Estimating the Nationwide Transmission Risk of Measles in US Schools and Impacts of Vaccination and Supplemental Infection Control Strategies

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BMC Infectious Diseases BMC Series

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DOI:
10.21203/rs.3.rs-16529/v1

SUBJECT AREAS
Infectious Diseases

KEYWORDS
measles, schools, transmission risk

Abstract

Background: The spread of airborne infectious diseases such as measles is a critical public health concern. The U.S. was certified measles-free in 2000, but the number of measles cases has increased in recent years breaking the record of the nationwide annual number of cases since 1992. Although the characteristics of schools have made them one of the most vulnerable environments during infection outbreaks, the transmission risk of measles among students is not completely understood. We aimed to evaluate how three factors influence measles transmission in schools: personal (vaccination), social (compartmentalizing), and building systems (ventilation, purification, and filtration).

Methods: We used a combination of a newly developed multi-zone transient Wells-Riley approach, a nationwide representative School Building Archetype (SBA) model, and a Monte-Carlo simulation to estimate measles risk among U.S. students. We compared our risk results with the range of reported transmission rates of measles in school outbreaks to validate the risk model. We also investigated the effectiveness of vaccination and ten supplemental infection control scenarios for reducing the risk of measles transmission among students.

Results: Our best nationwide estimate of measles transmission risk in U.S. schools were 3.5% and 32% among all (both unvaccinated and immunized) and unvaccinated students, respectively. The results showed the transmission risk of measles among unvaccinated students is >70 times higher than properly immunized ones. We also demonstrated that the transmission risk of measles in primary schools (assuming teacher self-contained classrooms) is less than secondary schools (assuming departmentalized systems). For building-level interventions, schools with ductless-with-air-filter and ductless-without-air-filter systems have the lowest and highest transmission risks of measles, respectively. Finally, our simulation showed infection control strategies could cut the average number of infected cases among all students in half when a combination of advanced air filtration, ventilation, and purification was adopted in the modeled schools.

Conclusions: Our results highlight the primary importance of vaccination for reducing the risk of measles transmission among students. Yet, additional and significant risk reduction can be achieved

through compartmentalizing students and enhancing building ventilation and filtration systems.

Full-text

Due to technical limitations, full-text HTML conversion of this manuscript could not be completed.

However, the manuscript can be downloaded and accessed as a PDF.

