*Open Forum Infectious Diseases*

MAJOR ARTICLE

# Cost of Public Health Response and Outbreak Control With a Third Dose of Measles-Mumps-Rubella Vaccine During a University Mumps Outbreak—Iowa, 2015–2016

**Mona Marin,[1] Tricia L. Kitzmann,[2] Lisa James,[3] Patricia Quinlisk,[4] Wade K. Aldous,[5] John Zhang,[1] Cristina V. Cardemil,[1] Chris Galeazzi,[4] Manisha Patel,[1] and Ismael R. Ortega-Sanchez[1]**

[1]Division of Viral Diseases, National Center for Immunization and Respiratory Diseases, Centers for Disease Control and Prevention, Atlanta, Georgia; [2]Johnson County Public Health, Iowa City, Iowa; [3]University of Iowa Student Health & Wellness, Iowa City, Iowa; [4]Iowa Department of Public Health, Des Moines, Iowa; [5]State Hygienic Laboratory at the University of Iowa, Coralville, Iowa

***Background.*** The United States is experiencing mumps outbreaks in settings with high 2-dose measles-mumps-rubella (MMR) vaccine coverage, mainly universities. The economic impact of mumps outbreaks on public health systems is largely unknown. During a 2015–2016 mumps outbreak at the University of Iowa, we estimated the cost of public health response that included a third dose of MMR vaccine.

***Methods.*** Data on activities performed, personnel hours spent, MMR vaccine doses administered, miles traveled, hourly earnings, and unitary costs were collected using a customized data tool. These data were then used to calculate associated costs.

***Results.*** Approximately 6300 hours of personnel time were required from state and local public health institutions and the university, including for vaccination and laboratory work. Among activities demanding time were case/contact investigation (36%), response planning/coordination (20%), and specimen testing and report preparation (13% each). A total of 4736 MMR doses were administered and 1920 miles traveled. The total cost was >$649 000, roughly equally distributed between standard outbreak control activities and third-dose MMR vaccination (55% and 45%, respectively).

***Conclusions.*** Public health response to the mumps outbreak at the University of Iowa required important amounts of personnel time and other resources. Associated costs were sizable enough to affect other public health activities.

**Keywords.** mumps; outbreak; cost; economic burden; third dose; MMR.

Mumps, a viral disease that affects the salivary glands, is spread by salivary or respiratory secretions. The disease is usually mild; up to one-third of infected individuals may have nonspecific symptoms, but complications such as meningitis, encephalitis, orchitis, and deafness can occur [1]. In the absence of vaccination, mumps is a childhood disease [2]. The United States' long-standing 2-dose measles-mumps-rubella (MMR) childhood vaccination program led to a 99% reduction in reported mumps cases by 2005 [3, 4]. From 1993–2005, only a few hundred mumps cases were reported annually. However, the United States has experienced a resurgence of mumps cases and outbreaks since 2006, with outbreaks with thousands of cases reported in 2006, 2009–2010, and 2015–2016 [5–8]. During 2016–2017, the outbreaks were typically smaller and more geographically spread and continued to occur mostly in populations/settings with high 2-dose vaccination coverage and environments with close contact that facilitate transmission (mainly universities); the highest incidence was in the 18–25 years age group [9].

Epidemiologic and laboratory data suggest that waning of immunity after 2 doses of a mumps virus–containing vaccine contributes to mumps outbreaks among young adults [10–13], leading to increased interest in the use of a third dose of MMR vaccine for mumps outbreak control [14–17]. In 2012, the US Centers for Disease Control and Prevention (CDC) issued guidance regarding *consideration for use* of a third dose of MMR vaccine in specifically identified target populations, on the basis of limited data on the effectiveness of the third dose. Administration of a third dose of MMR vaccine was neither a standard public health response to outbreaks nor a routine recommendation. A 2017 study showed a significant reduction in mumps incidence among third-dose MMR vaccine recipients [13].

Implementing vaccine interventions during outbreak response can be both time- and resource-intensive for local and state public health departments. Two studies have assessed the economic burden of mumps outbreak response that also included administration of a third dose of MMR vaccine [18, 19]. In both, the outbreak was community-wide and the third dose was implemented primarily during school campaigns. An economic assessment of mumps outbreaks in universities, the primary setting where US mumps outbreaks occur, has not been performed. We assessed the costs of response activities

Received 26 March 2018; editorial decision 3 August 2018; accepted 13 August 2018.

