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Original article

Epidemiology of mumps outbreaks and the impact of an additional dose of MMR vaccine for outbreak control in regional Queensland, Australia, 2017–2018

Jacina Walker, Odewumi Adegbija, Nicolas Smoll, Arifuzzaman Khan, Jordan Whicker, Heidi Carroll, Rachael Rodney Harris, Gulam Khandaker

Abstract

Background

In recent years, there have been ongoing outbreaks of mumps reported in Northern and North-Western Queensland, Western Australia and the Northern Territory, Australia. We aimed to define the epidemiology of mumps outbreaks in Central Queensland, Australia between October 2017 and October 2018 and evaluate the effectiveness of an additional dose of measles, mumps, rubella (MMR) vaccine.

Methods

A retrospective case control study was conducted, including outbreak investigations with laboratory-confirmed cases of mumps and subsequent comparison with matched controls. We analysed mandatory notifications from the Queensland Health Notifiable Conditions System database and immunisation information from the Queensland Health Vaccination Information and Admin System (VIVAS) and the Australian Immunisation Register.

Results

Between October 2017 and October 2018, there were 93 cases of mumps reported in Central Queensland with three distinct outbreaks: a discrete Indigenous community; a correctional facility; and a boarding school. Among all cases, 74 (79.6%) were fully vaccinated and 14 (15.1%) were partially vaccinated with MMR vaccine. Eighty-six cases (92.5%) were reported among Aboriginal and Torres Strait Islanderⁱ people. In all outbreaks, an additional dose of MMR vaccine was offered with 35.4%, 73.6% and 35.8% of the target population being immunised in the discrete Indigenous community, the correctional facility and the boarding school, respectively. Prior to this additional dose of MMR, the mumps attack rate was 31.0 (95% confidence interval [95% CI]: 24.2–39.0) per 1000 population, compared to the post-additional dose MMR attack rate of 10.6 (95% CI: 6.7–15.9) per 1000 population.

Conclusion

An additional or booster dose of MMR should be included as an effective public health intervention strategy, particularly in communal or high-density living conditions to control mumps outbreaks in highly vaccinated populations.

Keywords: Mumps; Boarding school; Indigenous; Prison; Outbreak; Queensland, Vaccination; MMR; Additional dose; Infection control

ⁱ Hereafter respectfully referred to as Indigenous.

Background

Mumps is a vaccine-preventable infectious disease belonging to the *Paramyxoviridae* family, spread through respiratory droplets and contact with contaminated fomites.¹ Although generally considered a mild disease, mumps can cause serious complications, including inflammation of the testicles (i.e. orchitis, which may cause infertility), ovaries, pancreas, liver, heart and brain, and hearing loss. Infection during the first trimester of pregnancy may increase the risk of miscarriage.^{2,3} Outbreaks of mumps are not very common in highly vaccinated communities, however, in recent years there has been a resurgence of mumps, mainly among the Australian Indigenous population.^{4,5}

In Australia, a single dose of mumps-containing vaccine was recommended for young children from 1980 to 1989. A second dose of mumps-containing (measles-mumps-rubella, MMR) vaccine has been nationally funded since late 1992, with various catch-up vaccination programs offered across the states and territories for school aged children and adults born during or after 1966 who had not received two doses of MMR vaccine.⁴

Two doses of mumps-containing vaccine are expected to provide adequate immunity to protect against mumps infections; however, there are reports of mumps resurgence in highly vaccinated communities.^{6–8} Important programmatic considerations regarding the introduction of a nationally funded mumps-containing vaccine into Australia's immunisation program have been instrumental in improving vaccine coverage and reducing the burden of disease. Nonetheless, despite the vaccination programs and high childhood vaccination rates, a national resurgence of mumps has been noted between 2015 to 2018,^{4,9} following the inception of reporting in 2001.

In Queensland, a tenfold increase over one year in 2017–2018 is thought to be due to a combination of waning immunity, particularly vaccine-derived immunity which can occur within a

decade of receiving a mumps-containing vaccine,³ and high-risk accommodation settings where close living conditions and overcrowding are prevalent.^{3,10} Ongoing outbreaks have also been reported in recent years in the Northern Territory and Western Australia. Moreover, while there is growing evidence on the effectiveness of an additional dose of MMR vaccine during mumps outbreaks, in Australia there is no specific recommendation in highly vaccinated communities.^{11,12} We aimed to define the epidemiology of mumps outbreaks in Central Queensland, Australia between 2017 and 2018 and to evaluate the effectiveness of the administration of an additional dose of MMR vaccine in the context of a mumps outbreak.

