ORIGINAL ARTICLE

A Measles Outbreak in an Underimmunized Amish Community in Ohio

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ABSTRACT

BACKGROUND

Although measles was eliminated in the United States in 2000, importations of the virus continue to cause outbreaks. We describe the epidemiologic features of an outbreak of measles that originated from two unvaccinated Amish men in whom measles was incubating at the time of their return to the United States from the Philippines and explore the effect of public health responses on limiting the spread of measles.

METHODS

We performed descriptive analyses of data on demographic characteristics, clinical and laboratory evaluations, and vaccination coverage.

RESULTS

From March 24, 2014, through July 23, 2014, a total of 383 outbreak-related cases of measles were reported in nine counties in Ohio. The median age of case patients was 15 years (range, <1 to 53); a total of 178 of the case patients (46%) were female, and 340 (89%) were unvaccinated. Transmission took place primarily within households (68% of cases). The virus strain was genotype D9, which was circulating in the Philippines at the time of the reporting period. Measles–mumps–rubella (MMR) vaccination coverage with at least a single dose was estimated to be 14% in affected Amish households and more than 88% in the general (non-Amish) Ohio community. Containment efforts included isolation of case patients, quarantine of susceptible persons, and administration of the MMR vaccine to more than 10,000 persons. The spread of measles was limited almost exclusively to the Amish community (accounting for 99% of case patients) and affected only approximately 1% of the estimated 32,630 Amish persons in the settlement.

CONCLUSIONS

The key epidemiologic features of a measles outbreak in the Amish community in Ohio were transmission primarily within households, the small proportion of Amish people affected, and the large number of people in the Amish community who sought vaccination. As a result of targeted containment efforts, and high baseline coverage in the general community, there was limited spread beyond the Amish community. (Funded by the Ohio Department of Health and the Centers for Disease Control and Prevention.)

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Measles is a highly contagious, albeit vaccine-preventable, disease that can lead to serious complications. Although endemic transmission of measles in the United States was declared to be eliminated in 2000,[1] importations from countries in which measles is still endemic continue to occur. Despite repeated challenges from measles introductions, most importations of measles do not lead to further spread, and outbreaks are generally small and short-lived.[2-4] The success of the measles-control program in the United States is the result of a high rate of coverage with a safe and efficacious vaccine (the measles–mumps–rubella [MMR] vaccine), combined with the aggressive implementation of control measures once cases are detected.[5]

When measles outbreaks occur in a region in which measles has been eliminated, they occur in clusters of unvaccinated persons,[6] including those in religious communities.[7-13] The Amish, a Christian sect descended from the Swiss Anabaptists, practice group solidarity and rejection of modern conveniences.[14,15] Although the Amish Church does not specifically prohibit vaccination, the personal and cultural beliefs of the Amish limit participation in preventive health care, which results in low immunization rates[16-19] and an increased risk of vaccine-preventable diseases.[20-25] During measles outbreaks, the infection can spread unchecked among community members,[11-13,20] which subsequently places susceptible persons in the general population at risk. Such outbreaks afford a unique opportunity to measure the ways in which high baseline immunity in a population and targeted public health responses contribute to the prevention of measles epidemics.

During 2014, the World Health Organization reported that there were 21,403 confirmed cases of measles and 110 measles-associated deaths in the Philippines.[26] In March 2014, a measles outbreak was reported in the United States after two unvaccinated Amish men had returned to their U.S. communities from the Philippines, where they had been unknowingly infected with measles while performing typhoon relief work. In this article, we describe the epidemiology of the outbreak in this distinctive unvaccinated population and detail the containment efforts instituted by local health departments to limit the spread of the disease.

Methods

Case Patient Definition and Confirmatory Testing

On the basis of criteria specified by the Council of State and Territorial Epidemiologists,[27] a case patient was defined as a person who, during the period from March 24, 2014, through September 3, 2014 (the time from the onset of rash in the first case to two maximum incubation periods [42 days] after the onset of rash in the last case), either had a laboratory-confirmed measles infection or had an acute febrile rash illness and was epidemiologically linked to a person with a laboratory-confirmed case (i.e., had contact with a person from, or resided in, the affected Amish community). The diagnosis of measles was confirmed by the detection of measles-specific IgM in serum with the use of enzyme immunoassays, the detection of measles virus RNA in a nasopharyngeal specimen with the use of real-time reverse-transcription–polymerase-chain-reaction (RT-PCR) assays, or both. Assays to detect IgM were performed either at commercial laboratories or at the Centers for Disease Control and Prevention (CDC), and the detection of measles virus RNA and the genotyping were performed at the CDC according to criteria specified by the World Health Organization.[28-30]

Data Collection

We obtained information on demographic characteristics, clinical presentation, and clinical outcomes through face-to-face interviews with case patients or their guardians, using standardized case-investigation forms. The vaccination status of case patients was verified by means of review of vaccination cards and review of records in the Ohio Department of Health immunization registry (ImpactSIIS). Since the investigation was part of a public health response, it was not considered by the Ohio Department of Health or the CDC to be research that was subject to institutional review board approval; written informed consent was not required.