Figures

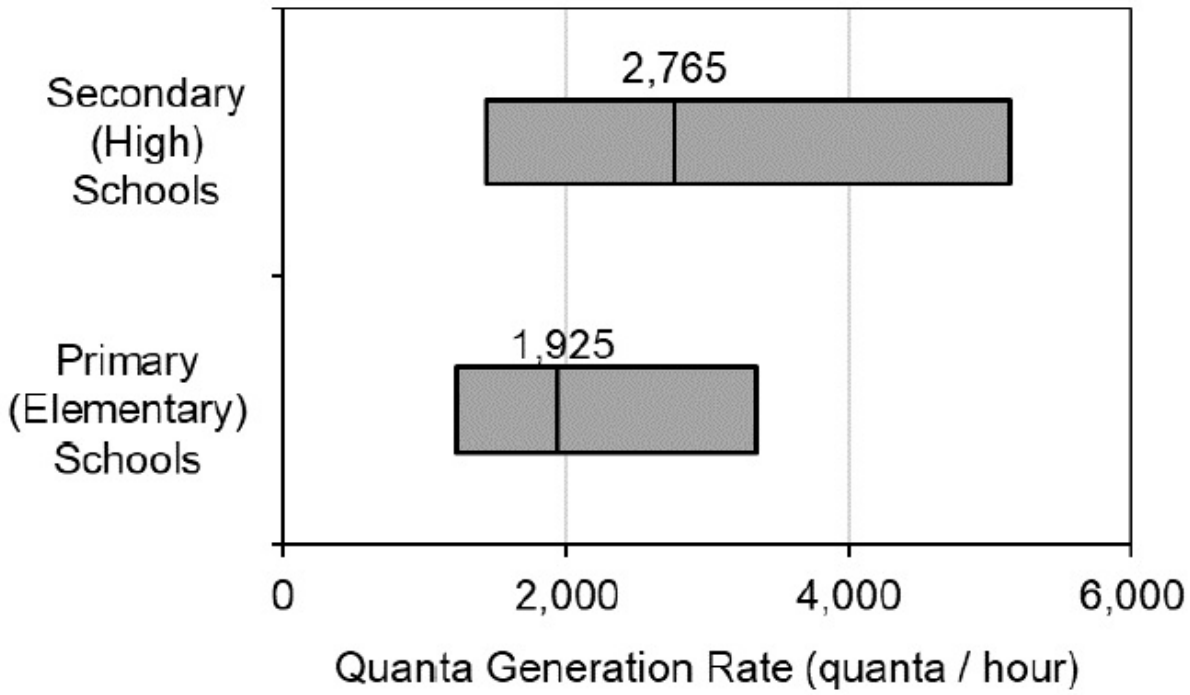


Figure 1

Best estimates (black line inside the boxes) and ranges of quanta generation rate for typical primary (elementary) teacher self-contained and secondary (high) departmentalized schools in the U.S.

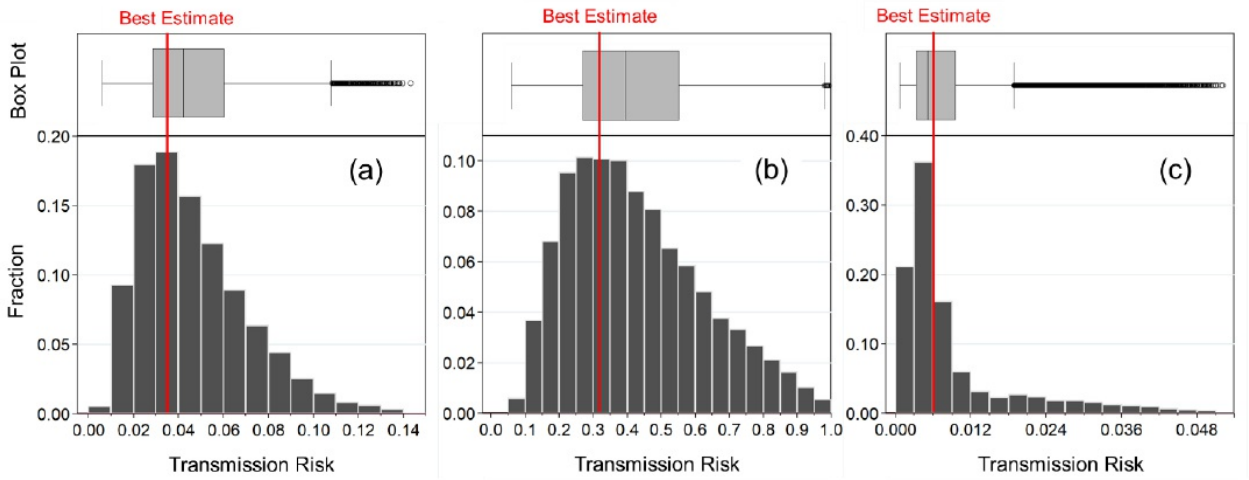
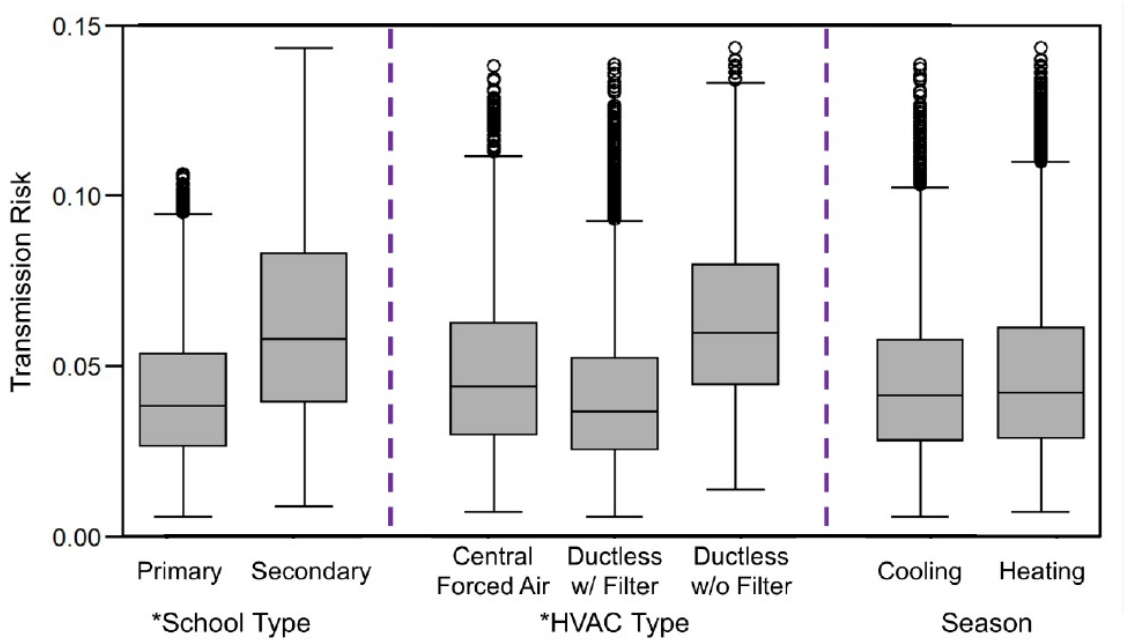


