

JAMA | Original Investigation

Associations of Statewide Legislative and Administrative Interventions With Vaccination Status Among Kindergartners in California

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IMPORTANCE California implemented 3 interventions to increase uptake of vaccines. In 2014, Assembly bill 2109 tightened requirements for obtaining a personal belief exemption. A 2015 campaign provided educational materials to school staff on the proper application of conditional admission for kindergartners who were not up to date on required vaccinations. In 2016, Senate bill 277 eliminated personal belief exemptions. Prior research has not evaluated these 3 interventions together with regard to the vaccination status of students.

OBJECTIVE To assess the changes in the yearly rates of kindergartners who were not up to date on required vaccinations who were entering school during the period of the interventions, by focusing on geographic clustering and the potential contacts of these kindergartners.

DESIGN, SETTING, AND PARTICIPANTS Observational study that used cross-sectional school-entry data from 2000-2017 to calculate the rates of kindergartners attending California schools who were not up to date on required vaccinations.

EXPOSURES Assembly bill 2109, a conditional admission education program, and Senate bill 277.

MAIN OUTCOMES AND MEASURES The primary outcome was the yearly rate of kindergartners without up-to-date vaccination status. The secondary outcomes were (1) the modified aggregation index, which was used to assess the potential within-school contacts among kindergartners without up-to-date vaccination status, (2) the number of geographic clusters of schools with rates for kindergartners without up-to-date vaccination status that were higher than the rates for schools located outside the cluster, and (3) the number of schools located inside the geographic clusters.

RESULTS In California between 2000 and 2017, 9 323 315 children started attending kindergarten and 721 593 were not up to date on required vaccinations. Prior to the interventions, the statewide rate of kindergartners without up-to-date status for required vaccinations increased from 7.80% during 2000 to 9.84% during 2013 and then decreased after the interventions to 4.87% during 2017. The percentage chance for within-school contact among kindergartners without up-to-date vaccination status decreased from 26.02% during 2014 to 4.56% (95% CI, 4.21%-4.99%) during 2017. During 2012-2013, there were 124 clusters that contained 3026 schools with high rates of kindergartners without up-to-date vaccination status. During 2014-2015, there were 93 clusters that contained 2290 schools with high rates of kindergartners without up-to-date vaccination status. During 2016-2017, there were 110 clusters that contained 1613 (95% CI, 1565-1691) schools.

CONCLUSIONS AND RELEVANCE In California, statewide legislative and educational interventions were associated with a decrease in the yearly rates of kindergartners without up-to-date vaccination status. These interventions also were associated with reductions in the number of schools inside the clusters with high rates of kindergartners without up-to-date vaccination status and the potential for contact among these kindergartners.

JAMA. 2019;322(1):49-56. doi:10.1001/jama.2019.7924

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Large-scale vaccination programs that included school-entry mandates have been essential to maintaining high levels of immunization coverage and low rates of vaccine-preventable diseases.^{1,2} However, an increasing number of parents are not vaccinating their children over concerns about potential adverse effects.³ These parental actions threaten the herd immunity established by decades of high vaccine uptake and increase the potential for disease outbreaks.⁴ Only 3 US states (California, Mississippi, and West Virginia) do not offer exemptions from vaccination requirements for nonmedical reasons (such as personal, philosophical, or religious beliefs).⁵ The administrative ease in obtaining a nonmedical exemption varies by state, and states with less restrictive policies have higher nonmedical exemption rates.⁶

Many US states have recently considered legislation pertaining to exemptions from vaccination.^{7,8} In California, prior to 2014, parents could claim a personal belief exemption by submitting a form with an objection to vaccination. In 2014, Assembly bill 2109 (AB 2109) required parents to submit proof they had discussed the risks of not vaccinating their children with a health care practitioner prior to obtaining a personal belief exemption.⁹ In 2015, the California Department of Public Health and local health departments began a campaign to educate school staff on the proper application of the conditional admission criteria, which allow students additional time to catch up on vaccination.^{10,11} In 2016, California implemented Senate bill 277 (SB 277) banning all personal belief exemptions.¹²

This study was an observational analysis of school-entry data from 2000-2017 that used a broad definition of vaccine uptake to evaluate the rate of kindergartners who were not up to date on 1 or more of the required vaccinations during the course of the 3 interventions implemented in California. The change in the likelihood of within-school contact among kindergartners without up-to-date vaccination status was analyzed because of the important role schools have in disease transmission.¹³ Geographic clustering of children in California without up-to-date vaccination status has been associated with disease outbreaks.¹³⁻¹⁵ Therefore, geographic clusters of schools with high rates of children without up-to-date vaccination status also were evaluated.

