

## Prevalence of antibodies against measles, mumps and rubella in the childhood population in Singapore, 2008–2010

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### SUMMARY

We undertook a national paediatric seroprevalence survey of measles, mumps and rubella (MMR) in Singapore to assess the impact of the national childhood immunization programme against these three diseases after introduction of the trivalent MMR vaccine in 1990. The survey involved 1200 residual sera of Singapore residents aged 1–17 years collected from two hospitals between 2008 and 2010. The overall prevalence of antibodies against measles, mumps and rubella was 83·1% [95% confidence interval (CI) 80·9–85·1], 71·8% (95% CI 69·1–74·2) and 88·5% (95% CI 86·6–90·2), respectively. For all three diseases, the lowest prevalence was in children aged 1 year (47·8–62·3%). The seroprevalence of the vaccinated children declined over time. The national MMR immunization programme is effective in raising the herd immunity of the childhood population, although certain age groups are more susceptible to infection, in particular, those who are not eligible for vaccination at age <15 months.

**Key words:** MMR vaccination, paediatrics, prevalence of disease.

### INTRODUCTION

Singapore has a comprehensive national childhood immunization programme (NCIP). The first comprehensive review of the immunization programme was conducted by the Expert Committee on Immunization (ECI), Ministry of Health (MoH) in 1975, followed by another review in 1982 [1]. Based on the recommendations of the first review, measles immunization for infants was included in the NCIP in

October 1976, followed by rubella immunization for pre-adolescent female primary school leavers (11–12 years) in November 1976 to eliminate congenital rubella syndrome (CRS) [2]. The rubella immunization programme was extended to male primary school leavers and national service recruits in April 1982 as periodic outbreaks of rubella with high sickness/absenteeism in national servicemen had affected the training schedules [3]. Owing to the low immunization coverage, outbreaks of measles continued to occur and measles immunization was made compulsory under the Infectious Diseases Act in 1985 [1].

In January 1990, the trivalent measles, mumps and rubella (MMR) vaccine was introduced into the

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NCIP with one dose of the vaccine given to children at age 12 months [4]. Following a small resurgence of measles in 1992/1993 and a larger one in 1997, a 'catch-up' measles immunization programme for secondary and pre-university students aged 12–18 years, using the MMR vaccine, was implemented between July and November 1997, and a two-dose schedule (with the first dose given at between 1 and 2 years and the second dose at 11–12 years) was introduced in 1998 [5]. The monovalent rubella vaccine given to both male and female primary school leavers continued until it was replaced by the second dose of MMR vaccine in January 1998. In 2008, the second dose of the MMR vaccine was brought forward from primary 6 (11–12 years) to primary 1 (6–7 years) and 'catch-up' vaccination was carried out for students from primary 2 to primary 5.

The National Immunization Registry (NIR), Health Promotion Board (HPB), is responsible for collecting and maintaining accurate, complete and current vaccination records of all children from birth to age 18 years [6]. Although only notifications of diphtheria and measles immunization are mandatory under the Infectious Diseases Act, both public and private healthcare institutions routinely notify NIR of all immunizations that are administered to pre-school children. The School Health Services keeps track of records of all immunizations performed in schools and at the Immunization Clinic in the Student Health Centre, HPB. Between 1994 and 2010, the coverage of the first dose of MMR vaccine in 2-year-old children ranged from 93% to 97% [7]. Between 2008 and 2010, the coverage of the second dose ranged from 92% to 94% in primary school entrants, and remained high at 95% in children aged 11–12 years.

Periodic seroprevalence surveys of the general population are conducted to monitor the changing levels of immunity against various vaccine-preventable diseases. The first survey was conducted in 1989–1990 [8] just prior to the introduction of the trivalent MMR vaccine into the NCIP, the second in 1993 [9], the third in 1998 [10] and the fourth in 2004 [11]. In the first three surveys, blood samples were collected from healthy children and adults aged between 6 months and >45 years at designated government polyclinics after consent had been obtained. The fourth survey was based on residual blood samples obtained from the general population aged 18–74 years during the National Health Survey [12] conducted between September and December 2004.

We undertook another national seroprevalence survey from 2008 to 2010 to assess the impact of the NCIP against MMR about two decades after introduction of the trivalent MMR vaccine.