Statewide rates of measles vaccination among children 19 to 35 months of age and adolescents 13 to 17 years of age were determined from the 2014 National Immunization Survey.[31,32] In addition, we examined data from the 2014–2015 Ohio Department of Health School Survey, which assesses vaccination levels among kindergarten

students.[33] Because data for Amish populations are not captured in the National Immunization Survey or in school surveys, immunization levels in the community were assessed by means of review of vaccination cards and of records in ImpactSIIS in a subset of affected families as part of a study of the transmission of measles within households that was conducted during the outbreak.

To evaluate containment measures, ImpactSIIS was queried for the doses of MMR vaccine that were administered at local health departments in affected counties during the period from April 22, 2014, through July 24, 2014, when walk-in prescheduled vaccine clinics were offered. Additional details of the study methods are provided in the Supplementary Appendix, available with the full text of this article at NEJM.org.

STATISTICAL ANALYSIS

Descriptive analyses were performed, and the results are reported as frequencies and proportions for categorical variables and as median values and ranges for continuous variables. Overall and age-specific attack rates were calculated as the number of Amish case patients with measles divided by the estimated Amish population in the affected settlement.[15] Age-specific populations were determined by applying the age distribution of families in the household transmission study described above to the estimated total population.[15] Analyses were performed with the use of SAS software, version 9.3 (SAS Institute).

RESULTS

CHRONOLOGY OF THE OUTBREAK

The two source patients, who were 22 and 23 years of age, returned to Knox County, Ohio, from the Philippines on March 21, 2014 (Fig. 1). Both men began having prodromal symptoms of measles (fever and cough, coryza, or conjunctivitis) on March 22, and a generalized red maculopapular rash developed in both men on March 24. A workup conducted on admission to a local hospital revealed thrombocytopenia, and both men received a diagnosis of dengue. The third and fourth case patients also returned from the Philippines with the source patients but had onsets of rash on April 6 and April 8, respectively. Patient 3 was hospitalized, was noted to have thrombocytopenia, and received a diagnosis of dengue; Patient 4 received intravenous fluids for dehydration at home. None of the four case patients had received pretravel anticipatory guidance.

After a febrile illness with rash developed in 12 additional Amish persons, measles was recognized and was reported to the Knox County health department on April 21. Laboratory testing results were positive for 7 of the initial case patients, including 3 of the 4 case patients who had returned from the Philippines.

CHARACTERISTICS OF CASE PATIENTS

During the outbreak, 573 suspected cases of measles were investigated, of which 190 (33%) were ruled out, which resulted in 383 confirmed cases. The outbreak affected one of the largest Amish settlements in the United States (estimated population, 32,630 persons)[15], which was centered in Holmes County and extended into surrounding counties (Fig. 2). A total of 380 of the 383 case patients (99%) were Amish and lived in 108 households; 3 case patients (<1%) were non-Amish but were epidemiologically linked to the Amish. The duration of the outbreak was 121 days (approximately 4 months).

The age distribution of the case patients (Table 1) shifted during the course of the outbreak. Before May 14, 2014, the approximate midpoint of the outbreak, 26% of the cases occurred among children and adolescents 5 to 17 years of age and 48% among young adults 18 to 39 years of age; on or after May 14, these rates changed to 52% and 25%, respectively ($P<0.001$ by the chi-square test). The corresponding reported source of exposure also changed over time; initially, the transmission setting for 38% of the cases was church, and for 48% was home; later in the outbreak, these rates changed to 5% and 90%, respectively ($P=0.10$ by the chi-square test).

LABORATORY TESTING

Diagnostic testing was performed in 69 of the 383 case patients (18%), and measles was confirmed in 57 of the case patients (15%) (Table 1). Rates of IgM and RT-PCR positivity were 33% and 75%, respectively, in specimens obtained 1 to 8 days before the onset of rash, 92% and 83%, respectively, in specimens obtained within 3 days after the onset of rash, and 94% and 73%, respectively, in specimens obtained on days 4 to 29 after