Methods

Data Sources and Definitions

Institutional review board approval for this study was obtained through Emory University. Informed consent was not obtained because the data were from publicly available sources. Publicly available kindergarten enrollment and vaccination data were gathered from the California Department of Public Health for 2000 through 2017 (the school years, which span calendar years, are identified by the year they begin).¹⁶ All schools with kindergarten programs (including home schools) are required to report annual enrollment by vaccination status. The kindergartners with up-to-date vaccination status at the start of the school year had received all required vaccina-

Key Points

Question Was there an association between 3 interventions (2 laws and an educational campaign) to increase uptake of vaccines in California and vaccination status for kindergartners?

Findings In this observational study of school-level data from 9 323 315 kindergartners who started attending school between 2000 and 2017, the rate of kindergartners without up-to-date vaccination status decreased from 9.84% during 2013 (before the interventions) to 4.87% during 2017 (after the interventions).

Meaning In California, statewide legislative and educational interventions were associated with a decrease in the yearly rates of kindergartners without up-to-date vaccination status.

tions (polio; diphtheria, tetanus, and pertussis; measles, mumps, and rubella; hepatitis B; and varicella), whereas those without up-to-date vaccination status had not completed 1 or more of the required vaccinations.¹⁶

From 2000 through 2014, there were 3 school-entry mechanisms for kindergartners without up-to-date vaccination status: personal belief exemption, permanent medical exemption, and conditional admission. Conditional admission allows kindergartners who have not received all doses of a vaccine series, but were not yet due for the next required dose or doses, to enter school and catch up later.¹⁶

In 2015, an overdue category was added for children without up-to-date vaccination status, but who were neither exempted nor met the requirements for conditional admission. The children with an overdue status may be excluded from school until they achieve up-to-date vaccination status or satisfy the requirements for conditional admission. Whether students with overdue status were excluded from school is not provided.

In 2016, the California Department of Public Health added the category of other, which was termed *not subject to immunization requirements* herein. Per SB 277, these students are exempt from vaccination requirements because they (1) attend home-based private schools or an independent study program without classroom-based instruction or (2) have an individual education plan and require special education services (they cannot be prohibited from accessing special education or related services required by their program).¹²

Although the definition of up-to-date vaccination status did not change during the study period, the administrative exemption categories that could be assigned did. The categories were fully inclusive of all kindergartners without up-to-date vaccination status in California. The **Table** summarizes the entry mechanisms and requirements for kindergartners without up-to-date vaccination status along with the years available.

Primary and Secondary Outcomes

The primary outcome was the yearly rate of kindergartners without up-to-date vaccination status. The counts for kindergartners without up-to-date vaccination status were calculated as the sum of the various entry mechanisms for each year (eTable 1 in the **Supplement**). The rate of kindergartners without up-to-date vaccination status is the percentage of these

Table. School Entry Mechanisms for Kindergartners Without Up-to-date Vaccination Status for 1 or More Required Vaccinations in California

School Entry Mechanism	Definition ^a	Years Available ^b
Personal belief exemption	Nonmedical exemption based on parents' personal or religious beliefs; statement signed by parent	2000-2013
	Nonmedical exemption based on parents' personal or religious beliefs after counseling; statement signed by health care practitioner and parents	2014-2016
Medical exemption	Exemption based on physician's assessment vaccination is not considered safe; statement signed by physician	2000-current
Conditional admission	1. Started but has not completed ≥1 series of required vaccinations, but not currently due for a dose or 2. Temporary medical exemption; statement signed by physician	2000-current
Not subject to immunization requirements	1. Attend home-based private school or an independent study program without classroom-based instruction ^c or 2. Cannot be denied access to special education services due to immunization status ^d	2016-current
Overdue	Without up-to-date vaccination status on ≥1 series of required vaccines, but does not have a personal belief or medical exemption, is not exempt, and does not meet the requirements for conditional admission; subject to exclusion from the school	2015-current

^a A summary of the circumstances under which the mechanism was used.