Methods

This is a retrospective case control study of laboratory-confirmed mumps cases reported from Central Queensland, Australia between 25 October 2017 and 31 October 2018. We used mandatory reported notifications and individual case follow-up data from the Queensland Health Notifiable Conditions System (NOCS) database and immunisation information from the Queensland Health Vaccination Information and Admin System (VIVAS) and the Australian Immunisation Register (AIR). We included two controls per case, matched for age (i.e. age groups for every five-year interval), sex, Indigenous status, and outbreak location. Controls for the discrete Indigenous communities were selected from the seasonal influenza registration data within the local Government area. The inmates at the correctional facility and the students at the boarding school formed the controls for the respective outbreaks. Comparison between the cases and control groups were made on timing of first and second dose of MMR vaccine and the time interval between the two doses. An epidemiologic analysis of all outbreak cases and persons immunised with MMR vaccine was conducted as the outbreak progressed.

Case definitions and laboratory investigations

A case definition of mumps consistent with Queensland Health Communicable Disease Control Guidance was adopted.³ A confirmed case of mumps required either: laboratory definitive evidence by mumps detection via nucleic acid testing; isolation of the mumps virus; immunoglobulin G (IgG) seroconversion or significant increase in antibody level; or a fourfold or greater rise in the titre via paired serology (in the absence of recent mumps immunisation). In addition, a confirmed case was also defined as anyone with laboratory suggestive evidence (detection of mumps specific IgM) and clinical evidence consistent with mumps.³ Only laboratory confirmed cases were included in this study.

Diagnosis of mumps was verified via laboratory testing using reverse transcription polymerase chain reaction (RT-PCR) on buccal, throat or urine samples specimens. All samples were tested at the Queensland Health reference laboratory, Forensics and Scientific Services (FSS), Public Health Virology Laboratory.

Outbreak cases

According to the Mumps Queensland Health Guidelines for Public Health Units, 'a mumps outbreak is defined as more than the expected incidence of cases in a defined community'. A mumps outbreak included any laboratory confirmed cases notified during October 2017 – October 2018 where an epidemiological link (contact between two individuals with clinically compatible illness suggestive of mumps) or a plausible mode of transmission during the infectious period could be established and the person contracted the disease within the incubation period of 12–25 days after contact. The Queensland Health Guidelines for Public Health Units defining epidemiological evidence criteria was adopted.³

Data management and analysis

Demographic and vaccination history were analysed for all notified mumps cases by location. Incidence was calculated using the number of acute infections as the numerator and the population at risk to the outbreak (i.e. prisoners at the correctional facility, students at the boarding school, or the Indigenous community) as the denominator. A discrete Indigenous community is defined as 'a geographic location, bounded by physical or cadastral (legal) boundaries, and inhabited or intended to be inhabited by predominantly Indigenous people, with housing or infrastructure that is either owned or managed on a community basis'.¹³ In addition, age-specific attack rates in Indigenous and non-Indigenous people have been compared. Individuals were defined as fully vaccinated if two or more doses of a mumps-containing vaccine had been given at least four weeks apart, and the individual was at least 12 months old at the time of the first vaccine.¹⁴ Individuals were defined as partly vaccinated if they had received one dose of mumps-containing vaccine. In each of the outbreaks, the number of years since the second dose of mumps-containing vaccine was also measured and analysed to explore the possibility of waning immunity and of susceptibility to mumps. To explore whether there are any differences in time duration between the last dose of MMR and risk of disease acquisition between cases and controls, we also compared the time duration from the last dose of MMR to infection for the cases and to the mid-point of each outbreak for the controls. The pre-vaccination period was defined as before the mass vaccination clinic began within each setting. The post-vaccinated period was defined as two weeks after the final vaccination clinic in each setting.

The independent t-test was used to assess the mean difference between cases and controls.

A *p*-value less than 0.05 was considered statistically significant. Data were aggregated into MS Excel spreadsheet and imported into R studio¹⁵ for data cleaning, manipulation, analysis and production of tables and graphs.

Ethical considerations

Ethics approval to conduct this study was obtained from the Central Queensland Hospital and Health Service Human Research Ethics Committee (HREC Ref number HREC/2020/QCQ/61302) and the Australian National University Human Research Ethics Committee (HREC Ref number 2020/629). In addition, project endorsement was obtained from the Indigenous Steering Committee in Central Queensland, with committee delegate signature.

Results

Between 25 October 2017 and 31 October 2018, there were 106 laboratory confirmed cases of mumps identified in the Central Queensland region, of which 93 cases were linked with three distinct outbreaks. Genotyping was available for one specimen and identified genotype G.