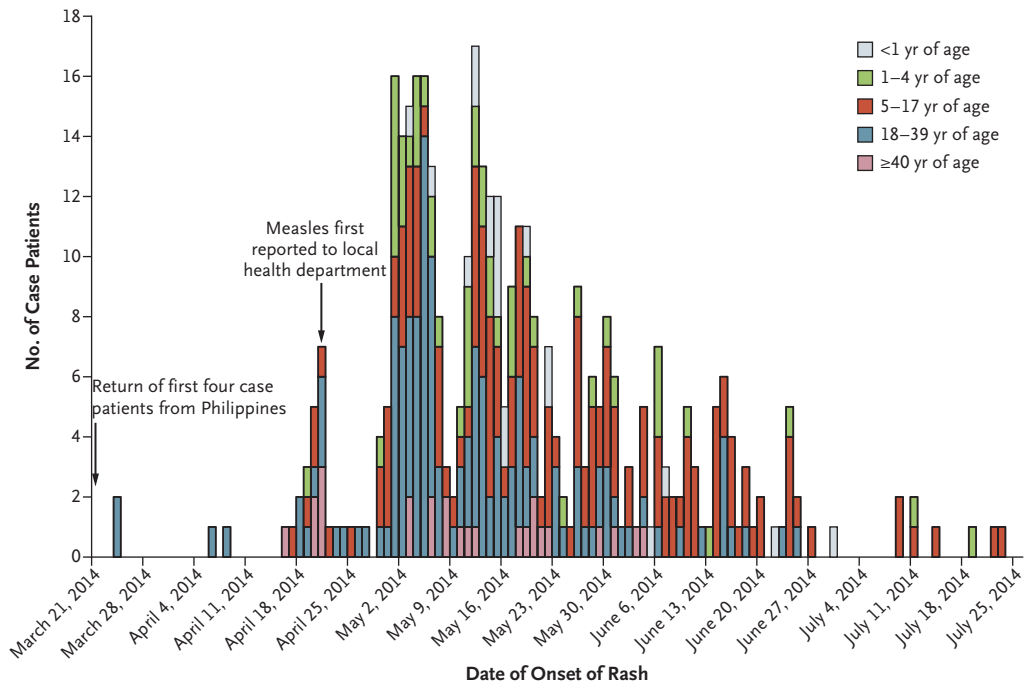

Figure 1. Epidemiologic Curve of 383 Case Patients with Confirmed Outbreak-Associated Measles in Ohio, March 24, 2014, through July 23, 2014.

Shown are the total numbers of case patients with measles according to age group and date of onset of rash. For three case patients with measles, the date of onset of rash could not be determined; therefore, the date of onset of illness plus 2 days (the median number of days between onset of illness and onset of rash for all other cases) is shown. In one case patient who had laboratory-confirmed measles, a rash did not develop; therefore, the date of onset of illness is shown. The first four case patients who returned from the Philippines on March 21, 2014, include the two patients from whom the measles outbreak originated.

the onset of rash. Molecular characterization was performed on 43 RT-PCR–positive specimens, of which 39 (91%) were genotype D9. The remaining 4 specimens were genotype A (the vaccine strain) and were categorized as a vaccine-associated reaction because these persons had received a vaccination 7 to 21 days before the onset of rash.

VACCINATION STATUS AND COVERAGE

Before the outbreak, 340 case patients (89%) were unvaccinated (Table 2). As part of the public health response, 106 case patients (28%) received the MMR vaccine; of these, 16 (15%) received the vaccine before assumed exposure. No case patients received immune globulin as prophylaxis after exposure.

In 2014 in the general population in Ohio, vaccination coverage with at least one dose or at least two doses of MMR among young children and adolescents was 95.6% and 88.2%, respectively,[31,32] and coverage with at least two doses of MMR among children in kindergarten was 91.9%.[33] On the basis of data collected from the affected households, coverage with at least a single dose of MMR vaccine in this community was estimated to be at least 14% before the outbreak.

ATTACK RATES

The crude attack rate of measles was 12 cases per 1000 Amish persons (Table 3). Attack rates ranged from 12 to 15 cases per 1000 Amish persons among persons younger than 1 year to 39 years of age, and rates were lower among persons older than 39 years of age.

RESPONSE MEASURES

Containment interventions were conducted according to CDC guidelines[34] and were similar to those instituted in other underimmunized religious communities.[11-13] Enhanced surveillance of measles was implemented by local health depart-