## MATERIALS AND METHODS

### Survey design

The national paediatric seroprevalence survey (NPSS) was conducted between August 2008 and July 2010. Residual sera of Singapore citizens and permanent residents of the three major ethnic groups (Chinese, Malay, Indian) aged between 1 and 17 years attending inpatient services or day surgery were collected prospectively following completion of routine biochemical investigations by the diagnostic laboratories in Kandang Kerbau Women's and Children's Hospital and National University Hospital, the two main paediatric hospitals in the public sector. To minimize selection bias, sera of children known to be immunocompromised, on immunosuppressive therapy, or who had been diagnosed with infectious diseases such as measles, mumps, rubella, chickenpox, diphtheria, pertussis, poliomyelitis, hepatitis B, dengue or hand, foot and mouth disease were excluded.

The survey was conducted in accordance with Section 7 of the Infectious Diseases Act which provides for the use of residual blood samples for the purpose of public health surveillance. Vaccination history of the subjects was obtained from the NIR.

On the premise of an anticipated antibody prevalence of at least 80% for MMR in each of the age groups (1–6, 7–12, 13–17 years), the minimum sample size required for each age group was 385, with a confidence level of 95% and a relative precision of 5%. A total of 1200 serum samples were collected, comprising 400 in each of the three age groups. The age-ethnic distribution of the subjects by gender is comparable to that of the Singapore resident population aged 1–17 years in 2009 (Table 1).

### Laboratory methods

The IgG antibody against measles and mumps was determined using enzyme immunoassay (Euroimmun kit, Germany). A titre of  $\geq 250$  mIU/ml was considered positive for measles, while a titre of  $\geq 20$  RU/ml was considered positive for mumps. The rubella IgG antibody was measured using chemiluminescent immunoassay (Abbott Architect, Abbott

Table 1. Age-ethnic distribution (%) of the 1200 subjects aged 1–17 years by gender, Singapore, 2008–2010

Demographics	Age group (years)			
	1–6 (n=400)	7–12 (n=400)	13–17 (n=400)	1–17 (n=1200)
Male	39.0	34.2	26.7	100.0
Chinese	26.4	25.0	17.3	68.7
Malay	9.8	7.2	6.2	23.1
Indian	2.9	2.1	3.3	8.2
Female	27.9	32.5	39.6	100.0
Chinese	18.0	22.6	22.6	63.1
Malay	6.2	6.5	11.0	23.7
Indian	3.7	3.4	6.0	13.1

Laboratories, USA). A titre of  $\geq 10$  IU/ml was considered positive.

### Statistical analysis

The 95% confidence intervals (CI) for binomial proportions were computed using Wilson's method [13]. Differences in proportion between two groups were compared using two-sample independent  $z$  tests, with standard error estimated using pooled value of the independent proportions. The Mantel–Haenszel  $\chi^2$  test for trend was used to evaluate the difference in seroprevalence in the three age groups. Age-standardized seroprevalence of MMR was calculated by the direct method, using the 2010 census resident population as the standard. Differences between the age-standardized seroprevalence by ethnic group and gender were computed and tested for statistical significance using the  $z$  test [14]. Statistical analyses were performed using SPSS software, version 19 (IBM, USA).  $P$  values  $< 0.05$  were considered statistically significant.

## RESULTS

### Seroprevalence of measles

The overall prevalence of antibody against measles in subjects aged 1–17 years was 83.1% (95% CI 80.9–85.1) (Table 2). The seroprevalence in adolescents aged 13–17 years (75.8%) was significantly lower than in the two younger age groups ( $P=0.005$ ), while the seroprevalence in those aged 1–6 years (84.3%) was also significantly lower than in the 7–12 years group (89.3%) ( $P<0.05$ ). Seroprevalence

increased from 62.3% in 1-year-olds to between 83.3% and 95.6% in children aged 2–13 years, followed by a dip to 64.1% in those aged 15 years before it increased again to 83.3% in adolescents aged 17 years (Fig. 1).

There was no significant difference in seroprevalence by gender (84.1% in males vs. 82.1% in females,  $P=0.372$ ). The seroprevalence of Malays (77.9%) was significantly lower compared to that of Chinese ( $P=0.008$ ), while it was similar to that of Indians ( $P=0.176$ ). The seroprevalence of Chinese (84.8%) and Indians (83.7%) was similar ( $P=0.750$ ). The difference in age-standardized seroprevalence of Chinese and Malays was also significant ( $P=0.016$ ).