Thirteen cases did not meet the outbreak case definition, as there was no established epidemiological link to the outbreaks; these were excluded from the study. Eighty-six (92.5%) of the outbreak cases were identified as Indigenous people (Table 1). Among the three outbreaks, 66/93 cases (71.0%) were identified from a discrete Indigenous community, with 27 of these cases (41.9%) male and 39 (59.1%) female. All cases identified in the other two outbreaks were male: 11/93 cases (11.8%) from a correctional facility; and 16/93 cases (17.2%) from a local boarding school, with a mean age for the boarding school cases of 16.8 years (standard deviation, SD: 1.1 years), and with a majority (10/16, 62.5%) of boarding school cases comprising Indigenous persons. The correctional facility is located 191 km and 251 km from the Indigenous community and boarding school, respectively.

The age, sex and distribution of outbreak cases by Indigenous status and location is reported in Table 1.

Timeline of outbreaks

The index case of the first mumps outbreak in the Central Queensland region was reported in a discrete Indigenous community on 25 October 2017. That outbreak lasted for 32 weeks (see Figure 1). We were unable to identify any epidemiological links between secondary cases and our first identified case in this outbreak.

While the Indigenous community outbreak was ongoing, a case was notified from a regional correctional facility on 17 December 2017. The correctional facility outbreak lasted twelve weeks. The primary case from the correctional facility outbreak was epidemiologically linked with a confirmed case from the discrete Indigenous community when an asymptomatic but infectious person visited an inmate.

The final outbreak was at a boarding school and commenced on 11 August 2018, lasting about twelve weeks. We were unable to identify any epidemiological link to the first identified case of the school outbreak. However, the primary case from the boarding school outbreak cluster visited their home in Torres Strait Islands where there was known community mumps transmission at that time. Figure 1 shows the epidemiological curve of the outbreaks and indicates the timeline for public health interventions.

Attack rates of mumps outbreaks

The overall attack rate (cases per 1,000 population at risk) was 41.6 cases per 1,000 population (95% CI: 33.3–49.8). The attack rate was highest in the discrete Indigenous community, 65.7 cases per 1,000 population (95% CI: 50.4–81.0), followed by the boarding school, 26.1 cases per 1,000 population (95% CI: 15.0–42.0) and the correctional facility, 17.2 cases per 1,000 population (95% CI: 7.1–17.2). Age-specific attack rates are shown in Table 2.

Among the discrete Indigenous community people, the attack rate was highest in the 20–24 years age group, 156.3 cases per 1,000 population (95% CI: 83.6–228.9), followed by the 10–14 years age

Table 1. Demographic characteristics of 93 mumps cases connected to outbreaks, Central Queensland, 2017–2018

Demographic characteristic	Location of outbreak			Total outbreak cases
	Discrete Indigenous community (N = 66)	Correctional facility ^a (N = 11)	Boarding school ^a (N = 16)	
Male, n (%)	27 (40.9%)	11 (100%)	16 (100%)	54 (58.1%)
Female, n (%)	39 (59.1%)	0 (0%)	0 (0%)	39 (41.9%)
Mean age (SD)	21.2 (11.9)	25.2 (6.5)	16.8 (1.1)	20.9 (10.5)
Median age [IQR] ^b	18.5 [14.3–24.8]	23.9 [21.3–26.6]	17.0 [16.7–17.5]	18.1 [15.1–23.2]
IS: ^c Indigenous, n (%)	66 (100)	10 (90.9)	10 (62.5)	86 (92.5)
IS: non-Indigenous, n (%)	0	1 (9.1)	6 (37.5)	7 (7.5)

a People with mumps in the boarding school or the correctional facility were listed by their school or correctional centre address, rather than by their permanent home address.

b IQR: Inter-quartile range.

c IS: Indigenous status.

group, 140.0 cases per 1,000 population (95% CI: 72.0–208.0). The 15–19 years age group had the highest attack rates in both the correctional facility (200.0 cases per 1,000 population; 95% CI: 25.2–556.1) and the boarding school (44.1 cases per 1,000 population; 95% CI: 24.9–71.7).

The attack rate was lowest in people aged over 50 years (Table 2, Figure 2). All children in the 0–4 years age group were fully vaccinated for age. Two children received their second dose of mumps-containing vaccine less than one year before acquiring the disease; one child had received the first scheduled dose of mumps-containing vaccine and was not eligible for dose 2 due to age, before acquiring the disease. Only one adult in the 40–44 years age group was fully vaccinated and the remaining cohort had either no vaccination history, or only a partial vaccination history, for a mumps-containing vaccine.