^b Period when the mechanisms were in effect (beginning in 2000).

^c Students in a home-based private school are educated at home. Students in an independent study program without classroom-based instruction generally do not attend classes with other students every day.

^d Students with an individual education program must be eligible for special

education and have been deemed to have a disability and require special education and related services to benefit from the general education program. The exact text in Senate bill 277 is, "This section does not prohibit a pupil who qualifies for an individualized education program, pursuant to federal law and §56 026 of the Education Code, from accessing any special education and related services required by his or her individualized education program."

types of students attending each school per year. The secondary outcomes were the modified aggregation index, the percentage of children attending a school with an up-to-date vaccination rate that was greater than the herd immunity threshold for various vaccine-preventable diseases, the number of geographic clusters of schools with high rates of kindergartners without up-to-date vaccination status, and the number of schools located in the geographic clusters.

The clustering analysis was restricted to 3 distinct 2-year eras between 2012 and 2017. The 2012-2013 era captures the 2 years preceding AB 2109. The 2014-2015 era covers the 2 years that AB 2109 was in effect and the first year of the conditional admission program. The 2016-2017 era covers the years SB 277 was in effect along with the conditional admission program. We pooled data within each era to temporally stabilize the rates used in the geographic clustering analysis. All other analyses used yearly data from 2000 to 2017.

Statistical Analysis

Data Imputation

The California Department of Public Health made considerable changes to the publicly available school-level vaccination data after 2015. The first change was that data from schools having fewer than 20 incoming kindergartners were fully censored; previously, only data from schools with fewer than 10 students were censored.¹⁷ The second change was that small counts at schools with 20 or more students were left-censored using a set of threshold percentages and a school's enrollment; the thresholds for censoring small counts were 5% or less for schools with 20 to 49 students, 2% or less for schools with 50 to 99 students, and 1% or less for schools with 100 or more students.

A multiple imputation approach was used to estimate the number of students without up-to-date vaccination status at schools with censored values. The approach leveraged the geographic location of the schools in combination with the noncensored county-level and statewide counts of students without up-to-date vaccination status attending public and pri-

private schools, which are provided in the California Department of Public Health's yearly summary files.¹⁶ The approach (detailed in eMethods in the Supplement) was a constrained allocation approach that used information from more aggregated county- and state-level data to identify and then allocate the missing values to schools having censored entries.

The approach was implemented such that the imputed counts of students without up-to-date vaccination status were consistent with the censoring rules (ie, the imputed value of students without up-to-date vaccination status at a particular school was restricted to be a potential censored value based on the school's enrollment). Furthermore, the approach preserved known information at the state and county level for the imputed school-level data as follows: (1) the state-level counts of students without up-to-date vaccination status, (2) the state-level counts of students without up-to-date vaccination status attending public and private schools, and (3) the county-level counts of students without up-to-date vaccination status. A total of 500 imputed data sets were created for 2016 and 2017 and were used for the analysis.