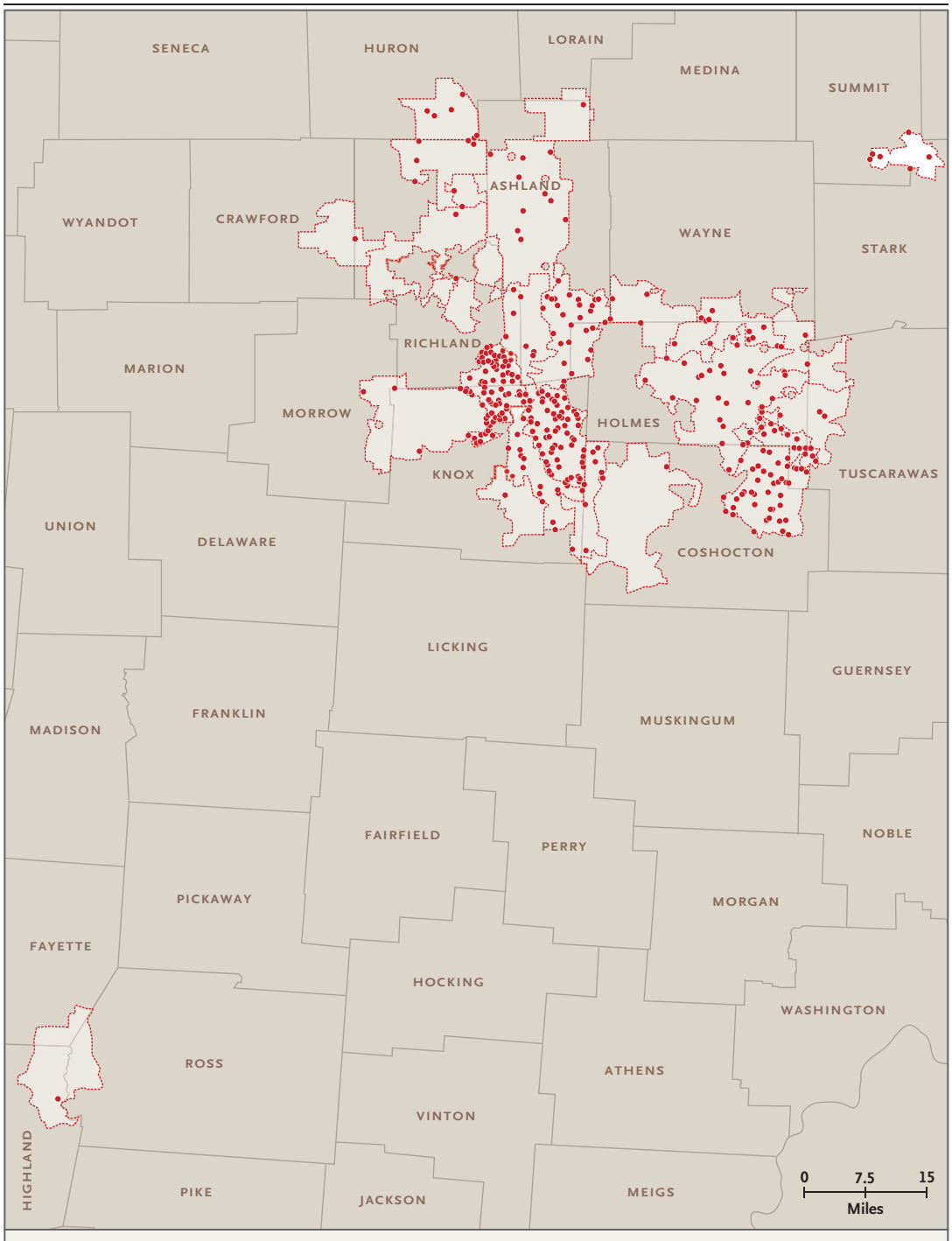

Figure 2. Location of Case Patients with Outbreak-Associated Measles in Ohio Counties.

The geographic distribution of case patients with confirmed measles in Ohio during the period from March 24, 2014, through July 23, 2014, is shown. Each dot represents one case patient; dots are placed randomly within the ZIP Code areas (outlined in red) in which the case patients lived. Measles first spread among Amish residents of Knox County and then to seven contiguous counties and one noncontiguous county (Highland). A total of 196 cases were reported in Knox County, 64 in Holmes, 48 in Coshocton, 46 in Ashland, 20 in Richland, 6 in Stark, and 1 each in Wayne, Crawford, and Highland. Measles was laboratory-confirmed in one or more case patients in all but one (Highland) of the affected counties. The single case in Highland County occurred in a person who had traveled to Ashland County. Within the affected counties, Amish families reside interspersed with, and surrounded by, non-Amish families.

Table 1. Characteristics, Outcomes, and Testing Results in 383 Case Patients with Outbreak-Related Measles in Ohio, March through July 2014.*

Variable	Value
Demographic characteristic	
Female sex — no. (%)	178 (46)
Median age (range) — yr	15 (<1–53)
Age distribution — no. (%)	
<1 yr	20 (5)
1–4 yr	49 (13)
5–17 yr	151 (39)
18–39 yr	138 (36)
≥40 yr	25 (7)
Transmission setting — no./total no. (%)	
Home	194/287 (68)
Church	64/287 (22)
Work	18/287 (6)
Community	6/287 (2)
Other†	5/287 (2)
Symptoms‡	
Fever — no./total no. (%)	
Any§	381/383 (99)
Temperature ≥38.3°C	280/296 (95)
Generalized rash — no./total no. (%)¶	382/383 (100)
Duration — days‖	
Median	5
Range	1–14
Cough — no./total no. (%)	357/380 (94)
Conjunctivitis — no./total no. (%)	296/365 (81)
Coryza — no./total no. (%)	277/361 (77)
Complications — no./total no. (%)‡	
Diarrhea	212/358 (59)
Otitis	92/347 (27)
Pneumonia	5/237 (2)
Thrombocytopenia	3/194 (2)
Encephalitis	0/224 (0)
Outcomes‡	
Hospitalization — no./total no. (%)	12/368 (3)
Duration — days‖	
Median	3
Range	1–6
Death — no./total no. (%)	0/383 (0)

Table 1. (Continued.)