Figure 2

Distributions, ranges, and best estimates of measles transmission risk among (a) all students with an average proper vaccination coverage of 91% (changes between 90% and 92%), (b) unvaccinated students, and (c) students with proper measles vaccination assuming 1% and 5% of individuals less than 14 and between 14 and 18 years old remain susceptible, respectively



***Transmission risks were significantly different based on nonparametric Wilcoxon rank sum tests with adjusted p-values for the sample size (i.e., $P = 1 - (1 - 0.05)^{1/\sqrt{N_1 N_2}}$, where N_1 and N_2 = number of iterations of compared scenarios)**

Figure 3

Measles transmission risk among all students in (a) primary teacher self-contained versus secondary departmentalized schools and (b) schools with central forced air and ductless with and without air filter heating and cooling systems, (c) schools during cooling and heating seasons

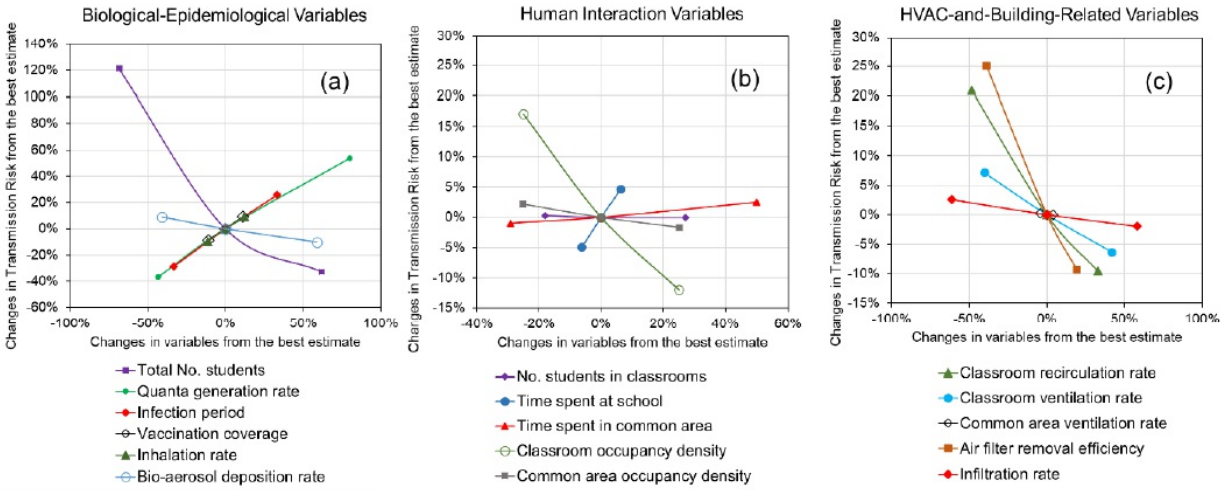
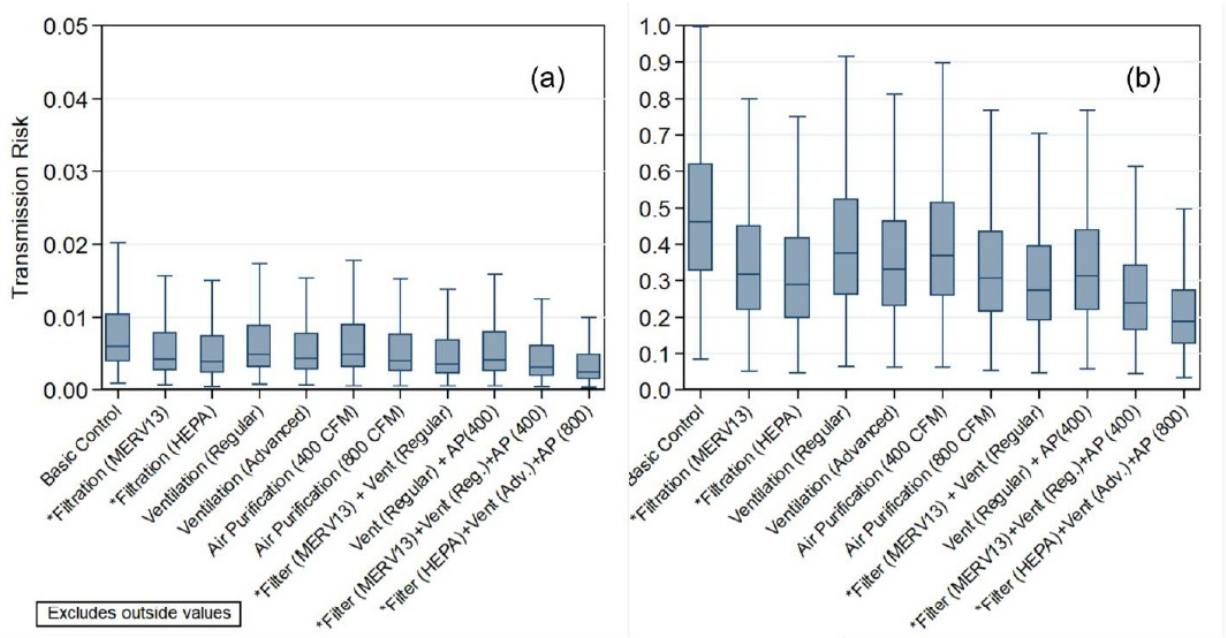