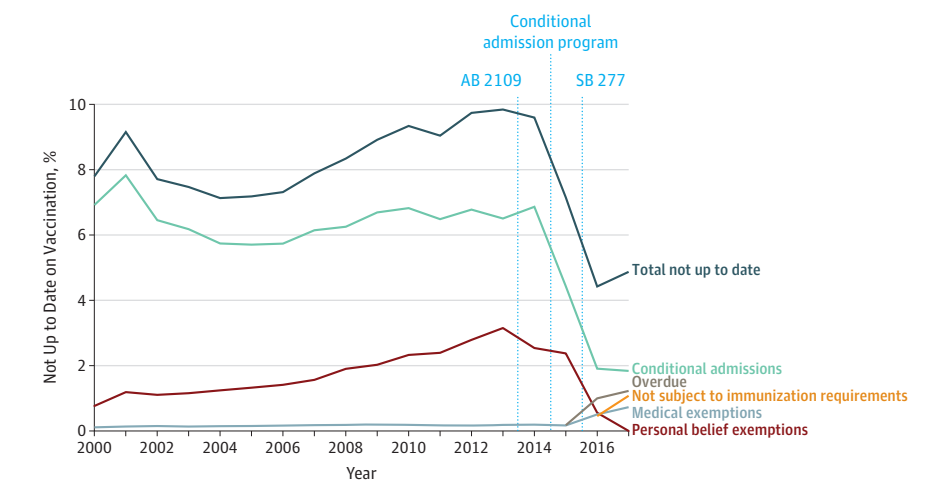
Within-School Clustering

A modified version of the aggregation index was used to estimate the average (statewide) percentage chance that any within-school contact for a kindergartner without up-to-date vaccination status would be with another kindergartner without up-to-date vaccination status (details appear in the eMethods in the Supplement).¹⁸ The modified index provided a measure of clustering of students without up-to-date vaccination status within schools and was calculated for all schools with at least 1 of these types of students:

$$\text{Modified aggregation index} = \sum_{i=1}^N \left(\frac{x_i}{X} \right) \left(\frac{x_i - 1}{k_i - 1} \right) \times 100$$

where x_i is the number of kindergartners without up-to-date vaccination status attending school i , X is the total number of kindergartners without up-to-date vaccination status for

Figure 1. State-Level Rates for Kindergartners Without Up-to-date Vaccination Status From 2000-2017



The definition of students without up-to-date vaccination status did not change over the time; however, the administrative categories in which students could be assigned did. In 2015, an overdue category was added and, in 2016, another category was added for students not subject to immunization requirements. The Table contains definitions for each school entry mechanism and eTable 2 in the Supplement contains the yearly count values for each category.

all schools, k_i is the total kindergarten enrollment at school i , and N is the number of schools within the state. Potential values ranged from 0 (no school has >1 kindergartner without up-to-date vaccination status) to 100 (kindergartners without up-to-date vaccination status only attend schools where all students are without up-to-date vaccination status). Higher modified aggregation index values indicated a greater potential disease outbreak risk because the metric estimates the likelihood of contact among susceptible kindergartners.¹⁸ We calculated the index for each year from 2000 to 2017. For 2016 and 2017, we calculated the index for each of the 500 imputations.

We calculated the percentage of California kindergartners who attended a school with an up-to-date vaccination percentage greater than the herd immunity threshold for various vaccine-preventable diseases for 2012 to 2017. For 2016 and 2017, this calculation was performed for each of the 500 imputations.

Geographic Distribution and Regional Clustering

We used the kriging method to estimate the geographic distribution of the rates for students without up-to-date vaccination status throughout California for each year separately from 2000 to 2017 for mapping and visualization purposes. Kriging is a method of interpolation that creates a continuous spatial surface of values based on observed values measured at discrete points. A weighted average of nearby observed values is used to predict locations without measured values.¹⁹ The top 1% of schools by rate of students without up-to-date vaccination status were excluded because the kriging method can be influenced by extreme values.²⁰ For 2016 and 2017, the mean count for students without up-to-date vaccination status from the 500 imputed values was used to calculate the rate for schools with censored values.

A clustering analysis using the SaTScan program was conducted for each of the 2-year eras to identify geographic clusters where the rates of students without up-to-date vaccination status attending schools located within the cluster

were higher than those attending schools located outside the cluster.^{14,21,22} The clustering analysis provided statistical confirmation for the geographic patterns of the maps that were created using the kriging method.²³ A spatial Poisson model was used, and the upper limit of the cluster size was set to 50% of the statewide kindergarten enrollment.¹⁴

For each era, we assessed the number and spatial location of the significant clusters for high rates of students without up-to-date vaccination status (1-sided $P \leq .05$). The clustering analysis was conducted using the 500 imputations for the 2016-2017 era, which produced 500 unique sets of clusters. The percentage of the 500 imputations in which a geographic area was included within a cluster was mapped for the entire state of California. All analyses were performed using R version 3.4.0 (R Foundation for Statistical Computing), SaTScan version 9.4 (SaTScan), and ArcGIS version 10.6 (Environmental Systems Research Institute).