Correspondence: M. Marin, MD, Centers for Disease Control and Prevention, 1600 Clifton Rd NE, MS A-34, Atlanta, GA 30333 (mmarin@cdc.gov).

**Open Forum Infectious Diseases®**



DOI: 10.1093/ofid/ofy199

during a 2015–2016 mumps outbreak in a university where the public health response included a university-wide third-dose MMR vaccination campaign [13, 17] to describe the economic burden of mumps outbreaks in university settings.

## METHODS

### Setting

The University of Iowa in Johnson County, Iowa, is a public university with ~22 000 undergraduate students. The university has had a 2-dose MMR vaccine requirement since 2012. Documentation of receipt of 2 MMR vaccine doses (ie, vaccination record with a provider signature) is required for registration. Compliance data are available from the university's electronic database. Before the 2015 fall semester, 98% of students had documentation of ≥2 MMR vaccine doses [13]. In summer and fall of 2015, a large mumps outbreak was reported at the university. An intensive outbreak containment effort began, with implementation of standard outbreak control measures: enhanced surveillance for early case-finding; rapid testing and isolation; public health messages to increase student awareness regarding mumps presentation, prevention of transmission, and adherence to isolation recommendations; verification of vaccination status; and catch-up 2-dose vaccination [17]. In October, a targeted third-dose MMR vaccine intervention was implemented at 1 fraternity (24 of 100 members were vaccinated).

As cases continued to occur despite these measures and given the high 2-dose MMR vaccine coverage among students, in early November the university and Johnson County Public Health (JCPH), in consultation with the Iowa Department of Public Health and the CDC, decided to implement a third-dose MMR vaccination. The third dose was provided free of charge to all students aged <25 years through vaccination clinics that took place at central campus locations. The university purchased the MMR vaccine from the private sector, and the state health department provided the vaccine for Vaccines for Children–eligible students. By the final week of the academic year on May 7, 2016, 319 mumps cases had been reported at the university (298 among students, 21 among staff) and 130 in the surrounding Johnson County community; 25% of students had received a third dose of the MMR vaccine [17].

### Data Collection and Analysis

The first mumps case at the university had symptom onset on July 13, 2015. The cost study included outbreak response activities that occurred during July 12, 2015–May 7, 2016; data collection was retrospective and ongoing between January 28 and May 7, 2016. Third-dose MMR vaccination was provided during 8 clinics from November 10 to 19, 2015.

Response activities, personnel involved, and other resources allocated were identified by each institution. Personnel reported hours allocated weekly by specific activities based on chronological reports, time sheets, calendars, and personal records. Technicians who performed laboratory tests did not complete individual questionnaires; the respective section chiefs reported the collective time allocated weekly to perform the testing. Personnel time reported in hours was converted to costs using the reported hourly earnings of each individual, plus fringe benefits; labor costs for laboratory technicians were included in laboratory test costs. Overhead costs, that is, costs related to the resources required to support personnel work (eg, equipment, buildings), were based on the number of person-hours and each institution's rate. To calculate ancillary costs, counts and unitary costs were obtained for laboratory tests, vaccines administered, and miles traveled.

The third-dose vaccination clinics were staffed with volunteers, in addition to university and JCPH employees. Volunteers were University of Iowa nursing, public health, or pharmacy students and visiting nurses from a neighboring county. Volunteers performed specific activities: prevaccination screenings, vaccination, vaccine transport, and attendance in the post-vaccine area. JCPH provided spreadsheets created at the time of the vaccination clinics with activities performed during the vaccination clinics, number of persons, and personnel hours for each activity. To estimate the value of volunteers' time (ie, the cost that would have been incurred by the university and JCPH had they needed to hire personnel to complete vaccination activities at the clinics), we converted the volunteer time to cost using the mean hourly earnings for Iowa from the Bureau of Labor Statistics for specific occupational codes based on the activities performed (Supplementary Table 1). No fringe benefits were allocated to volunteer time, but we applied the university's overhead cost as the vaccination clinics took place in spaces provided by the university. The cost for the third-dose vaccination clinics included double the regular hourly earnings for JCPH employees when the vaccination clinic was held during a national holiday (November 11).