### Seroprevalence of mumps

The overall prevalence of antibody to mumps was 71.8% (95% CI 69.1–74.2) (Table 3). Seroprevalence increased significantly with age from 61.5% in the 1–6 years group to 73.3% in the 7–12 years group and 80.5% in adolescents aged 13–17 years (test for trend,  $P<0.0005$ ). Seroprevalence increased from 47.8% in 1-year-olds to between 55.2% and 71.1% in children aged 2–6 years, followed by a dip to 64.5% in those aged 10 years before it increased again to between 76.7% and 86.7% in adolescents aged 12–17 years. Mumps seroprevalence was lower than that of measles and rubella in children aged 1–13 years (Fig. 1).

The prevalence of mumps antibody was 70.2% for males and 73.2% for females, with no significant difference detected ( $P=0.249$ ). However, there were significant differences in seroprevalence by ethnic group ( $P<0.0005$ ). The prevalence of Malays

Table 2. Age-specific prevalence (%) of measles antibody (with 95% confidence intervals) by gender and ethnic group

Demographics	Age group (years)			
	1–6 (n=400)	7–12 (n=400)	13–17 (n=400)	1–17 (n=1200)
All	84.3 (80.4–87.5)	89.3 (85.8–91.9)	75.8 (71.3–79.7)	83.1 (80.9–85.1)
Gender				
Male	85.5 (80.4–89.5)	89.5 (84.5–93.0)	75.0 (67.7–81.1)	84.1 (80.9–86.8)
Female	86.4 (81.8–90.0)	89.0 (83.9–92.6)	75.4 (69.6–80.4)	82.1 (78.9–85.0)
Ethnic group				
Chinese	82.6 (76.2–87.5)	90.2 (86.2–93.1)	76.7 (70.9–81.6)	84.8 (82.1–87.1)
Malay	77.9 (68.6–85.1)	85.4 (76.1–91.4)	72.1 (62.8–79.8)	77.9 (72.7–82.4)
Indian	85.0 (70.9–92.9)	100.0 (89.6–100.0)	78.6 (66.2–87.3)	83.7 (76.4–89.1)

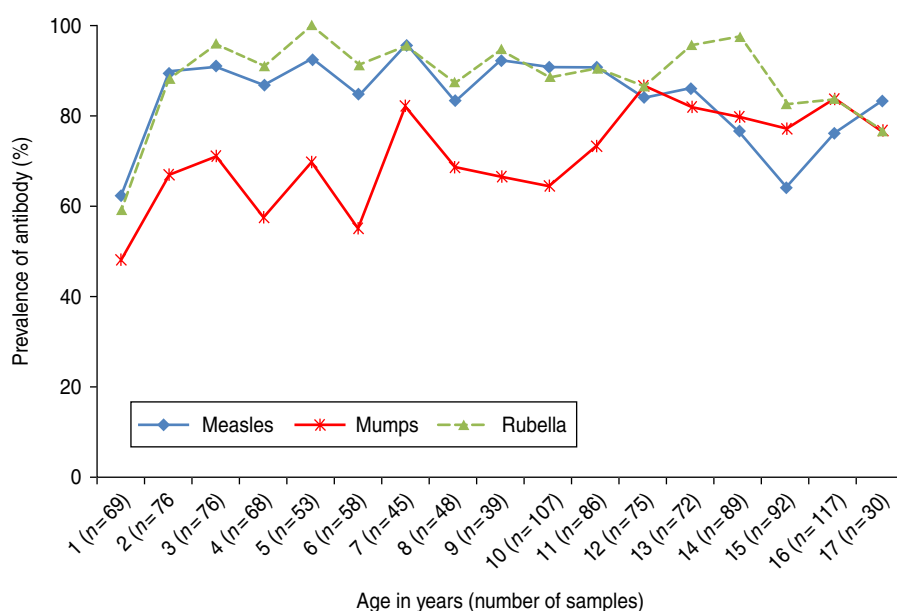


Fig. 1 [colour online] Prevalence of antibody against measles, mumps and rubella by age.

(59.4%) was significantly lower compared to Chinese ( $P < 0.005$ ) and Indians ( $P < 0.031$ ). Similar differences were observed in age-standardized seroprevalence of Malays compared to Chinese ( $P < 0.005$ ) and Indians ( $P = 0.008$ ). The prevalence of Chinese (76.3%) and Indians (70.5%) was similar ( $P = 0.156$ ).

### Seroprevalence of rubella

The overall prevalence of antibody against rubella was 88.5% (95% CI 86.6–90.2) (Table 4). Seroprevalence was not significantly different in the three age groups: 1–6 years (87.3%), 7–12 years (90.0%) and 13–17 years (88.3%). Seroprevalence increased from 59.4% in 1-year-olds to about 92.6% in children aged 2–14 years, followed by a dip to about 81.0% in adolescents aged 15–17 years (Fig. 1).