Variable	Value
Laboratory testing — no. (%)	
IgM-positive, RT-PCR–positive, or both	57 (15)
IgM-positive alone	15 (4)
RT-PCR–positive alone	17 (4)
Both IgM-positive and RT-PCR–positive	25 (7)

* The total number of respondents varies among the characteristics assessed because of varying completeness of responses to the questionnaire. RT-PCR denotes reverse-transcription–polymerase chain reaction.
† "Other" includes international travel (four case patients) and a doctor's office (one case patient).
‡ Symptoms, complications, and outcomes were self-reported. Pneumonia was medically diagnosed and thrombocytopenia was confirmed by means of laboratory testing. The number of persons who were clinically evaluated and in whom no pneumonia was reported is unknown. The number of persons who had a complete blood count performed and in whom no thrombocytopenia was reported is unknown.
§ Two case patients in whom fever was not reported had generalized rash plus cough, coryza, or conjunctivitis and had laboratory-confirmed measles.
¶ One case patient in whom rash was not reported had fever plus cough, coryza, or conjunctivitis and had laboratory-confirmed measles.
‖ Duration of rash and duration of hospital stay are based on 190 cases and 7 cases, respectively.

ments in each affected county. Meetings that included bishops and local health department personnel were held[12] to encourage reporting, to emphasize the importance of vaccination, and to inform residents about the availability of testing. Knowledge of the outbreak spread rapidly by word of mouth, and several news stories were published in the local Amish newspaper, *The Budget*. The Ohio Department of Health sent periodic health alerts to health care providers throughout Ohio to inform them about the outbreak.[11-13]

An incident command system that was based on the principles of emergency disaster management was established to streamline communication among local health departments, and dedicated telephone lines were set up to answer public inquiries.[12] Public health advisors from the CDC assisted in contact investigations. Door-to-door case finding was conducted in areas suspected of having unreported cases of measles. Contacts of case patients were identified, and susceptible contacts were offered vaccination.

During 120 free vaccination clinic sessions, 12,229 doses of MMR vaccine were administered to 10,644 persons; 6461 of the persons who received at least one dose (61%) were 5 to 39 years of age (Table 3 and Fig. 3). Case patients were isolated until they were no longer infectious (4 days after the onset of rash), and nonimmune persons who were exposed to measles were voluntarily quarantined at home and followed for the development of symptoms until beyond the maximum incubation period (21 days).[34,35] The church-related entity that organized the charitable work in the Philippines adopted pretravel immunization measures for subsequent volunteers.

DISCUSSION

This outbreak serves as a reminder that measles remains endemic in many countries and that unvaccinated U.S. residents who return from abroad continue to place themselves and others at risk for measles. Although genotype B3 was detected in most importations of measles associated with the outbreak in the Philippines during 2014, genotype D9 viruses were endemic in the Philippines before that outbreak and were circulating in some parts of the country during the outbreak.[36,37] The measles outbreak in Ohio that we describe here was the largest such outbreak documented in the United States in more than two decades, with a crude attack rate that was several orders of magnitude larger than the annual incidence of measles in the country (which is <1 case per million persons),[3,5] and lasted for approximately 4 months, which was longer than any other measles outbreak since the disease was eliminated in the United States. The magnitude and duration of the outbreak illustrate how communities that object to vaccination are at increased risk for the spread of measles and for

Table 2. Measles Vaccination Status of 383 Case Patients with Outbreak-Related Measles in Ohio, March through July 2014.*

Characteristic	Value
Vaccine-eligible — no. (%)†	363 (95)
Vaccination status — no. (%)‡	
Before start of outbreak§	
0 doses	340 (89)
1 dose	4 (1)
2 doses	1 (<1)
Unknown	38 (10)
Before exposure¶	
0 doses	324 (85)
1 dose	20 (5)
2 doses	1 (<1)
Unknown	38 (10)
By end of outbreak‖	
0 doses	234 (61)
1 dose	82 (21)
2 doses	29 (8)
Unknown	38 (10)
Reasons for not receiving measles vaccine — no./total no. (%)**	
Philosophical beliefs, religious beliefs, or both††	281/340 (83)
Ineligible‡‡	20/340 (6)
Other§§	39/340 (11)

* The total number of respondents varies among the characteristics assessed because of varying completeness of responses to the questionnaire.