Hours allocated and associated cost are reported separately for standard outbreak response activities and for enhanced response with a third dose of MMR vaccine. The outbreak occurred simultaneously on the university campus and in the adjacent local community; cases were epidemiologically linked between the 2 settings (many students resided in the community with nonuniversity roommates and worked and attended activities in the community). This made it difficult to retrospectively distinguish the time allocated to responding to university population cases vs community cases. Therefore, data collected reflect outbreak response activities for all Johnson County cases (72% occurred in persons affiliated with the university).

This study aimed to assess the outbreak's economic impact from a public health perspective; therefore, we only evaluated cost of outbreak response activities and cost associated with a third dose of MMR vaccine. We did not measure the medical and indirect costs of mumps patients. Response costs accrued

by the federal government (CDC) also were not included; the CDC provided technical assistance for the outbreak response.

The Iowa Department of Public Health and the CDC determined that this study was public health–practice nonresearch and was therefore not subject to review by an institutional review board.

## RESULTS

### Standard Outbreak Response Activities

Forty-six responders participated in standard outbreak response activities from 4 institutions: JCPH (22), Iowa Department of Public Health (12), University of Iowa (9), and Iowa State Hygienic Laboratory (3, not including the number of technicians who performed outbreak-associated laboratory testing). Approximately 5000 hours of personnel time were allocated to response; slightly more than one-third were by JCPH employees (Table 1). The main activities demanding personnel time were case and contact investigation (36%), response planning and coordination (20%), and specimen testing and report preparation (13% each). The distribution of personnel time over the course of the outbreak was characterized by peaks generally following the number of cases reported weekly (Figure 1).

The estimated cost for standard outbreak response activities was $357 979, which was relatively evenly distributed among the 4 agencies involved (20%–29%) (Table 1). Considering all mumps cases in Johnson County during the study period (449), the cost per case for outbreak response activities was $797.

### Enhanced Response: Third-Dose MMR Vaccine Intervention

A total of 1333.5 hours of personnel time were allocated to third-dose vaccination clinics; 72% were spent at vaccination clinics (Table 2). Important personnel resources were mobilized for the vaccination clinics: 84 individuals worked as vaccinators during the 8 vaccination clinics (Table 3). Most personnel assisting with vaccination clinic tasks were volunteers; volunteer time accounted for 42% of the overall time allocated for vaccination clinics. The cost associated with personnel time was $77 608 (this is an estimated amount that included the estimated value of volunteer time [$17 580]). Overall, the estimated cost for the third-dose MMR vaccination clinics was $291 368, or $61.50 per vaccinee. Most of the expenses (73%) in vaccination clinics were due to the cost of the MMR vaccine.

Combining the personnel time and cost for standard outbreak response activities and the third-dose MMR vaccine intervention, 6305 personnel hours, 4736 MMR vaccine doses, and 1920 miles (among other resources) were allocated by public health institutions. This amounted to $649 347 in economic impact.

## DISCUSSION

We estimated the economic burden of mumps outbreak response including a third-dose MMR vaccine intervention in a highly 2-dose–vaccinated university population from the perspective of the public health and university system. The response required important resource and cost outlays by local and state public health institutions and the university.

**Table 1. Number of Personnel Hours, Miles Traveled, and Associated Costs Attributable to the Mumps Outbreak Response at the University of Iowa and Johnson County, Iowa, by Institution and Type of Activity, July 12, 2015–May 7, 2016**

| | Personnel Hours and Costs (%) | | | | | |
|---|---|---|---|---|---|---|
| Activity[a] | JCPH | IDPH | University of Iowa | Public Health Laboratory | Total Hours | Total Costs (%), $[b] |
| Response planning and coordination | 195 (20) | 391 (40) | 344 (35) | 50.5 (5) | 980.5 (20) | 85 495 (24) |
| Case and contact investigation | 1259.5 (71) | 260 (15) | 248 (14) | - | 1767.5 (36) | 98 293 (28) |
| Laboratory, specimen testing | - | - | - | 637[c] (100) | 637 (13)[c] | 49 257 (14)[d] |
| Develop/distribute educational materials | 79 (16) | 208 (43) | 148 (30) | 52 (11) | 487 (10) | 40 869 (12) |
| Prepare reports | 220.5 (35) | 239 (38) | 97 (16) | 67 (11) | 623.5 (13) | 43 851 (12) |
| Answer public inquiries | 37 (11) | 95 (29) | 51 (16) | 142 (44) | 325 (6) | 26 320 (7) |
| Other | 68.25 (45) | 82 (55) | - | - | 150.25 (3) | 10 884 (3) |
| Total hours (%) | 1859.25 (37) | 1275 (26) | 888 (18) | 948.5 (19) | 4971.25[e] | |
| Miles traveled | | 1240 | | | | 484[f] |
| Overtime paid, $ | 2526 | | | | | 2526 |
| Total costs (%), $ | 89 245 (25) | 103 354 (29) | 92 675 (26) | 72 705[d] (20) | | 357 979 |