No significant difference by gender was observed (88.9% in males vs. 88.1% in females,  $P = 0.696$ ). The seroprevalence of Malays (82.9%) was significantly lower compared to Chinese ( $P < 0.005$ ), while it was similar to that of Indians ( $P = 0.102$ ). The age-standardized seroprevalence of Malays was also significantly lower compared to that of Chinese ( $P = 0.001$ ). The seroprevalence of Chinese and Indians was similar at 90.4% and 89.1%, respectively ( $P = 0.662$ ).

### Seroprevalence in subjects vaccinated against MMR

Of the 1200 subjects, 92.2% had received at least one dose of vaccine against measles, 91.7% against mumps and 91.8% against rubella, prior to the collection of their residual samples for the NPSS. These subjects were either vaccinated with the monovalent

Table 3. Age-specific prevalence (%) of mumps antibody (with 95% confidence intervals) by gender and ethnic group

Demographics	Age group (years)			
	1-6 (n=400)	7-12 (n=400)	13-17 (n=400)	1-17 (n=1200)
All	61.5 (56.6-66.1)	73.3 (68.7-77.4)	80.5 (76.3-84.1)	71.8 (69.1-74.2)
Gender				
Male	61.0 (54.5-67.1)	73.5 (67.0-79.1)	79.5 (72.5-85.1)	70.2 (66.4-73.8)
Female	62.2 (54.8-69.1)	73.0 (66.5-78.7)	81.1 (75.8-85.6)	73.2 (69.6-76.6)
Ethnic group				
Chinese	67.2 (61.3-72.5)	76.5 (71.2-81.0)	86.3 (81.3-90.0)	76.3 (73.2-79.2)
Malay	47.4 (37.6-57.3)	58.5 (47.7-68.6)	71.2 (61.8-79.0)	59.4 (53.6-65.0)
Indian	57.5 (42.2-71.5)	81.8 (65.6-91.4)	73.2 (60.4-83.0)	70.5 (62.2-77.7)

Table 4. Age-specific prevalence (%) of rubella antibody (with 95% confidence intervals) by gender and ethnic group

Demographics	Age group (years)			
	1-6 (n=400)	7-12 (n=400)	13-17 (n=400)	1-17 (n=1200)
All	87.3 (83.6-90.2)	90.0 (86.7-92.6)	88.3 (84.7-91.0)	88.5 (86.6-90.2)
Gender				
Male	87.3 (82.3-91.0)	91.0 (86.2-94.2)	88.5 (82.5-92.6)	88.9 (86.1-91.2)
Female	87.2 (81.4-91.4)	89.0 (83.9-92.6)	88.1 (83.5-91.6)	88.1 (85.4-90.5)
Ethnic group				
Chinese	90.2 (86.0-93.2)	91.2 (87.4-94.0)	89.6 (85.1-92.8)	90.4 (88.1-92.2)
Malay	77.9 (68.6-85.1)	84.1 (74.7-90.5)	86.5 (78.7-91.8)	82.9 (78.1-86.9)
Indian	90.0 (76.9-96.0)	93.9 (80.4-98.3)	85.7 (74.3-92.6)	89.1 (82.6-93.4)

vaccine or with the combination MMR or MMR varicella vaccines. The prevalence of antibody against MMR were all significantly higher in subjects with a past history of vaccination compared to those with an unknown or no history of vaccination ( $P < 0.005$ ). For measles, it was 86.5% vs. 42.6%; for mumps it was 75.3% vs. 33.0%; and for rubella it was 92.9% vs. 39.4%.