Statistical Testing

Because the vaccination and enrollment data include a near census of all schools within California, confidence intervals and inferential tests were not required to evaluate changes occurring between 2000 and 2015. For 2016 and 2017, we calculated 95% CIs based on the multiple imputation results.

Results

Statewide Changes Among Students Without Up-to-date Vaccination Status

Between 2000 and 2017, 9 323 315 children started attending kindergarten at 10 391 unique California schools. The yearly mean kindergarten enrollment was 517 962 and the yearly mean number of schools was 7278. During this period, 721 593 kindergartners without up-to-date vaccination status started attending school statewide. The yearly rate of students without up-to-date vaccination status increased from

7.80% during 2000 to 9.84% during 2013, before decreasing to 4.87% during 2017.

The statewide composition of students without up-to-date vaccination status for 2000-2017 appears in **Figure 1**, which highlights decreases in conditional admissions beginning during 2015 and personal belief exemptions beginning during 2016. Nearly all personal belief exemptions were eliminated with only 5 recorded throughout California during 2017 (these 5 students started attending a transitional kindergarten program prior to the passage of SB 277). The conditional admission rate decreased from 6.50% during 2013 to 1.84% during 2017. Conversely, the medical exemption rate increased from 0.19% during 2013 to 0.73% during 2017. Kindergartners not subject to immunization requirements increased from 0.46% during 2016 to 1.08% during 2017, and kindergartners who were overdue for immunizations increased from 0.18% during 2015 to 1.23% during 2017. Yearly counts for enrollment and the reasons for students not having up-to-date vaccination status appear in eTable 2 in the [Supplement](#).

Data Imputation

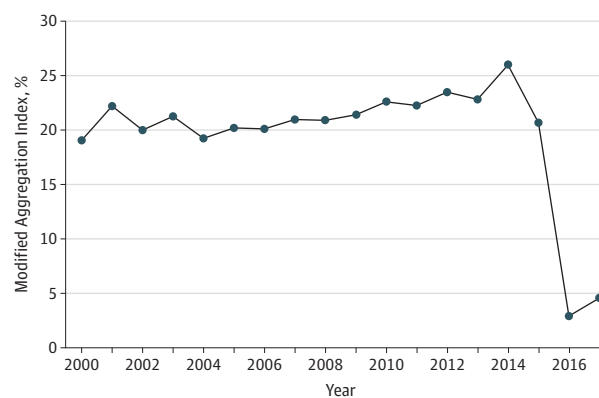
During 2016, 4634 of 7816 schools (59.28%) had censored entries. However, 21 221 of the 24 932 total kindergartners without up-to-date vaccination status (85.11%) were accounted for in the noncensored school data. Thus, using the imputation approach, the 3711 censored kindergartners without up-to-date vaccination status were allocated to the 4634 schools with missing data. During 2017, 4690 of 7957 schools (58.94%) had censored entries. There were 27 479 kindergartners without up-to-date vaccination status; of these, 23 626 (85.98%) were accounted for in the noncensored school data. The remaining 3853 kindergartners without up-to-date vaccination status were allocated to the 4690 schools having censored entries.

Within-School Clustering

Yearly values of the modified aggregation index are plotted in **Figure 2**. The index value was 19.07% during 2000 and increased steadily to 26.02% during 2014, which is the first year of AB 2109. There was a decrease to 20.70% during the second year of AB 2109 and the first year of the conditional admission program. The values decreased to 2.90% (95% CI, 2.55%-3.27%) during 2016, which was the first year of SB 277 and the second year of the conditional admission program, before increasing slightly to 4.56% (95% CI, 4.21%-4.99%) during 2017.

Across the interventions, the percentage of kindergartners attending schools with an up-to-date vaccination status percentage that was greater than the herd immunity threshold also increased for various vaccine-preventable diseases (eTable 3 in the [Supplement](#)). For example, the proportion of kindergartners attending a school with a rate of 95% or greater (thought to be pertinent for measles and pertussis) for up-to-date vaccination status increased from 46.34% during 2012 to 49.09% during 2014, to 59.40% during 2015, and to 76.15% (95% CI, 76.10%-76.20%) during 2016. Increases of similar magnitude were observed across the various threshold values for herd immunity.