Abbreviations: IDPH, Iowa Department of Public Health; JCPH, Johnson County Public Health.

[a]Activities included in "response planning and coordination": meetings/conference calls with state/local health department/university/lab to initiate surveillance, determine management of cases and of exposed students, develop protocols for diagnosis and testing, develop isolation recommendations and other activities part of planning response; activities included in "case and contact investigation": tracking of cases, case interviews, screening of suspected cases, collection of specimens and transport to lab, tracking lab results and notification of students, checking vaccination status, database development, data entry and analysis.

[b]Total costs calculated as hourly earnings+fringe benefits+overhead cost. The rate of overhead cost was specific to each institution and varied from 17.2% to 29.5%.

[c]Includes laboratory technician time.

[d]Includes laboratory technician time and cost of laboratory tests, $49 142; tests performed: 709 polymerase chain reaction (PCR), 103 serology IgM, specimens from Johnson County; unitary costs were $60.45 for PCR and $61.00 for serology.

[e]Out of total hours, 151.5 (3%) were self-reported as overtime.

[f]Cost of miles were calculated by using the IDPH reimbursement rate of 0.39/mile.

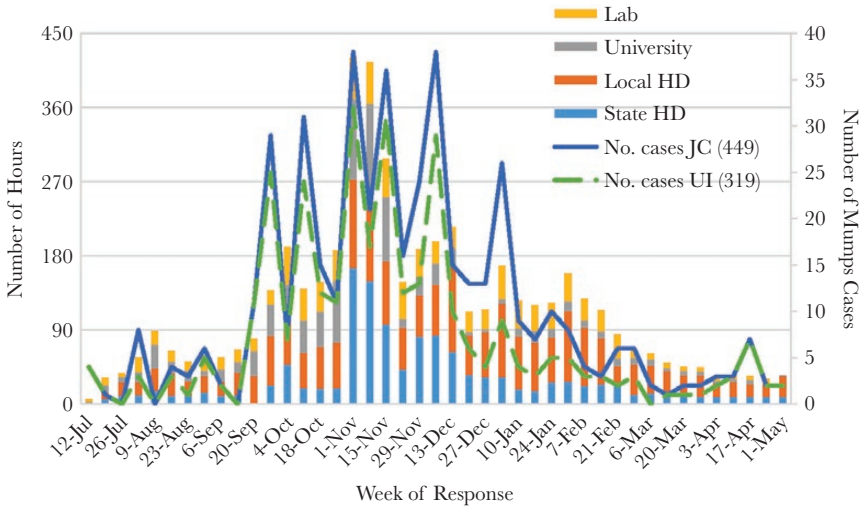


**Figure 1.** Person-hours for standard outbreak response activities by institution and week of response and weekly number of mumps cases in Johnson County and at the University of Iowa, July 12, 2015–May 7, 2016. Abbreviations: HD, Health Department; JC, Johnson County; UI, University of Iowa.

Approximately 6300 hours of personnel time were required, including time needed to conduct vaccination clinics and laboratory work, for a total of >$649 000 spent for outbreak control. Costs were roughly equal between standard outbreak control activities (planning, coordination, and implementation of response) and the third-dose MMR vaccine intervention (55% and 45%, respectively).

Mumps is usually a mild disease, and incidence of complications is further reduced among persons who have received 2 doses of MMR vaccine [4, 9]. Nonetheless, the prolonged outbreak at the University of Iowa had a substantial impact on both public health institutions and the university. Following protocols for investigation of vaccine-preventable disease outbreaks, state and local public health departments, the state laboratory, and the university performed detailed epidemiological investigation, testing, and response activities to prevent further spread of mumps.