The attack rate (cases per 1,000 population at risk) in the outbreak was significantly reduced from 31.0 (95% CI: 24.2–39.0) to 10.6 (95% CI: 6.7–15.9) after vaccination with a third dose. This reduction was found significant for the discrete Indigenous community only (54.9 [95% CI:

41.0–71.8] to 17.6 [95% CI: 10.1–28.4]), $p < 0.001$; significance was not evident for other groups (Table 4).

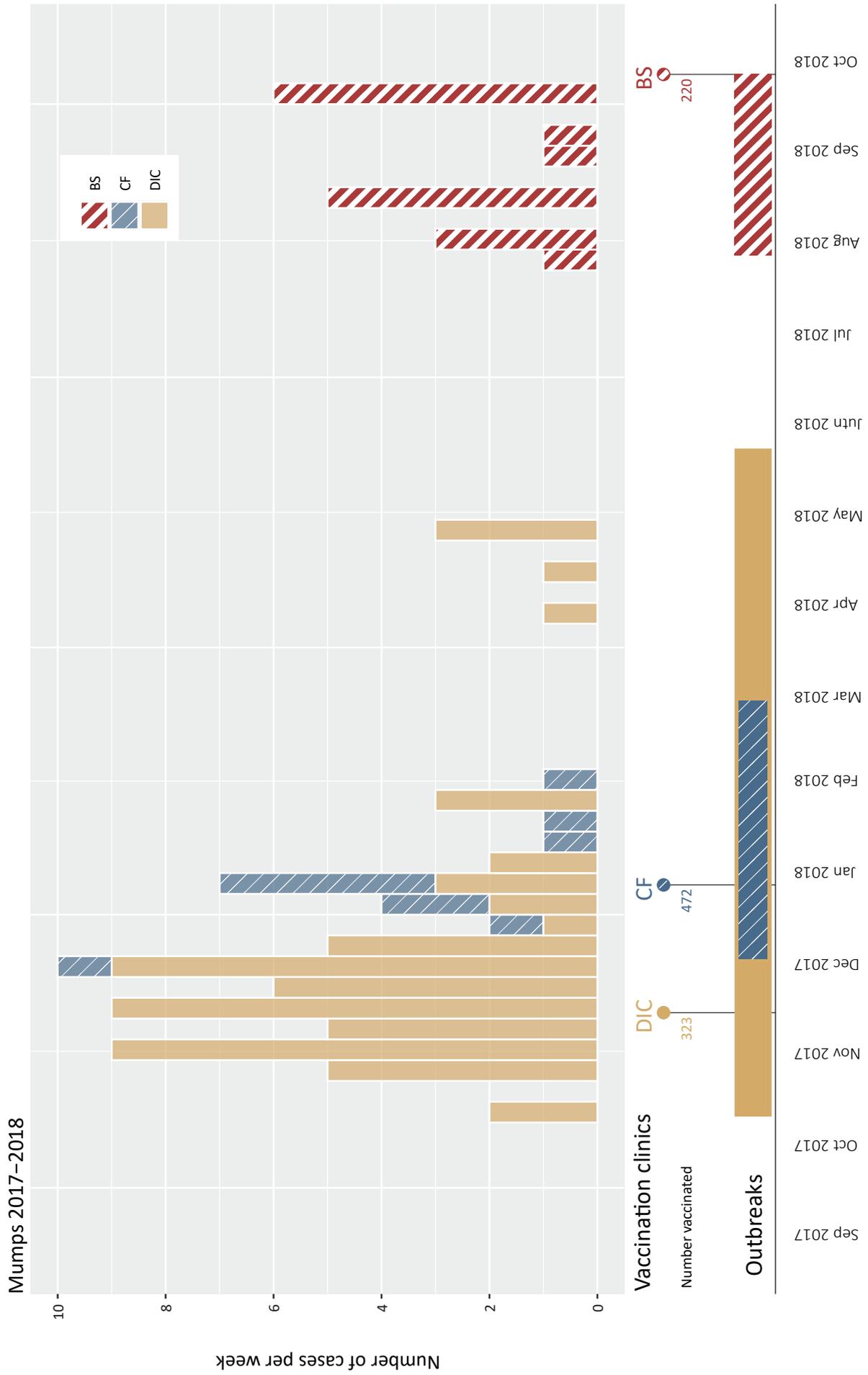
MMR immunisation status among outbreak cases and controls

Seventy-four cases (79.6%) had received two documented doses of MMR vaccine, compared with 141/168 (83.9%) in the control population. Fourteen cases (15.1%) and 16 controls (9.6%) were partially vaccinated with one dose of MMR vaccine; five cases (5.4%) and 11 controls (6.5%) had no evidence of receiving a mumps-containing vaccine (Table 3).

i) Time interval between dose 1 and dose 2

The mean interval between dose 1 and dose 2 of the MMR vaccine for the cases was 3.0 years, versus 4.1 years for the controls ($p = 0.01$). For those born before 1 March 2000 (prior to the introduction of the two-dose MMR vaccination catch-up program in Australia), the mean interval between the first and second dose of MMR vaccine was significantly less ($p = 0.0003$) for cases (3.6 years) than for controls (5.9 years).

