals as of March 6, 2023,[20] is worth the additional effort and resources.

Following the operational guidelines of the Centers for Disease Control and Prevention (CDC),[21] and in light of authorization regarding pediatric bivalent boosters,[22] we considered those aged 5 and older to be eligible if they had received the last dose of their primary series or booster dose at least 4 months prior.

Vaccine effectiveness was specific to the regimen (primary vs. booster), time since previous dose, and strain (eTables 3,4, eFigure 1, eMethods in the Supplement). Although the bivalent vaccines have been shown to generate significantly higher levels of neutralizing antibodies against the Omicron subvariants,[23,24] real-world estimates of their effectiveness are currently

lacking. In our analysis, we set the effectiveness of a bivalent booster against infection, symptomatic disease, and severe disease caused by any Omicron subvariant to the corresponding estimates for a booster dose of the monovalent vaccines countering the BA.1 variant (eTables 3,4, eMethods in the Supplement).[25–27]

Model outcomes

We projected the age-specific number of asymptomatic infections, mild symptomatic cases, severe non-hospitalized cases, hospitalized cases, and intensive care unit (ICU) cases across the study period of October 1, 2022, and March 31, 2023, for the baseline scenario and each counterfactual. We further calculated isolation days among the entire pediatric population (0-17 years) and school absenteeism among those aged 5-17 years. Guidance from the CDC stipulates that individuals who test positive for COVID-19 should isolate for at least five days and at least one day beyond the resolution of symptoms.[28] A minimum ten-day isolation period is advised for those who experience severe illness including shortness of breath, low oxygen levels, or hospitalization. In our model, we calculated pediatric isolation days as five days per event for children who experience mild symptomatic illness, and ten days for those with severe illness or hospitalization.

Considering that school is typically only five days in a week, when calculating days of school absenteeism we multiplied pediatric isolation days among children aged 5-17 years by 5/7. We further adjusted the total days of absenteeism by 3.23% to account for children who are homeschooled.[29]

Based on the model projections, we estimated the average days of student and teacher absenteeism averted under each counterfactual, compared to the baseline scenarios, for typical school sizes at the elementary, middle, and high levels. We obtained data on school enrollment and teacher count from the National Center for Education Statistics,[30] stratified into tertiles by enrollment as “lower-enrollment,” “middle-enrollment,” or “higher-enrollment,” which we refer to as “small,” “midsize,” and “large,” respectively (Table 2). We assumed that students in elementary, middle, and high schools were aged 5-10, 11-13, and 14-17 years, respectively. We also assumed that teachers were representative of the population aged 21-64. To calculate student and teacher isolation days and absenteeism, we multiplied the projected age-specific per-capita isolation and absentee rates by the number of students or teachers at each category of school.

Statistical analysis

The simulation model was calibrated using 500 independent Monte Carlo realizations (eMethods). For each Monte Carlo realization, we calculated the cumulative outcomes of simulations during the study period and derived the 95% credible intervals (CrIs) using a bias-corrected and accelerated bootstrap method with 500 replications, which corrects for bias and skewness in the distribution of bootstrap estimates when scaled from the per capita to the entire population. The adjustments for days of school absenteeism were applied to each independent Monte-Carlo realization. The computational model was implemented in Julia language, and statistical analyses were conducted in Matlab, version R2022B (MathWorks). For hypothesis

testing, 2-sided *P* = .05 was considered to be significant. Simulation code is available at: https://github.com/thomasvilches/USomicron/tree/booster_scenarios

Results

Nationally, a bivalent booster campaign which achieved half of the age-specific coverage of the 2020-21 influenza vaccination levels among eligible individuals was estimated to avert 4,506,119 (Credible Interval [CrI]: 3,956,423 - 5,208,525) isolation days among the pediatric population and 2,875,926 (2,524,351 - 3,332,783) days of school absenteeism during the study period, compared to the baseline scenario (Table 1). For the more ambitious bivalent booster campaign reaching the same level of influenza vaccination uptake for eligible individuals across all ages, the corresponding isolation and school absenteeism days averted were estimated to be 8,572,225 (95% CrI: 7,772,630 - 9,364,837) and 5,448,694 (95% CrI: 4,936,933 - 5,957,507), respectively.