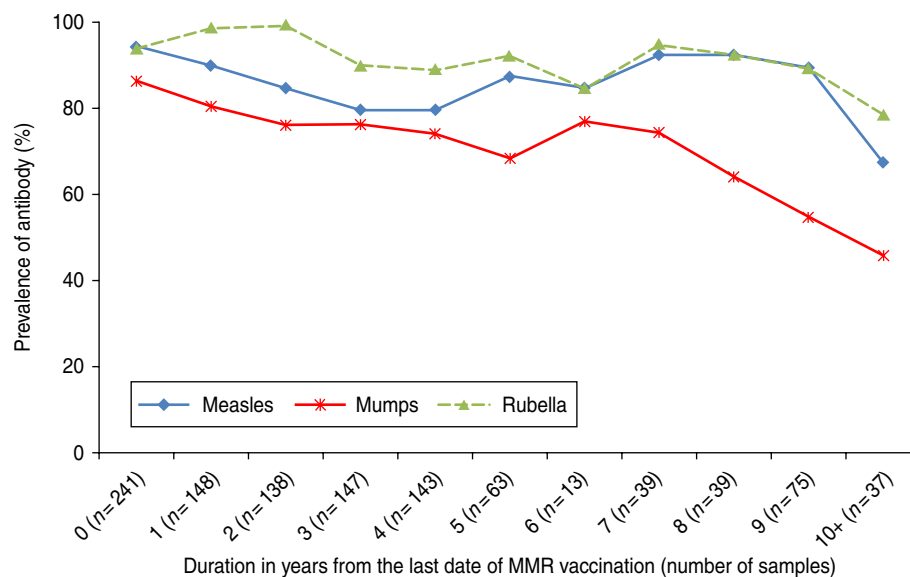
Of 1106 subjects with a past history of vaccination against measles, the prevalence of antibody against measles was significantly higher in children who had received one dose (90.3%) of vaccine compared to those receiving two doses (82.8%) ( $P < 0.005$ ). Of 1100 subjects with a past history of vaccination against mumps, the prevalence of antibody against mumps was significantly higher in children who had received two doses (86.7%) of vaccine compared to those receiving only one dose (64.1%) ( $P < 0.005$ ). Of 1101 subjects with a past history of vaccination against rubella, there was no significant difference in the prevalence of antibody against rubella in children who had received one dose of vaccine compared

to those receiving two doses (93.4% vs. 92.4%) ( $P = 0.552$ ).

A total of 1083 (90.3%) subjects were known to have received only the MMR vaccine. Of these subjects, 544 (50.2%) had only received one dose of MMR vaccine, while the others who had received two doses were aged  $\geq 6$  years. The seroprevalence of all of MMR was lowest in those who were last vaccinated  $\geq 10$  years ago. For measles, it declined from 89.9% at 1 year post-vaccination, to 79.6% at 3-4 years post-vaccination, and increased to between 84.6% and 92.3% at 5-9 years post-vaccination, before falling to 67.6% at  $\geq 10$  years post-vaccination (Fig. 2).

The prevalence of antibody against mumps decreased significantly since the date of the last MMR vaccination ( $P < 0.0005$ ). It decreased from 74.4% at  $\geq 7$  years post-vaccination to  $< 50\%$  at  $\geq 10$  years post-vaccination.

The post-vaccination seroprevalence of rubella was highest compared to measles and mumps. It was between 88.8% and 99.3% within 9 years



**Fig. 2** [colour online]. Prevalence of antibody against measles, mumps and rubella by duration (in years) from the last date of MMR vaccination.

post-vaccination but declined to 78.4% at  $\geq 10$  years post-vaccination.

## DISCUSSION

The proportion of the study population with vaccination records was consistent with that of the national coverage rate. The considerably high seroprevalence of MMR in children aged 1–17 years between 2008 and 2010 reflects the effectiveness of the national MMR immunization programme in raising the herd immunity of the childhood population. The absence of large outbreaks ( $> 10$  cases) of MMR in Singapore residents since 2000 also provides good evidence that there is indeed herd immunity in the population.

About 8% of the subjects had not received any MMR vaccine prior to the collection of their residual samples for the NPSS. Of these subjects with an unknown or no history of vaccination, seroprevalence was 42.6% for measles, 33.0% for mumps and 39.4% for rubella. It is likely that they acquired the antibody by natural infection through close contact with other infected persons.

### Measles

The overall prevalence of measles IgG antibody was 83.1% (95% CI 80.9–85.1), which was within the lower range of the estimated threshold ranging from 83% to 94% required for herd immunity [15].

The serological findings of the childhood population surveyed with MMR vaccination coverage of 92% are as expected, as the median vaccine effectiveness (VE) is 92.5% for a single dose of measles vaccine administered at age  $\geq 12$  months [16].

Measles seroprevalence was 89.1% in children aged 2–4 years, and 89.3% in the 5–9 years group. This is comparable to that in Australia (89.2% in children aged 2–4 years, and 92.0% in the 5–9 years group in 2002) [17], and England and Wales (81.1% in children aged 2–4 years, and 89.8% in the 5–9 years group in 2000) [17]. The seroprevalence of 81.0% in older children aged 10–17 years was lower compared to 92.1% in Australia and 93.1% in England and Wales. Seroprevalence in children aged 6–10 years (89.2%) is similar to that in New Zealand (92.9% in 2009) [18]. However, in older children aged 11–15 years, it was lower at 79.7% in Singapore compared to 91.9% in New Zealand.