Figure 1: Epidemic curve of the mumps outbreak in three different communities^a



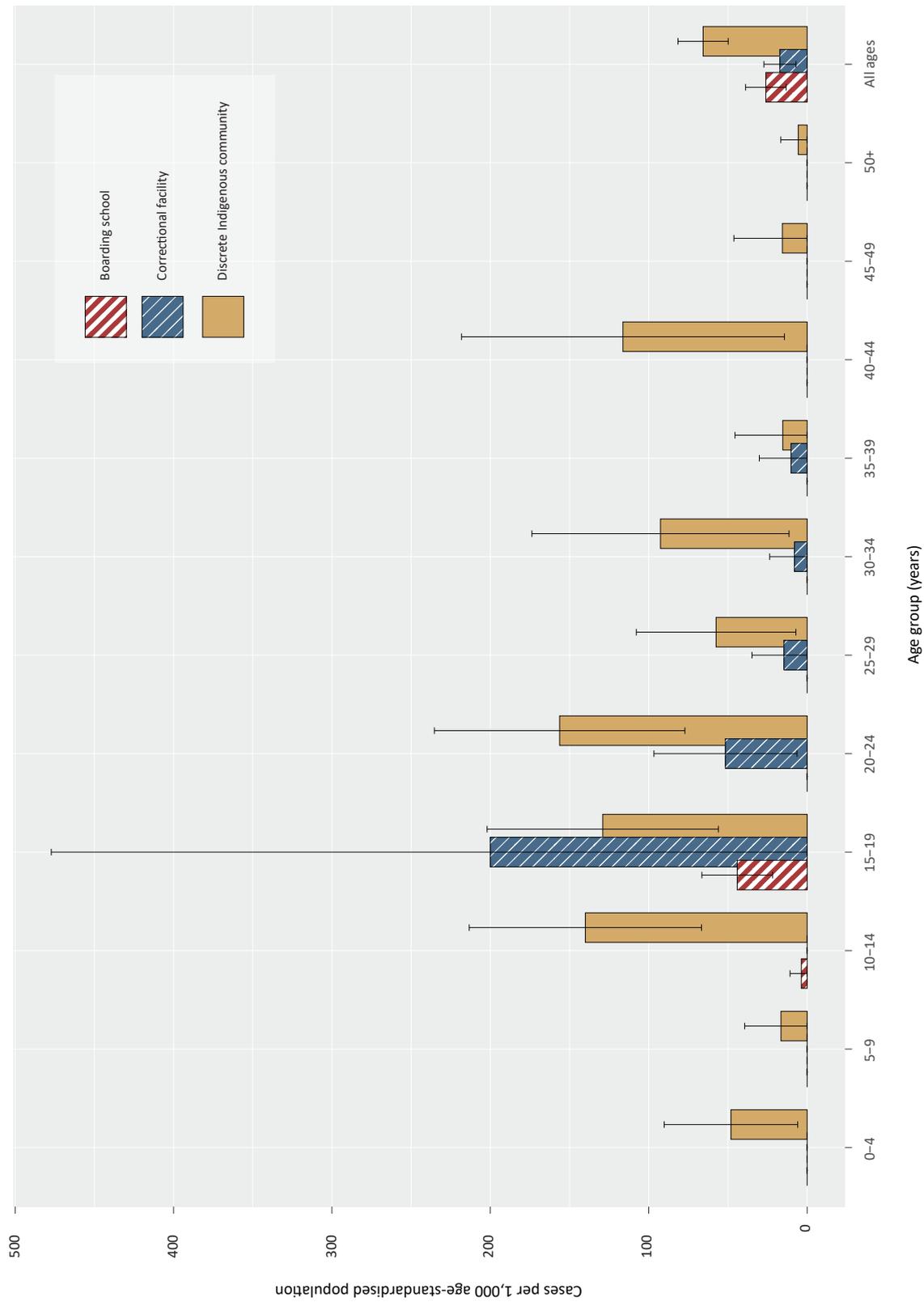
^a DIC: discrete Indigenous community; CF: correctional facility; BS: boarding school.