To contextualize our results for local communities, we estimated the average days of student and teacher absenteeism that could have been averted under each of the counterfactuals compared to the baseline scenario for elementary, middle, and high schools at different sizes (Table 2). Specifically, the mean days of student absenteeism averted per school by a campaign that achieved half of age-specific coverage of influenza vaccination ranged from 10 to 25 days in elementary schools during the study period. For the same booster uptake scenario, student absenteeism averted ranged from 27 to 36 days for middle schools, and from 21 to 28 days for high schools. As there are fewer teachers than students, campaign impact on teacher absenteeism was substantially lower, ranging from 0.7 to 1.1 days in different school sizes. When the booster campaign mimicked the same uptake as age-specific influenza vaccination coverage, we found that the mean days of student absenteeism averted was at least 75% higher for any school irrespective of its level or enrollment size.

For health outcomes, we estimated that the a bivalent booster campaign achieving half of influenza-like coverage could have averted 5,791 (95% CrI: 4,391 - 6,932) pediatric hospitalizations during the study period, of which 1,397 (95% CrI: 846 - 1,948) were estimated to require intensive care (Table 1). With booster coverage of eligible individuals reaching influenza-like uptake, we estimated that 10,019 (95% CrI: 8,756 - 11,278) hospitalizations could have been averted, of which 2,645 (95% CrI: 2,152 - 3,147) were estimated to require ICU admission. During the period of October 1, 2022 to March 4, 2023, over 22,000 COVID-19 hospitalizations of children aged 0-17 were reported.[20] An influenza-like coverage of bivalent booster could have reduced pediatric hospitalization by at least 45%.

We performed additional analyses, assuming that only 50% of mildly symptomatic cases follow guidelines for a 5-day isolation. The estimates of outcomes averted in each counterfactual were similar (Kriskull-Wallis test; P-values>0.12) to those obtained in the corresponding scenario when all mildly symptomatic cases practiced isolation (eTable 5 in the Supplement).

Discussion

The findings of this simulation model underscore the benefits that an accelerated bivalent booster campaign achieving high coverage across all age groups in the US would have provided for the pediatric population specifically. In addition to substantial reductions in pediatric illness and hospitalization, our estimates show that widespread booster vaccination can support school attendance.

Reducing school absenteeism benefits students, families and the society as a whole. For students, reduced absenteeism maintains in-person learning, supporting educational recovery in the wake of pandemic-driven learning loss.[4] In addition to those who personally become ill, classroom outbreaks or teacher absenteeism are also disruptive to uninfected students. For families, school absenteeism can impose productivity losses and economic burden. In most cases, an adult caregiver would need to stay home with an isolated child. Our estimates of averted absenteeism do not include the benefits for parents, but isolation of children on weekend days would further strain those parents who work on weekends. Society as a whole functions better when there are fewer schedule disruptions among working parents, and having well-educated and healthy children is a societal value in its own right.

The reduction of pediatric outcomes of COVID-19, and especially hospitalization, is particularly salient during an academic year. The early onset and significant rise of both respiratory syncytial virus and influenza cases in fall 2023 demonstrated how a concomitant surge of various respiratory diseases could strain pediatric hospital capacity nationwide.[31] Improving bivalent booster uptake across all age groups could prevent recurrence of this scenario in future academic years as SARS-COV-2 continue to evolve and more transmissible and immune evading variants emerge. Specifically, it is important to achieve high coverage among the pediatric population itself, as revealed when comparing the two counterfactual scenarios. Indirect protection also plays a role, and indeed in this model it is entirely responsible for any benefits of booster vaccination to children under 5 years of age. Raising coverage for the 18-49 year old group from 19% in scenario 1 to 38% in scenario 2 was particularly important for indirect protection, as this age group includes many parents of school-age children. Bivalent booster campaigns could emphasize the indirect benefits for children and school attendance in order to motivate this age group.

Achieving a high booster uptake requires investment and outreach at the national level. Despite direct costs associated with vaccination (e.g., vaccination clinic setup, vaccine storage and transportation, vaccine administration, vaccine doses, and vaccine wastage), and those incurred indirectly as a result of workdays lost for visiting vaccination clinics or due to adverse reactions to vaccines, the return on this investment could be substantial[32] with the reduction of severe outcomes and school absenteeism.