Outbreaks cause disruptions, with public health staff and other resources often being reassigned to outbreak response from other public health activities. About one-third of the overall 5000 personnel hours allocated for the response activities were spent by the local health department; all of the aspects of health department activities were affected: school immunization audits and other less urgent communicable disease

**Table 2. Number of Personnel and Volunteer Hours, Miles Traveled, Doses of Measles-Mumps-Rubella (MMR) Vaccine Administered and Associated Costs Attributable to the Third-Dose MMR Vaccination at the University of Iowa, by Institution and Type of Activity, November 10–19, 2016**

| | Personnel Hours, Other Inputs, and Costs (%) | | | | | |
|---|---|---|---|---|---|---|
| Activity | JCPH | IDPH | University of Iowa | Volunteers | Total Units (%) | Total Costs (%), $[a] |
| Personnel hours | | | | | | |
| Preparing for clinics (planning meetings, setting up clinics) | 159 (55) | 16 (6) | 115 (39) | - | 290 (22) | 19 444 (25) |
| Develop/distribute information materials about clinics | 9 (10) | - | 77 (90) | - | 86 (6) | 7328 (9) |
| Time spent at the vaccination clinics, h | 135 (14) | 28 (3) | 238.5 (25) | 556 (58) | 957.5 (72) | 50 836 (66) |
| Total hours (%) | 303 (23) | 44 (3) | 430.5 (32) | 556 (42) | 1333.5[b] | |
| Personnel costs (%), $ | 16 226 (21) | 2622 (3) | 41 180 (53) | 17 580 (23) | | 77 608 |
| Other inputs | | | | | | |
| Miles traveled | 106 | 574 | | | 680 (100) | 265[c] |
| MMR vaccine doses administered | | 1240 | 3496 | | 4736 (100) | 213 495 |
| Other inputs costs, $ | 41 | 24 900 | 188 819 | | | 213 760 |
| Total costs, $ | 16 267 | 27 522 | 229 999 | 17 580 | | 291 368 |

Abbreviations: IDPH, Iowa Department of Public Health; JCPH, Johnson County Public Health; MMR, measles-mumps-rubella.

[a]Total costs calculated as hourly earnings+fringe benefits+overhead cost. The rate of overhead cost was specific to each institution and varied from 17.2% to 29.5%. For volunteers, the mean hourly earnings for Iowa from the Bureau of Labor Statistics for specific occupational codes were uses, no fringe benefits attributed.

[b]Out of total hours, 76 hours (6%) were self-reported as overtime.

[c]Costs of miles were calculated by using the IDPH reimbursement rate of $0.39/mile.

[d]Unitary costs were $54.01 for the MMR doses privately purchased by the university and $19.90 for the MMR doses administered to Vaccines for Children–eligible students.

**Table 3. Number of Persons Who Participated in the Vaccination Clinics and Time Spent by Activity Performed and Number of Measles-Mumps-Rubella Vaccine Doses Administered per Vaccination Clinic, University of Iowa, November 10–19, 2016**

| | Vaccination Clinic | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Activity | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Total Different Persons/Activity | Number Hours |
| Screening of volunteers | 23 | 14 | 5 | 14 | 6 | 9 | - | 4 | 64 | 176:40 |
| Physician | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 46:50 |
| Vaccinator supervisor | 2 | 2 | 1 | 1 | 1 | 1 | - | 1 | 3 | 48:35 |
| Vaccinator | 31 | 34 | 8 | 10 | 4 | 13 | 2 | 5 | 84 | 307:10 |
| Vaccine transporter | 2 | 1 | 1 | 1 | 1 | 1 | - | 1 | 4 | 39:50 |
| Floater | 4 | 3 | - | - | - | - | - | - | 6 | 39:40 |
| Postvaccine area | 1 | 1 | 1 | 2 | - | 1 | - | - | 6 | 19:45 |
| IT coordinator | 2 | 2 | 1 | 1 | 1 | 2 | 1 | 1 | 2 | 67:35 |
| Volunteer coordinator | 1 | 1 | 1 | 1 | - | - | 1 | - | 2 | 33:55 |
| Volunteer nonmedical | 1 | 2 | - | - | - | - | - | - | 2 | 29:45 |
| MMR doses administered | 1768 | 1424 | 433 | 213 | 126 | 680 | 36 | 56 | | |

Ten JCPH, 3 IDPH, and 7 university employees participated in the vaccination clinics; the rest of the vaccination clinic staff were volunteers from the university student population (College of Nursing, College of Public Health, and College of Pharmacy) or local visiting nurses from a neighboring county.