Table 2: Age-specific mumps attack rates (per 1,000 population) for all outbreak cases (n=93)

Age group	Cluster												All three outbreaks combined		
	Discrete indigenous community			Correctional facility			Boarding school			Total cases	Total denominator population	Attack rate per 1,000 population (95% CI)			
	n = cases	N = total population	Attack rate per 1,000 population (95% CI)	n = cases	N = total population	Attack rate per 1,000 population (95% CI)	n = cases	N = total population	Attack rate per 1,000 population (95% CI)						
0-4	5	104	48.1 (7.0-89.2)	0	0	-	0	0	-	0	0	5	104	48.1 (7.0-89.2)	
5-9	2	121	16.5 (0-39.2)	0	0	-	0	0	-	0	0	2	121	16.5 (0-39.2)	
10-14	14	100	140.0 (72.0-208.0)	0	0	-	1	274	3.6 (0-10.8)	1	274	15	374	40.1 (20.2-60.0)	
15-19	12	93	129.0 (60.9-197.7)	2	10	200.0 (25.2-556.1)	15	340	44.1 (24.9-71.7)	15	340	29	443	65.5 (42.4-88.5)	
20-24	15	96	156.3 (83.6-228.9)	5	97	51.5 (7.5-95.5)	NA ^a	NA	-	NA ^a	NA	20	193	103.6 (60.6-146.6)	
25-29	5	87	57.5 (8.6-106.4)	2	137	14.6 (0-34.7)	NA	NA	-	NA	NA	7	224	31.3 (8.5-54.0)	
30-34	5	54	92.6 (15.3-169.9)	1	125	8.0 (0-23.6)	NA	NA	-	NA	NA	6	179	33.5 (7.2-59.9)	
35-39	1	65	15.4 (0-45.3)	1	98	10.2 (0-30.1)	NA	NA	-	NA	NA	2	163	12.3 (0-29.2)	
40-44	5	43	116.3 (20.5-212.1)	0	62	0	NA	NA	-	NA	NA	5	105	47.6 (6.9-88.4)	
45-49	1	64	15.6 (0-46.0)	0	55	0	NA	NA	-	NA	NA	1	119	1.6 (0-9.0)	
50+	1	178	5.6 (0-16.6)	0	57	0	NA	NA	-	NA	NA	1	235	4.3 (0-12.6)	
Total	66	1,005	65.7 (50.4-81.0)	11	641	17.2 (7.1-27.2)	16	614	26.1 (15.0-42.0)	93	2,260	41.6 (33.3-49.8)			

a NA: not applicable.

Figure 2: Age-specific mumps attack rates during outbreaks in three different settings (a boarding school, a correctional facility and a discrete Indigenous community)^a



^a Error bars indicate the 95% confidence interval.

Table 3: Result from matched case-control study regarding MMR vaccination status and timeliness

MMR vaccination status among cases and controls					
Traits	Cases (N = 93)		Controls (N = 168)		p-value
MMR vaccination status	n	%	n	%	
Not vaccinated	5	6.4	11	6.5	0.9 ^a
1 dose only	14	14.9	16	9.5	
2 doses	74	78.7	141	84.0	
Time interval between doses 1 and 2 for those who received two doses of MMR vaccine (years)					
Traits	Cases (n = 74) ^b		Controls (n = 141) ^b		p-value
All	3.0 (1.4)		4.1 (3.9)		0.01
Persons born prior to 1 March 2000	3.6 (1.8)		5.9 (5.2)		0.0003
Persons born after 1 March 2000	2.6 (1.1)		2.9 (1.9)		0.2
Time interval from most recent MMR vaccine (i.e. either dose 1 or dose 2) to infection (years)					
Traits	Cases (n = 74) ^b		Controls (n = 141) ^{b,c}		p-value
Discrete Indigenous community	12.1 (0.7)		11.1 (0.5)		0.13
Correctional facility	12.8 (0.3)		11.9 (0.2)		0.01
Boarding school	16.1 (1.3)		8.1 (1.8)		0.004
All	12.7 (0.5)		10.9 (0.4)		0.01

a Comparison includes only individuals with zero, one or two doses.

b Mean (standard deviation).

c Interval from most recent MMR vaccine to outbreak midpoint.

ii) Time interval from last dose of MMR vaccine

The respective mean durations between the last MMR vaccination and the date of test for the correctional facility cases, and for cases within the boarding school, were significantly greater than the mean durations between the last MMR dose and the local outbreak midpoint in the corresponding control populations ($p = 0.01$ and $p = 0.004$ respectively) (Table 3). There was no significant difference found in mean duration among cases and controls for the discrete Indigenous community ($p = 0.13$).