† Persons were considered to be vaccine-eligible if they were between 12 months of age (the minimum age for routine measles vaccination) and 57 years of age (persons born before 1957 were considered to be immune) and did not have other evidence of immunity to measles.[35]

‡ Vaccination status refers to the number of doses of measles–mumps–rubella (MMR) vaccine received. Persons who were categorized as unvaccinated had reported that they had no history of being vaccinated. Persons who were categorized as vaccinated had their vaccination status confirmed by review of the date of receipt of vaccine on their vaccine cards and by review of records in the Ohio Department of Health immunization registry (ImpactSIIS). The vaccination status of persons for whom vaccination status could not be verified was classified as unknown.

§ The time period before the start of the outbreak was defined as the period before the onset of rash in the first case patient in the outbreak (March 24, 2014).

¶ Exposure was assumed to have occurred 14 days before the onset of rash.

‖ The end of the outbreak was defined as the date of the onset of rash in the last case patient in the outbreak (July 23, 2014).

** A total of 340 case patients were unvaccinated before the outbreak began.

†† This category includes persons who were unvaccinated because of their own or their parents' beliefs.

‡‡ This category includes persons who were ineligible for the measles vaccination and were generally those younger than 12 months of age.

§§ This category includes persons who were known to be unvaccinated and the reason was unknown (37 persons) and those who had either documentation of physician-diagnosed disease before the outbreak (1 person) or laboratory evidence of immunity to measles (1 person).

potentially becoming a source of further transmission.[6] Despite considerable societal interaction among Amish and non-Amish persons in Ohio, the spread of the disease was limited almost exclusively to the Amish, which indicates that high baseline vaccination coverage in the general community was probably effective against further spread of measles.

A few notable features of the outbreak revealed important characteristics of the affected community. First, the degree of opposition to immunization was less strenuous than it was in previous outbreaks among the Amish, in which vaccination was refused.[7,20] In addition, infectious and exposed persons were willing to limit attendance at church gatherings, weddings, and other events, which may explain the changes in age distribution and exposure setting during the outbreak; initial transmission seemed to occur more often among adults, whereas subsequent transmission occurred more often among younger age groups once measles was introduced into households. Second, the rate of hospitalization due to measles was lower among the Amish (approximately 3%) than in the general U.S. population (approximately 20%),[3] which may reflect differences in health-seeking behavior and the cost of medical care, because the Amish tend to be uninsured. Third, measles attack rates were 1.5 to 1.9 times as high among persons younger than 40 years of age as among those 40 to 54 years of age, which suggests that older age groups had previous natural immunity; this finding is consistent with reported measles outbreaks in Ohio in the late 1980s.[20,38] The fact that no case patients were 55 years of age or older supports the statement in official recommendations that persons born before 1957 have presumptive evidence of measles immunity.[35] Fourth, although we had expected lower attack rates among children younger than 1 year of age because of transfer of maternal antibodies, unvaccinated mothers had a high probability of remaining susceptible through early adulthood because of the low background incidence of measles in an area in which measles has been eliminated, which therefore diminished any potential transfer of protective antibodies to their neonates.

This investigation highlighted several challenges for measles control during outbreaks. Because of the late recognition of measles, the outbreak was well under way by the time public

Table 3. Measles Cases and Vaccination Coverage among Amish Case Patients in Ohio, According to Age Group, March 24 through July 24, 2014.*

Age Group	Estimated Amish Population†	Case Patients with Measles	Attack Rate	Estimated Vaccine Coverage‡	Receipt of MMR Vaccine during Outbreak		
					1 dose	2 doses	Total
		no.	*no. of cases/1,000 Amish persons*	*no. of persons/ total no. (%)*	*no. of persons*		
<1 yr	1,375	20	15	0/19 (0)	122	16	138
1–4 yr	3,473	46	13	5/48 (10)	1,695	220	1,915
5–17 yr	11,793	151	13	25/155 (16)	2,584	687§	3,271
18–39 yr	11,214	138	12	23/135 (17)	2,804	386	3,190
40–54 yr	3,328	25	8	4/37 (11)	1,378	170	1,548
≥55 yr	1,447	0	0	0/17 (0)	476	106	582
All	32,630	380¶	12	57/411 (14)	9,059	1,585	10,644‖

* Because of broad circulation, and because infants are a high-risk group, the recommended age of vaccination was lowered to 6 months of age during the outbreak. Data from 38 persons who received the MMR vaccine are not included because information on age was missing. County health department clinic sessions, at which MMR vaccines were administered as part of the containment efforts to limit the spread of measles, were held during the period from April 22 through July 24, 2014.