Abbreviations: IDPH, Iowa Department of Public Health; JCPH, Johnson County Public Health; MMR, measles-mumps-rubella.

follow-up or routine inspections were delayed; accreditation and quality improvement projects were put on hold; staff pulled to help with the outbreak response from noninfectious diseases departments could not attend their routine program and grant meetings; the women, infants, and children supplemental nutrition program and maternal and child health clinics were short-staffed; clerical support for grant and other program billing was delayed. For the university, apart from dedicating important personnel time to outbreak investigation, various activities were affected. During the outbreak, students missed classes, exams were rescheduled, sport events were canceled, and University of Iowa student volunteers were restricted from participating in activities in the university hospital or interaction with patients and families at the cancer center. Although these disruptions were not quantified in our economic analysis, they represent a significant loss of productivity, and they support the measures employed to control the outbreak and limit virus transmission.

At the time of the study, a third dose of MMR vaccine was neither part of standard public health response to mumps outbreaks nor a routine recommendation, but guidance existed regarding consideration for its use in specific target populations, along with criteria for public health departments to consider for decision-making. These criteria included settings with high (>90%) 2-dose coverage, intense exposure with high attack rates (>5/1000), and ongoing transmission (>2 weeks). Whereas a more limited third-dose approach was initially implemented at 1 fraternity, as the outbreak continued, the decision was made to hold a university-wide third-dose campaign [17]. During the campaign, >4700 doses of MMR vaccine were administered, for an uptake of 25% among eligible students. Most of the costs associated with the third-dose campaign were vaccine expenses. As persons aged >18 years are not eligible for the Vaccines for Children program and state public health discretionary funds are limited, the university purchased MMR vaccine from the private sector at a higher price ($54.01/dose). Even if purchased by the state immunization program using immunization grant funds at CDC contract prices, the vaccine cost would still have been important (the 2015 contract price per MMR vaccine dose for adults was $40.97) [20]. The personnel resources needed for the third-dose campaign during outbreak response competed with the resources needed to implement control measures. Additional volunteer personnel were engaged to perform vaccination clinic activities and to supplement specific university and JCPH efforts.

After years of low numbers of reported mumps cases and no outbreaks, the United States has in the past decade experienced increases in outbreaks and states reporting outbreaks [8, 9]. However, few studies have assessed the economic burden of mumps outbreaks. Only 2 other studies have reported cost data from the public health perspective; in these outbreaks, a third-dose MMR intervention was used [18, 19]. Cost estimates are difficult to compare across outbreaks because of differences in methods used to calculate containment cost and in outbreak setting types. One study was conducted in Guam in 2009–2010, where 505 mumps cases were reported in a highly vaccinated population, with the highest attack rate in children aged 9–14 years [19]. Over 9 months of response, 8264 hours of personnel time were spent, and 2800 MMR vaccine doses were administered. The overall cost for outbreak response and control was estimated at $256 785; the economic impact per household with ≥1 mumps case was estimated at $761, with days missed from work because of illness or caregiving for a child with mumps accounting for most of the cost. The second study was conducted during a mumps outbreak in a highly vaccinated population in Orange County, New York, in 2009–2010; 790 mumps cases were reported [18]. The highest attack rate was in adolescents aged 11–17 years. Over 9 months of response, a total of 7736 hours of personnel time were spent,

and 1812 MMR doses were administered. The overall cost for outbreak response and control was estimated at $463 202, with a per-household cost of $827.

In 2017, the US Advisory Committee on Immunization Practices (ACIP) examined the evidence on use of a third dose of MMR vaccine during mumps outbreaks. Only 3 studies have examined the impact of a third-dose MMR vaccine for outbreak control. The outbreak investigations in Guam and Orange County, New York [14, 15] found a decline in incidence shortly after the intervention and lower attack rates among third-dose vaccine recipients than among 2-dose recipients, but the difference was not statistically significant. Additionally, the vaccine interventions occurred after the peak of the outbreaks, so the possibility that declines were unrelated to the intervention could not be excluded. The third study was conducted during the outbreak at the University of Iowa where we performed the cost study. That study found that a third dose of MMR vaccine was associated with a lower incidence of mumps, with an incremental vaccine effectiveness of the third dose vs the second dose of 78% (95% confidence interval, 61%–88%) at 28 days postvaccination [13]. The evidence remains limited and insufficient to fully characterize the impact of a third dose of MMR vaccine on reducing the size and duration of an outbreak. After reviewing the evidence on effectiveness and safety of a third dose of MMR vaccine, in October 2017, the ACIP recommended use of a third dose of a mumps virus–containing vaccine (ie, MMR vaccine, or measles-mumps-rubella-varicella [MMRV] vaccine) for persons previously vaccinated with 2 doses who are identified by public health authorities as being part of a group or population at increased risk for mumps because of an outbreak to improve protection against mumps disease and related complications [21]. Our cost study provides additional data on resource allocation and associated costs that are useful for policy-makers and public health professionals when assessing mumps outbreak control strategies.