Figure 2. Modified Aggregation Index for California From 2000-2017



The modified aggregation index represents the average percentage chance of any within-school contact for a student without up-to-date vaccination status with another student with the same status. For the 2016 and 2017 data, the 95% CIs are based on the results of the 500 imputations.

Overall, kindergartners without up-to-date vaccination status had a much lower chance of interacting with other kindergartners with this same vaccination status at their school after the interventions were in place.

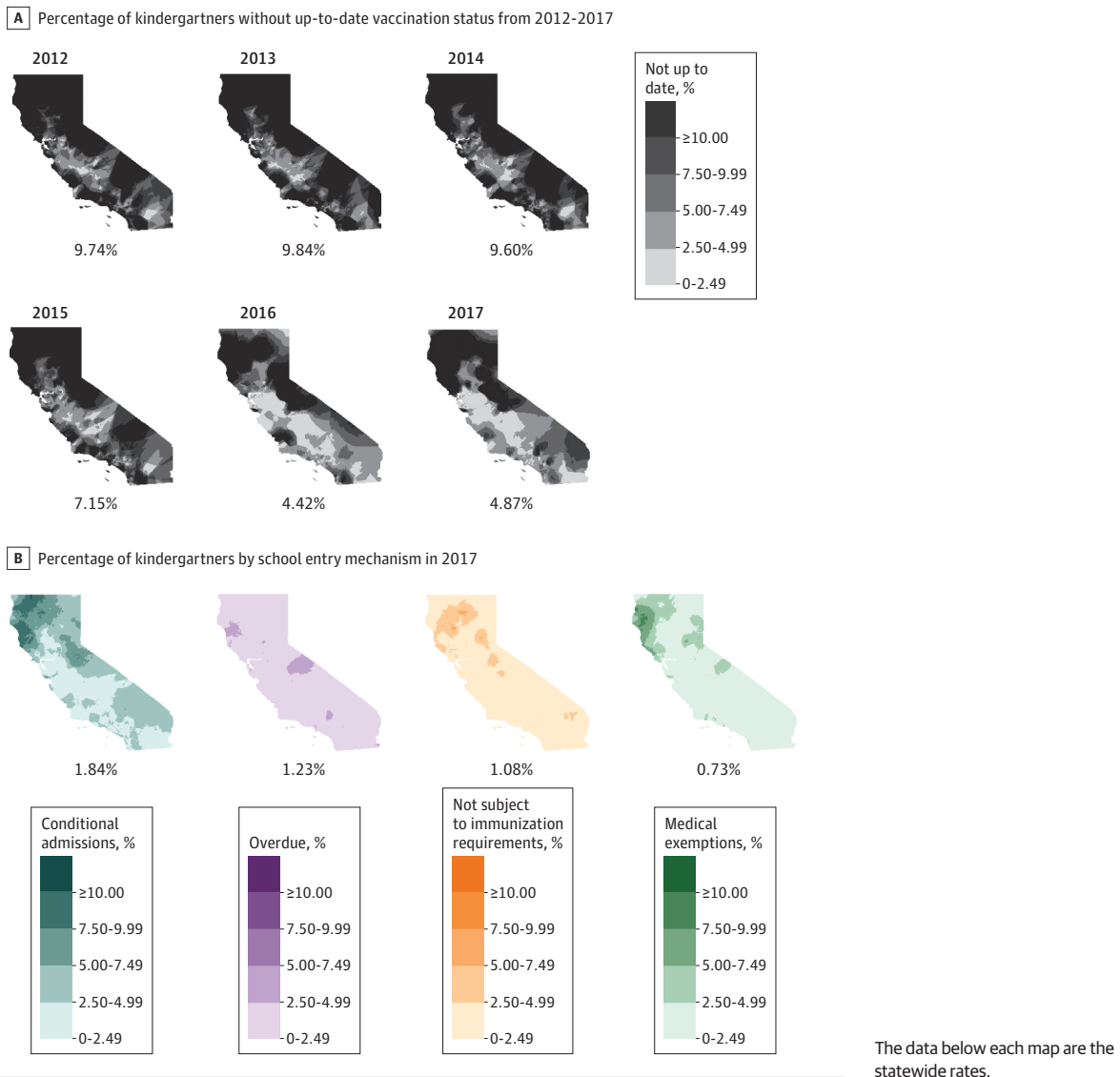
Geographic Distribution and Regional Clustering