Figure 4

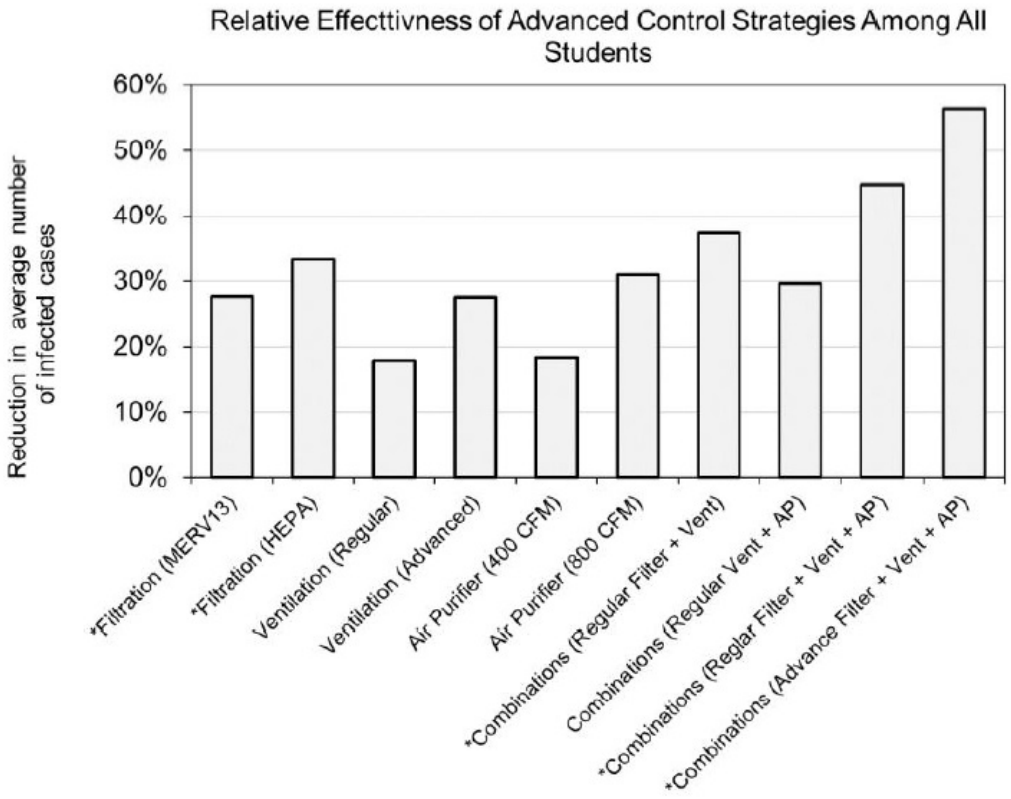
Sensitivity of the measles transmission model in U.S. schools to changes in (a) biological-epidemiological variables, (b) human-interaction-related parameters and (c) HVAC-building-related variables