Our study has several limitations. First, personnel time during the first part of the outbreak when the response was most intense was assessed retrospectively rather than in real time. Thus, even with use of memory aids or official documentation, the potential for recall bias remains. Second, simultaneous outbreak response to cases in the community (28%) and at the university (72%) made the discrimination of activities and resources impractical. Thus, our estimates include cost for response in both settings. Third, the cost study did not cover the entire outbreak period due to logistics; 5 more cases were reported in Johnson County (of which 4 in university students) during the week of finals (May 8–May 13, 2016), and only sporadic cases were reported after, with the last case on July 11, 2016. Fourth, not all costs could be included in our estimates. The cost of disrupting normal activities for the university and students was not evaluated; therefore, the amount of personnel hours and resources diverted for this outbreak investigation is likely an underestimate. The assessed costs should be considered a gross estimate of the real impact of the outbreak. Finally, the number of contacts investigated was not available, precluding determination of cost per contact. In a low–disease incidence era, outbreak response efforts (and associated costs) typically focus on contact tracing and investigation. Assuming 2–5 contacts per case [19, 22], cost per contact would be $289–$723.

The natural history of mumps outbreaks in settings with high 2-dose coverage is unknown. Most US outbreaks reported during 2010–2017 were small (the median number of cases per outbreak [interquartile range] was 10 [4–26] during 2016–2017), but large outbreaks also occurred (13% of outbreaks reported during 2016–2017 had ≥50 cases [range, 50–>300 cases]) [8, 9]. In general, there is high variability regarding timing of an outbreak, the number of cases, outcomes, and resources required for containment. Therefore, cost estimates are specific to each outbreak, and the costs we report may not be applicable to other jurisdictions.

Nonetheless, we documented that response to the 2015–2016 mumps outbreak at the University of Iowa required a substantial public health effort, with reallocation of important amounts of personnel time and resources, comparable to responses to other diseases [22, 23]. The disruptions caused by diverting personnel and resources from other activities are reflected in the important number of personnel hours and associated costs reported.

## Supplementary Data

Supplementary materials are available at *Open Forum Infectious Diseases* online. Consisting of data provided by the authors to benefit the reader, the posted materials are not copyedited and are the sole responsibility of the authors, so questions or comments should be addressed to the corresponding author.

## Acknowledgments

We would like to thank all responders from Johnson County Public Health, Iowa Department of Public Health, University of Iowa, and Iowa State Hygienic Laboratory who provided the data on personnel hours allocated and CDC colleagues Minesh Shah, MD, for consultancy regarding the outbreak and public health response and Mary Ann Hall, MPH, for editorial assistance.

***Disclaimer.*** The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention, US Department of Health and Human Services.

***Funding.*** This work was supported by the Centers for Disease Control and Prevention.

***Potential conflicts of interest.*** All authors: no reported conflicts of interest. All authors have submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest. Conflicts that the editors consider relevant to the content of the manuscript have been disclosed.

## References

1. Rubin SA. Mumps vaccines. In: Plotkin SA, Orenstein WA, Offit PA, Edwards KM, eds. Vaccines. 7th ed. Philadelphia, PA: Elsevier; **2018**:663–88.
2. Galazka AM, Robertson SE, Kraigher A. Mumps and mumps vaccine: a global review. Bull World Health Organ **1999**; 77:3–14.
3. Barskey AE, Glasser JW, LeBaron CW. Mumps resurgences in the United States: a historical perspective on unexpected elements. Vaccine **2009**; 27:6186–95.