Public health measures and infection prevention and control measures

During the mumps outbreak within the discrete Indigenous community, the correctional facility and the boarding school, outbreak investigation and control measures were led by Central Queensland Public Health Unit (CQPHU) in collaboration with key stakeholders. These measures included community education on disease transmission, infection prevention and control advice including use of personal protective equipment (PPE) where appropriate, case isolation, testing on clinical suspicion, hand hygiene, refraining from sharing food, drinks, cigarettes and utensils, environmental cleaning, cough etiquette and vaccination of household/household-like contacts.

Table 4. Vaccination timeline, vaccination coverage and pre- and post- additional vaccination attack rate

Outbreak setting	Duration of mass immunisation program	Population targeted for an additional MMR dose	Number of target population immunised with an additional MMR dose	Proportion of target population vaccinated	Pre-additional vaccination attack rate per 1,000 population (95% CI)	Post-additional vaccination attack rate per 1,000 population (95% CI)
Discrete Indigenous community	21 Nov 2017 – 29 Nov 2017	911 ^{ab}	323	35.4%	54.9 (41.0–71.8)	16.8 (8.6–24.9)
Correctional facility	21 Dec 2017 – 11 Jan 2018	641 ^c	472	73.6%	15.6 (7.5–28.5)	1.6 (0.0–4.7)
Boarding school	26 Aug 2018 – 11 Oct 2018	614 ^a	220	35.8%	16.3 (7.5–29.7)	9.9 (2.0–17.7)
Overall total	21 Nov 2017 – 11 Oct 2018	2,166	1,015	46.8%	31.0 (24.2–39.0)	10.6 (6.7–15.9)

a An additional dose of MMR vaccine was offered to those born between 1966 and 2009 (i.e. aged between 8 and 52 years).

b Australian Bureau of Statistics 2017 Census data include age groups of persons 5 to 54 years within the discrete Indigenous community.

c An additional dose of MMR vaccine was offered to all inmates.

During the outbreak within the correctional facility, asymptomatic inmates were able to attend scheduled appointments (e.g. court appearances); however, transfers to other correctional facilities were suspended for 25 days (one maximum incubation period) after the last confirmed case. To minimise the risk of exposure to the correctional facility population, admissions and transfers to unaffected units within the facility were minimised and were permitted only for inmates who had a previous confirmed mumps infection during the outbreak and those who had received a minimum of two doses of mumps-containing vaccine, with the last dose administered at least two weeks prior to transfer.

To minimise the risk of exposure to the boarding school population, symptomatic and confirmed cases were excluded from school activities and from the boarding houses (if a boarding student) and were either sent home or isolated in the school health clinic until non-infectious.

Mass immunisation campaign with an additional dose MMR vaccine

In response to these outbreaks, the CQPHU initiated a mass immunisation campaign targeting specific populations (Table 4):

- people aged between 8 and 52 years (i.e. people born between 1966 and 2009 inclusive) in the Indigenous community;
- students at the boarding school; and
- the entire correctional facility population.

These groups were chosen to narrow down the number within the target population requiring an additional dose of MMR vaccine, since the majority in this group (particularly those born before 1998) were too old to have reliably received a second dose of MMR vaccine during the 1998 Australian Measles Control Campaign and too young to have had a mumps infection.¹⁶

The discrete Indigenous community outbreak lasted eight months, during which a targeted seven-day mass vaccination program delivered 323 doses which commenced four weeks after the onset of the outbreak. The correctional facility outbreak lasted three months, during which a two-week mass vaccination campaign delivered 472 doses commencing 3.5 weeks after the onset of the outbreak. The final outbreak at the boarding school lasted three months, during which a targeted mass vaccination delivered 220 doses commencing 2.5 weeks after the onset of the outbreak.

Table 4 demonstrates mumps attack rates in each of these outbreaks both before and after the mass immunisation campaign.

Discussion

To the best of our knowledge this is the first reported mumps outbreak investigation, among high-risk communities within Australia, demonstrating the impact of an additional dose of MMR vaccine as part of a public health response to mumps outbreaks in various settings.