Limitations

Our analysis is subject to limitations. Specifically, we have assumed that school absenteeism only applies to symptomatic children. The CDC guidance states that all individuals who test positive should be isolated for at least five days, irrespective of symptoms.[28] Although testing of close contacts is far from universal, many people still test when they have a known infectious

contact. This practice will identify a proportion of asymptomatic and presymptomatic cases in children, which will lead to additional absenteeism of infected students. Even with reduced testing, and increasing rates of asymptomatic infection and mildly symptomatic cases owing to the rise of immunity in the population and propagation of less severe variants, the benefits of booster vaccination could be substantial (eTable 5 in the Supplement). Our analysis assumed that the bivalent booster vaccines have the same effectiveness against the Omicron subvariants as those estimated for the monovalent booster vaccines against the Omicron BA.1 variant. Despite continual evolution of SARS-CoV-2 that challenges pandemic control, we did not consider the potential rise of further immune-evasive variants in our analysis. Our model also did not include the use of COVID-19 outpatient treatments, as temporal data regarding uptake have been scarce. However, this omission is not likely to have a large effect on pediatric outcomes, as treatment is most commonly directed to older adults.[33]

Conclusions

Throughout the pandemic, children have experienced direct health burdens as well as enormous upheaval in their personal and educational lives. Booster vaccination campaigns of eligible individuals across all ages can reduce the risk of SARS-CoV-2 infection, protecting children both directly and indirectly and providing them with additional stability in terms of school attendance and other social activities. By contrast, the cost of inaction will be steep: millions more days of school absenteeism and thousands of preventable hospitalizations.

Author Contributions: Drs Fitzpatrick and Moghadas had full access to all of the data in the study, and take responsibility for the integrity of the data and the accuracy of the data analysis.

Concept and design: Fitzpatrick, Moghadas, Shah, Vilches, Pandey, Galvani.

Acquisition, analysis, or interpretation of data: Fitzpatrick, Moghadas, Vilches, Pandey.

Drafting of the manuscript: Fitzpatrick, Moghadas, Pandey, Galvani.

Critical revision of the manuscript for important intellectual content: Fitzpatrick, Moghadas, Galvani.

Statistical analysis: Fitzpatrick, Moghadas.

Obtained funding: Fitzpatrick, Moghadas, Galvani.

Administrative, technical, or material support: Fitzpatrick, Moghadas, Shah, Vilches, Pandey, Galvani.

Supervision: Moghadas, Galvani.

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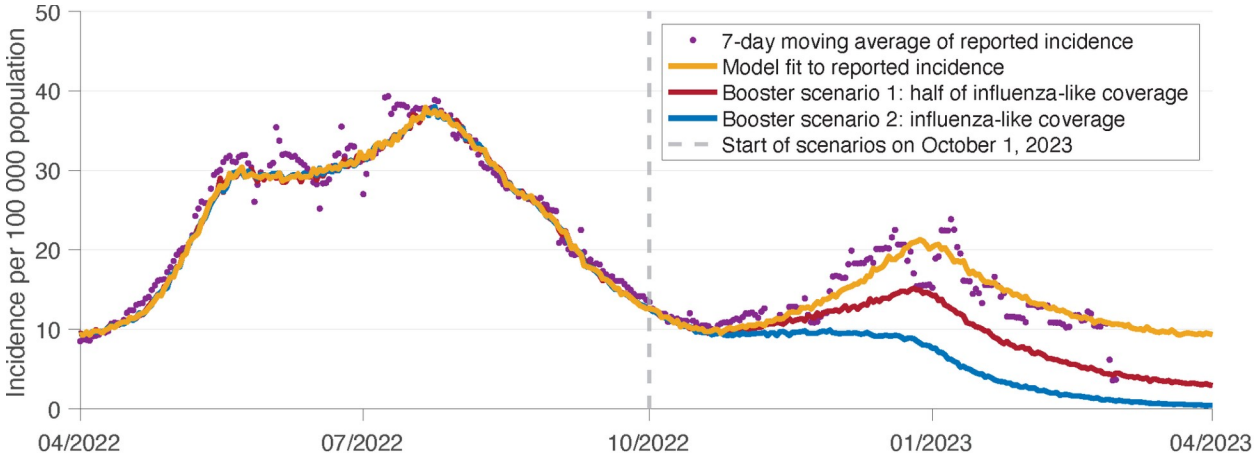

Figure 1. Model fit to incidence per 100,000 population with simulated scenarios of bivalent booster vaccination from October 1, 2022 to end of March 2023.