4. McLean HQ, Fiebelkorn AP, Temte JL, Wallace GS; Centers for Disease Control and Prevention. Prevention of measles, rubella, congenital rubella syndrome, and mumps, 2013: summary recommendations of the Advisory Committee on Immunization Practices (ACIP). MMWR Recomm Rep **2013**; 62:1–34.
5. Barskey AE, Schulte C, Rosen JB, et al. Mumps outbreak in Orthodox Jewish communities in the United States. N Engl J Med **2012**; 367:1704–13.
6. Clemmons NS, Lee A, Redd SB, et al. Mumps 2016: a national overview. Paper presented at: ID Week 2017; October 2017; San Diego, CA.
7. Dayan GH, Quinlisk MP, Parker AA, et al. Recent resurgence of mumps in the United States. N Engl J Med **2008**; 358:1580–9.
8. Clemmons NS, Redd S, Fiebelkorn AP, et al. Mumps: July 2010–2015, 2016 and beyond. Paper presented at: 47th National Immunization Conference; September, 2016; Atlanta, GA.
9. Clemmons NS, Lee AD, Lopez A, et al. Reported mumps cases (Jan 2011-Jun 2017) and outbreaks (Jan 2016-Jun 2017) in the United States. In: ID Week 2017; October 2017; San Diego, CA.
10. Cohen C, White JM, Savage EJ, et al. Vaccine effectiveness estimates, 2004–2005 mumps outbreak, England. Emerg Infect Dis **2007**; 13:12–7.
11. LeBaron CW, Forghani B, Beck C, et al. Persistence of mumps antibodies after 2 doses of measles-mumps-rubella vaccine. J Infect Dis **2009**; 199:552–60.
12. Davidkin I, Kontio M, Paunio M, Peltola H. MMR vaccination and disease elimination: the Finnish experience. Expert Rev Vaccines **2010**; 9:1045–53.
13. Cardemil CV, Dahl RM, James L, et al. Effectiveness of a third dose of MMR vaccine for mumps outbreak control. N Engl J Med **2017**; 377:947–56.
14. Ogbuanu IU, Kutty PK, Hudson JM, et al. Impact of a third dose of measles-mumps-rubella vaccine on a mumps outbreak. Pediatrics **2012**; 130:e1567–74.
15. Nelson GE, Aguon A, Valencia E, et al. Epidemiology of a mumps outbreak in a highly vaccinated island population and use of a third dose of measles-mumps-rubella vaccine for outbreak control—Guam 2009 to 2010. Pediatr Infect Dis J **2013**; 32:374–80.
16. Albertson JP, Clegg WJ, Reid HD, et al. Mumps outbreak at a university and recommendation for a third dose of measles-mumps-rubella vaccine - Illinois, 2015-2016. MMWR Morb Mortal Wkly Rep **2016**; 65:731–4.
17. Shah M, Quinlisk P, Weigel A, et al. Mumps outbreak in a highly vaccinated university-affiliated setting before and after a measles-mumps-rubella vaccination Campaign-Iowa, July 2015-May 2016. Clin Infect Dis **2018**; 66:81–8.
18. Kutty PK, Lawler J, Rausch-Phung E, et al. Epidemiology and the economic assessment of a mumps outbreak in a highly vaccinated population, Orange County, New York, 2009–2010. Hum Vaccin Immunother **2014**; 10:1373–81.
19. Mahamud A, Fiebelkorn AP, Nelson G, et al. Economic impact of the 2009–2010 Guam mumps outbreak on the public health sector and affected families. Vaccine **2012**; 30:6444–8.
20. Centers for Disease Control and Prevention. CDC vaccine price list. https://www.cdc.gov/vaccines/programs/vfc/awardees/vaccine-management/price-list/index.html. Accessed 24 September 2018.
21. Marin M, Marlow M, Moore KL, Patel M. Recommendation of the advisory committee on immunization practices for use of a third dose of mumps virus-containing vaccine in persons at increased risk for mumps during an outbreak. MMWR Morb Mortal Wkly Rep **2018**; 67:33–8.
22. Ortega-Sanchez IR, Vijayaraghavan M, Barskey AE, Wallace GS. The economic burden of sixteen measles outbreaks on United States public health departments in 2011. Vaccine **2014**; 32:1311–7.
23. Leung J, Rue A, Lopez A, et al. Varicella outbreak reporting, response, management, and national surveillance. J Infect Dis **2008**; 197(Suppl 2):S108–13.