Prior to these outbreaks in Central Queensland, there had been ongoing outbreaks of mumps in Northern and North-Western Queensland since early 2017. These may be linked to outbreaks in Western Australia^{4,17} and the Northern Territory, as there is movement between Indigenous communities.¹⁰ In addition, several countries such as France,⁸ the United States of America,^{7,8} Canada¹⁸ and various countries within Europe¹⁹ have reported mumps outbreaks in highly-vaccinated populations with increasing frequency. Possible factors such as waning vaccine-induced immunity,^{6,8} mismatch between the wild type and the vaccine virus genotypes leading to immune escape,^{20,21} and social conditions such as high-density living settings may contribute to more intense exposure and a high force of infection.⁷

The coverage and timeliness of vaccination among Indigenous children is reported to be suboptimal.^{22,23} Indigenous children experience

higher notification rates for vaccine-preventable diseases than do non-Indigenous children, highlighting the importance of timely vaccination and early individual protection as contributors to herd immunity.^{22,24} In the correctional facility and boarding school outbreaks, the increased duration between MMR dose one and two, or the shorter interval between the last MMR dose and the outbreak, in the controls would suggest increased protection (see table 3). However, we are guarded in making a strong conclusion from these findings due to the potential for healthy user bias in the controls, as we selected our controls from the discrete Indigenous community based on recent influenza vaccination. Other controls were selected from the unaffected student population in the boarding school and from the prisoners in the correctional facility.

In Australia, since 2013, two mumps-containing vaccinations have been recommended at 12 and 18 months of age (i.e. dose 1 MMR and dose 2 MMRV).¹⁴ However, among cases the mean time period between dose 1 and dose 2 of MMR vaccine for the cases was 3.0 years. Among controls, the time interval between MMR dose 1 and dose 2 was significantly longer ($p = 0.01$), at 4.1 years. Since, for those born after 1 March 2000, the interval between dose 1 and dose 2 should be six months, this suggests vaccine timeliness is an area of concern.

Whilst there is no significant difference between cases and controls for the cohort born after 1 March 2000, further investigation is required to determine the impact of MMR vaccination timeliness on antibody response, which would provide long-term protection. Although we have demonstrated a high proportion of immunised cases and controls, the timeliness of vaccinations is an important issue which needs further exploration to ensure there is an optimum gap between dose 1 and dose 2.

There is emerging international evidence, supporting the Centres for Disease Control and Prevention Advisory Committee on Immunization Practices, on the use of an additional dose of MMR during outbreaks.^{12,25–27}

We found that, in large high-density living situations such as a correctional facility or boarding school, vaccinating a minimum of 1/3 of the target population during an outbreak significantly reduces the attack rate, assisting in containment.

Rubin and colleagues²⁸ have reported that the duration since last vaccination impacts on the ability of a MMR immunisation to effectively neutralise an outbreak of mumps genotype G compared to the vaccine strain. In the present study, the reduction in attack rate was found significant only in the discrete Indigenous community where the rate was substantially higher than other groups. Our study findings (consistent with a previous outbreak in western Australia)¹⁷ provide an indication of future exploration whether a second dose of MMR vaccine really provides long-term protection to the Indigenous people or whether they need a further vaccination with a third dose of MMR vaccine for prevention and control of mumps outbreaks. Earlier studies^{29,30} did not report any serious adverse events following a third dose of MMR vaccine, findings consistent with our mass immunisation response. The combined strategies of infection prevention and control, case isolation, and vaccination formed an effective public health response.

Limitations

There are several limitations in this study. As an observational study, often the selection of controls can be biased, since we cannot verify that the controls had the same exposure risk as our cases. The retrospective case control nature of the study was inherent with limitations in determining the impact of vaccinations. We did not include confirmed cases with positive mumps IgM and clinical features consistent with mumps, which might have introduced underestimation of cases in this study. Although 78.7% of our cases had two documented doses of MMR vaccine prior to infection, the remainder of the population may have had either one dose or none, and thus we were potentially delivering the first or second dose of MMR to

some individuals. Additionally, we were able to perform genotyping on only one specimen among the laboratory-confirmed cases. It is acknowledged there might be some missing documentation on previous immunisation histories both in VIVAS and AIR, as neither of these vaccination registers is complete (e.g. VIVAS is a Queensland only childhood vaccination database). Whilst Indigenous status is confirmed as part of routine data collection by a public health nurse during case investigation, however, there may still be a possibility of under-reporting. Males may also be over-represented as the correctional facility and boarding school are males only. Lastly, our findings are generalisable only to those living in high-density living conditions and among the Indigenous population.

Conclusion

Mumps outbreaks in highly vaccinated populations can be safely and effectively controlled by an additional dose of the MMR vaccine. Emphasis should be given to identifying under-vaccinated high-risk populations so that timeliness for vaccination can be ensured. Further studies should include the effect of vaccination timeliness on vaccine effectiveness and waning immunity. Additionally, public health units should focus on combined strategies of infection prevention and control, case isolation and mass immunisation campaigns among target populations as early as possible for an effective public health response.

Declaration of competing interest

The authors declare they have no known competing financial interests or personal relationships that could have appeared to influence this reported work.

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