† The estimated Amish population size in each age group was determined on the basis of a total estimated population size of 32,630 in the affected settlement,[15] and the age distribution of 451 persons in 62 affected households (19 [4%] were younger than 1 year of age, 48 [11%] were 1 to 4 years of age, 163 [36%] were 5 to 17 years of age, 155 [34%] were 18 to 39 years of age, 46 [10%] were 40 to 54 years of age, and 20 [4%] were 55 years of age or older).

‡ Vaccination status was known for 411 of the 451 persons (91%) in 62 affected households.

§ Seven previously unvaccinated persons who were 5 to 17 years of age received three doses of MMR vaccine and are included in the two-dose category.

¶ Three non-Amish case patients were excluded from the calculations of attack rate, because the attack rates were calculated among Amish persons, with the Amish population as the denominator.

‖ Among the 1585 persons who received two doses (15% of the 10,644 persons who were vaccinated during the outbreak), the median number of days between the first and second doses was 35 days (range, 4 to 79). Of the 10,644 persons who were vaccinated during the outbreak, 1918 (18%) had documentation of having received at least one dose of MMR vaccine before the outbreak, and 8726 (82%) lacked documentation of a previous vaccination.

health responses began. Earlier recognition of the correct diagnosis and source of infection in the first four case patients might have led to better measles control and cost savings[8,39]; therefore, health care providers should maintain a high awareness of measles when returning unvaccinated travelers present with a fever and rash. When the measles vaccine is administered within 72 hours after exposure, it may prevent or modify illness.[34,35] The finding that measles developed in 16 persons who had received a vaccination near the time of exposure underscores the need to administer the vaccine as early as possible during outbreaks. When community concern about measles is heightened, laboratory confirmation of the disease in suspected case patients is important, but it is labor-intensive if the case burden is high. This situation is further complicated by the most appropriate timing of testing to minimize false negative results (>72 hours after the onset of rash for the detection of IgM and ≤72 hours after the onset of rash for the detection of measles virus RNA). In addition, because vaccine-associated reactions can manifest as fever and rash, which can result in case misclassification, genotype identification is required to distinguish wild-type virus from the vaccine strain in persons vaccinated within 21 days after the onset of rash; however, it is often challenging to perform genotyping during outbreak responses. In the case of the Amish outbreak, it would have been necessary to obtain a nasopharyngeal specimen for genotyping from 98 case patients.

Vaccination of susceptible persons is the backbone of measles outbreak control, and the data suggest that the control measures that were instituted may have been effective in curtailing some measles transmission. A decline in infections coincided with the scaling up of vaccine