*** Only for central-forced-air and ductless-with-air-filter heating and cooling systems**

Figure 5

Transmission risk of measles among (a) properly immunized and (b) unvaccinated students and the effects of 10 infection control strategies including regular and advanced filtration, ventilation, and air purification (AP) techniques and their combinations



*** Only for central-forced-air and ductless-with-air-filter heating and cooling systems**

Figure 6

Relative effectiveness of advanced control strategies on measles transmission risk among all students

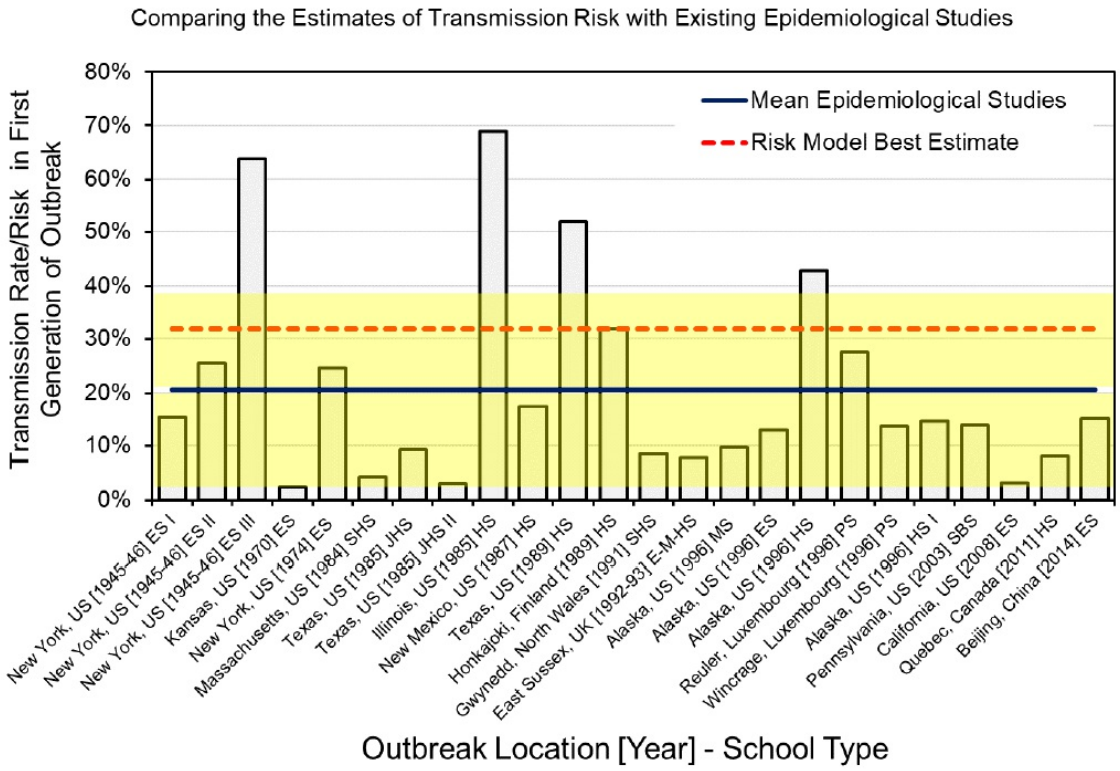


Figure 7

Comparing our best estimate of nationwide measles transmission risk in U.S. schools with estimated transmission rates of measles during first generations of the infection outbreaks in developed countries' schools reported in existing epidemiological studies

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

Measles_Transmission_Risk_US_Schools_Appendix.pdf