Visual inspection of the maps created using the kriging method for the yearly rates of students without up-to-date vaccination status show increases in the statewide rate from 2000 to 2013 (eFigure in the [Supplement](#)). Overall, Northern California had the highest rates of students without up-to-date vaccination status during every year. From 2007 to 2014, Southern California had large pockets with high rates of students without up-to-date vaccination status. Decreases across the state appear to begin during 2015, the first year of the conditional admission program, and continue through 2017. During 2016 and 2017, the reductions appear to be largest in the southern portion of the state. Northern California maintained the highest predicted rate of students without up-to-date vaccination status throughout the study period with relatively minor changes during the implementation of the 3 interventions compared with the rest of the state (**Figure 3**).

During 2012-2013, there were 124 clusters that contained 3026 schools (40.55%) with high rates of kindergartners without up-to-date vaccination status. During 2014-2015, there were 93 clusters that contained 2290 schools (31.06%) with high rates of kindergartners without up-to-date vaccination status. During 2016-2017, across the 500 imputations, there were 110 (95% CI, 106-113) clusters that contained 1613 (95% CI, 1565-1691) schools. The cluster locations for each era appear in **Figure 4**.

Across all eras, Northern California was located within a high-rate cluster of students without up-to-date vaccination status. A number of smaller clusters were identified throughout the central and southern part of the state across eras. The clusters for the 2012-2013 era appear to be larger and in fewer

Figure 3. Maps Using the Kriging Method to Calculate the Percentage of Kindergartners Without Up-to-date Vaccination Status in California From 2012 to 2017 and the School Entry Mechanisms in 2017



locations than those identified during the 2014-2015 era. During the 2016-2017 era, the remaining clusters in Southern California appear smaller than during the earlier eras.

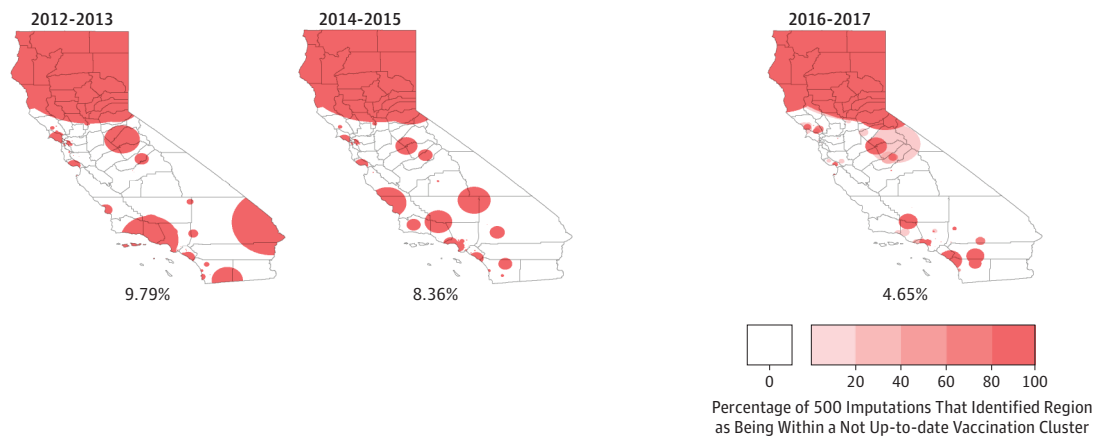
Discussion

During the period of the 3 interventions in California, the percentage of kindergartners without up-to-date vaccination status at school entry decreased. There were large decreases in conditional admissions during 2015 and 2016 and decreases in personal belief exemptions during 2016 and 2017. Increases in medical exemptions, children who were overdue for vaccinations, and children not subject to immunization requirements resulted in a slight increase in the rate of students without up-to-date vaccination status from 2016 to 2017. Prior studies showed increases in medical exemptions and chil-

dren not being subject to immunization requirements occurring in regions that had high rates of personal belief exemptions prior to 2016 and have highlighted questionable practices surrounding medical exemptions.^{24,25}