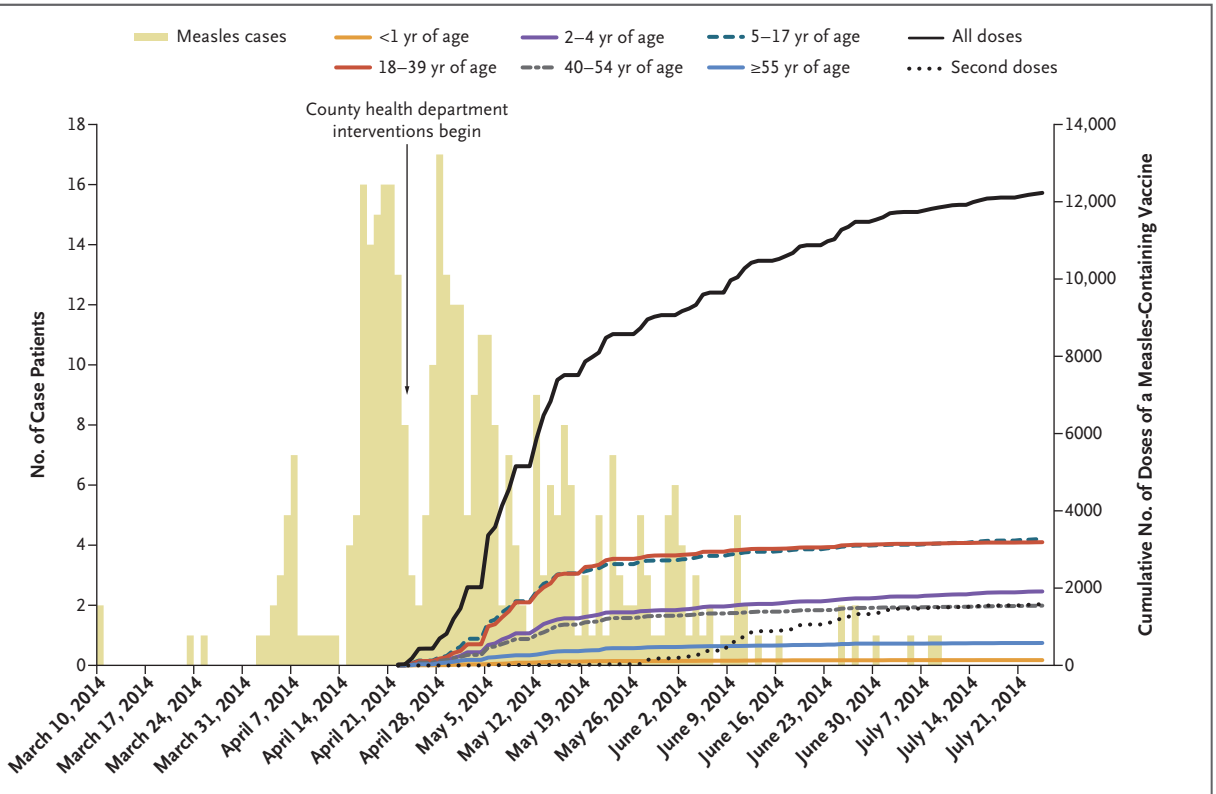

Figure 3. Cumulative Number of Doses of MMR Vaccine Administered during Local Health Department Clinic Sessions.

The cumulative number of first doses (displayed according to age group), second doses, and total doses of measles–mumps–rubella (MMR) vaccine administered during efforts to contain the outbreak are shown according to the day of administration. County health department clinic sessions were held from April 22 through July 24, 2014. Also shown are the daily total numbers of measles infections according to the assumed day of exposure (14 days preceding the onset of rash).

administration, and vaccination efforts effectively removed close to a third of the susceptible pool (8726 of approximately 28,100 previously unvaccinated Amish persons received the MMR vaccine). In addition, more than one quarter of the case patients (28%) were vaccinated around the time of exposure or while incubating measles, which suggests that the subpopulation most at risk — that is, susceptible persons in areas where measles was circulating — may have preferentially sought vaccination. This finding may be particularly relevant in a community composed of many local congregations attended by clusters of families who are physically proximate and are engaging in collective activities. However, because approximately 19,300 Amish persons in the community remained unprotected, other factors probably contributed to limiting the spread of the disease. Social distancing, both behavioral as a result of illness and self-imposed as recommended by health agencies, may have had a substantial and more immediate effect. This possibility is supported by the small percentage of families in the settlement in which measles was reported (<3% based on a household size of 7 persons) and the finding that most transmission occurred at home rather than in the community, particularly late in the outbreak. In addition, the fact that the outbreak occurred during summer vacation, when Amish parochial schools were closed, and that congregations were geographically scattered, probably lessened the number of exposures.

Several limitations of this analysis should be considered. The reluctance of a subgroup of very conservative Amish persons to collaborate with health officials may have resulted in underreporting of measles. However, enhanced surveillance,

widespread knowledge of the outbreak, and involvement of local health department personnel who had established relationships with the community are likely to have resulted in improved case ascertainment. Underlying immunity levels among the Amish were unknown. Our assessment of vaccination coverage included households where at least one case patient resided and underestimated coverage in the settlement. Thus, the remaining number of susceptible persons may have been considerably lower than the number estimated on the basis of an initial coverage of 14%. Yet, given the large number of persons who sought vaccination, anecdotal reports from local health departments of MMR coverage of approximately 40 to 50% in the settlement, and a recent study showing that only 68% of children in Holmes County reported receipt of at least one dose of any vaccine,[18] it is likely that the community was underimmunized. Attack rates are dependent on the estimated population at risk and on the assumption that the age distribution in affected households is similar to that in households without cases, so cautious interpretation is warranted. Measles was laboratory-confirmed in 15% of case patients, and some case patients in whom measles was not laboratory-confirmed may have had an unrelated febrile illness with rash or a vaccine reaction. However, all case patients who did not undergo testing had an illness that was clinically compatible with measles and were epidemiologically linked to the Amish, and rates of fever and rash associated with the MMR vaccine are rare (5 to 15% for fever and 5% for rash).[40]

This evaluation illustrates the way in which a clustering of persons who do not routinely vaccinate against measles can result in an accumulation of susceptible persons and can subsequently create a niche of sustained measles transmission. Since the outbreak, local health departments have continued to promote and offer vaccination. Although acceptance of vaccination among some of the Amish has generally improved, the demand for immunization has varied by county, and efforts to ascertain and to improve coverage in this and other Amish communities are needed. We highlight the importance of early recognition of measles and suggest that prompt initiation of control measures ahead of the epidemic curve may be key to limiting the spread of measles. Effective strategies rely on community commitment through engagement of local leaders,[12] isolation of infectious persons, quarantine of those exposed, and vaccination of susceptible persons. The single best means of containment of measles, however, is maintenance of high initial levels of measles immunity in the population.

The findings and conclusions in this article are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention (CDC).

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