Table 1. Estimates of averted outcomes during the study period between October 1, 2022 and March 31, 2023, comparing accelerated booster vaccination campaigns with the baseline scenario. Averted outcomes for isolation days, hospitalizations, and ICU hospitalizations were estimated for the entire pediatric population aged 0-17 years. Averted days of school absenteeism were estimated for children aged 5-17 years. Accelerated bivalent booster coverage among eligible individuals were: (Scenario 1) equal to half of the 2020–21 age-specific influenza vaccination levels; and (Scenario 2) the same as the 2020–21 age-specific influenza vaccination levels.

Averted COVID-19 outcomes: mean (95% credible interval)		
Outcome	**Scenario 1**	**Scenario 2**
Isolation days	4,506,119 (3,956,423 - 5,208,525)	8,572,225 (7,772,630 - 9,364,837)
Hospitalizations	5,791 (4,391 - 6,932)	10,019 (8,756 - 11,278)
Hospitalizations requiring ICU	1,397 (846 - 1,948)	2,645 (2,152 - 3,147)
Days of school absenteeism [a]	2,875,926 (2,524,351 - 3,332,783)	5,448,694 (4,936,933 - 5,957,507)

[a] Among children aged 5-17

Table 2. Days of student and teacher absenteeism averted by accelerated vaccination campaigns for the study period between October 1, 2022 and March 31, 2023, compared with the baseline scenario. Accelerated vaccination scenarios among eligible individuals were: (Scenario 1) equal to half of the 2020–21 age-specific influenza vaccination levels; and (Scenario 2) equal to the 2020–21 age-specific influenza vaccination levels.

Averted COVID-19 outcomes per school: mean (95% credible interval)						
			Scenario 1		**Scenario 2**	
School level	Individuals	Average enrollment	Absent Individuals	Days of Absenteeism	Absent Individuals	Days of Absenteeism
Elementary						
Small	Students	214	5 (3 - 9)	22 (11 - 35)	10 (5 - 17)	41 (21 - 66)
	Teachers	17	0.2 (0.1 - 0.3)	0.7 (0.4 - 1.1)	0.3 (0.2 - 0.5)	1.4 (0.8 - 2.1)
Midsize	Students	412	5 (2 - 8)	19 (10 - 31)	9 (5 - 15)	35 (18 - 57)
	Teachers	28	0.1 (0.1 - 0.2)	0.6 (0.4 - 0.9)	0.3 (0.2 - 0.5)	1.3 (0.8 - 1.9)
Large	Students	669	6 (3 - 10)	25 (13 - 41)	11 (6 - 18)	45 (23 - 72)
	Teachers	42	0.2 (0.1 - 0.3)	0.8 (0.5 - 1.2)	0.4 (0.2 - 0.5)	1.5 (0.9 - 2.3)
Middle						
Small	Students	233	8 (3 - 14)	31 (13 - 54)	15 (6 - 26)	57 (24 - 101)
	Teachers	17	0.2 (0.1 - 0.4)	0.9 (0.4 - 1.5)	0.4 (0.2 - 0.7)	1.8 (0.8 - 2.9)
Midsize	Students	556	7 (3 - 12)	27 (11 - 47)	13 (6 - 23)	52 (22 - 92)
	Teachers	37	0.2 (0.1 - 0.3)	0.8 (0.4 - 1.3)	0.4 (0.2 - 0.6)	1.7 (0.8 - 2.7)
Large	Students	976	9 (4 - 16)	36 (15 - 63)	16 (7 - 28)	63 (26 - 110)
	Teachers	59	0.3 (0.1 - 0.4)	1.1 (0.5 - 1.7)	0.5 (0.2 - 0.8)	2.0 (0.9 - 3.2)
Secondary and High						
Small	Students	110	6 (1 - 21)	25 (6 - 83)	12 (3 - 40)	47 (11 - 158)
	Teachers	10	0.2 (0.1 - 0.5)	0.8 (0.3 - 2.3)	0.4 (0.1 - 1.0)	1.6 (0.5 - 4.5)
Midsize	Students	47	6 (1 - 19)	21 (5 - 72)	11 (3 - 37)	43 (10 - 144)
	Teachers	33	0.2 (0.1 - 0.5)	0.7 (0.2 - 2.0)	0.4 (0.1 - 1.0)	1.5 (0.5 - 4.1)
Large	Students	1585	7 (2 - 25)	28 (7 - 95)	13 (3 - 44)	51 (12 - 173)
	Teachers	90	0.2 (0.1 - 0.6)	1.0 (0.3 - 2.6)	0.4 (0.1 - 1.2)	1.8 (0.5 - 4.9)