The geographic analysis provided additional contextual information about how rates for students without up-to-date vaccination status changed over the course of the interventions at the local level. The maps created using the kriging method showed that the rates for students without up-to-date vaccination status decreased throughout much of Central and Southern California, but continued to be high in much of the northern part of the state. These results were corroborated by the clustering analysis; a large cluster of high rates for students without up-to-date vaccination status was identified in Northern California across all 3 eras. This region of the state has relatively low population density and smaller school enrollments so this cluster may not rep-

Figure 4. Clusters of High Rates of Students Without Up-to-date Vaccination Status in California During 2012-2013, 2014-2015, and 2016-2017



The red shading in the 2012-2013 and 2014-2015 maps indicates clusters with high amounts of students without up-to-date vaccination status. The data below each map are the statewide rates for students without up-to-date vaccination status during each period.

resent an area with high risk of an outbreak. However, this analysis substantiates analyses showing that vaccine hesitancy persisted in parts of Northern California throughout the interventions.^{24,26,27} As such, the results demonstrate the importance of considering differences among local regions when crafting legislation, as well as during the implementation phase.

According to state surveillance reports, California had large outbreaks of pertussis during 2010 and 2014 and measles during 2014 and 2015.²⁸ Presumably, the goal of improving vaccine uptake in kindergartners in California was to reduce the probability of disease outbreaks in the state; whether they are ultimately successful remains to be seen. This work examined multiple measures of potential contact among students without up-to-date vaccination status to understand how the probability of disease outbreaks changed over the course of the interventions, which included geographic clustering, potential within-school contacts among students, and the percentage of students attending schools that were above the herd immunity threshold for vaccine-preventable diseases. Overall, the results suggest that the risk of disease outbreak via potential contact among susceptible children decreased over the course of the interventions.

Limitations

This study has several limitations. First, only schools with 10 or more students were analyzed due to data availability. Smaller schools tended to have higher rates of students without up-to-date vaccination status, which may have caused the overall rates to be underestimated. Second, the limited period for analyzing each intervention, as well as the overlap of the con-

ditional admission program, did not allow for separate evaluation of each intervention; thus, implementing all 3 interventions in another setting may not be necessary to achieve similar results. Third, the main outcome variable, students without up-to-date vaccination status, contained students with varying vaccination status and was not specific to particular vaccines, thus limiting the ability to distinguish among the various school entry mechanisms. However, this variable is effective for capturing the overall effects of the interventions and vaccine uptake. Fourth, the ability to characterize disease outbreak risk was also limited by the use of school-level data, which only captures 1 potential environment where children interact. However, state-level data describing connections via social groups or communities are not available to our knowledge. Fifth, the analysis was limited by the use of imputed data for 2016 and 2017. However, because the missing values were not at random, other methods such as complete case analysis would not have been appropriate and the multiple imputation approach provided a viable alternative.²⁹⁻³²

Conclusions

In California, statewide legislative and educational interventions were associated with a decrease in the yearly rates of kindergartners without up-to-date vaccination status. These interventions also were associated with reductions in the number of schools inside the clusters with high rates of kindergartners without up-to-date vaccination status and the potential for contact among these kindergartners.

ARTICLE INFORMATION

Accepted for Publication: May 21, 2019.

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Administrative, technical, or material support: Salmon, Omer.

Supervision: Buttenheim, Omer.

Conflict of Interest Disclosures: Dr Salmon reported receiving consulting fees from Merck; and receiving grants from Pfizer and Walgreens. Dr Klein reported receiving grants from Pfizer, Merck, GlaxoSmithKline, Sanofi Pasteur, Protein Science (now Sanofi Pasteur), Dynavax, and MedImmune. No other disclosures were reported.

Funding/Support: This work was supported by grant R01AI125405 from the National Institutes of Health.

Role of the Funder/Sponsor: The National Institutes of Health had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication.

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