Of the three major ethnic groups in Singapore, measles seroprevalence in Malays was significantly lower than that of Chinese and Indians. This was not due to differences in vaccination coverage as measles vaccination is compulsory by law. Ethnic differences related to different allele frequencies in immune response genes may account for potential differences in immune response and racial differences have been noted in the antibody response to measles vaccine or the measles component of MMR vaccine in other studies [19, 20].

Measles seroprevalence has increased significantly from 64.3% in children aged 1–14 years in 1998 [21] when the two-dose schedule was first introduced, to 85.7% in 2008–2010 ( $P < 0.005$ ). In adolescents aged 13–17 years, seroprevalence (75.8%) was significantly lower than that of the two younger age groups (84.3% in the 1–6 years group and 89.3% in the 7–12 years group), which might suggest waning vaccine-induced immunity. This was also observed in Taiwan where the vaccination coverage rate was >95% for more than a decade [22]. In Taiwanese aged 2–25 years who had received at least two doses of measles-containing vaccine, measles seroprevalence decreased significantly from 94.5% at 2 years to 50.6% at 21–25 years ( $P < 0.0001$ ). While measles antibody levels induced by vaccination decline over time and may become undetectable, immunological memory persists [23], and most vaccinated persons produce a measles virus-specific immune response without clinical symptoms after exposure to the virus.

In 2003, the goal to eliminate measles from the WHO Western Pacific Region was formally declared [24]. In 2005, a target for the elimination of the transmission of endemic measles by year 2012 was established [25]. Singapore has been moving towards achieving the regional goal with the incidence of laboratory-confirmed cases between 0.3/100 000 population and 1.0/100 000 population during the 3-year period from 2008 to 2010.

### Mumps

The seroprevalence of mumps in children aged <5 years was 22% in 1989 before introduction of the MMR vaccine. It increased to 72.4% in 1993 after introduction of the mumps vaccines using the Urabe and Jeryl-Lynn strains. A large outbreak affecting mainly children aged <15 years occurred in 1999. It was due to poor protection conferred by the Rubini mumps strain of the MMR vaccine which was subsequently deregistered and replaced by the Jeryl-Lynn mumps strain [26, 27]. The low level of protection was confirmed in the 1998 serological survey when the prevalence in children aged <5 years fell steeply to 25.6% [28]. The introduction of the MMR vaccine containing the more efficacious Jeryl-Lynn strain in 1999 has resulted in a significantly higher prevalence of antibody against mumps in the 13–17 years group who had received two doses (83.9%) of vaccine compared to those vaccinated with only the first dose (63.4%) ( $P = 0.001$ ). Natural immunity following the

large mumps outbreak from 1999 to 2000 could have also accounted for the higher seroprevalence. This difference was not seen in the case of measles and rubella. Higher seroprevalence was also observed in children aged 12 years and 7 years, which corresponded to the ages when the second dose of the MMR vaccine was administered before and since 2008, respectively (Fig. 1).

In 2008–2010, the overall prevalence of mumps IgG antibody in the 1–17 years age group was higher. However, the seroprevalence of mumps was the lowest at 71.8% compared to that of measles at 83.1% and rubella at 86.6%. The mumps seroprevalence in children aged 6–17 years (75.4%) was lower than in New Zealand (87.6% to 89.2% in children aged 6–15 years in 2009) [18] and the USA (90.3% in children and adolescents aged 6–17 years from 1999 to 2004) [29].

Despite the consistently high MMR vaccination coverage in Singapore, seroprevalence was below the herd immunity threshold of 75–86% [15]. The median estimate of VE for two doses of Jeryl-Lynn mumps vaccine is 88% (range 79–95%) [30]. However, outbreak-based observational studies have generally shown lower effectiveness of the vaccine ranging between 63% and 96%, depending on the number of vaccinations given [31, 32]. The lower seroprevalence of mumps compared to measles and rubella could be partly attributed to the commercial test kit (Euroimmune, Germany) used for the detection of mumps IgG antibody in this study. It was prepared using the wild-type Enders strain of mumps virus. Its lower sensitivity compared to kits containing both Enders and Jeryl-Lynn strains in determining antibody titres of the wild-type Enders strain has been reported [33, 34].

There is limited data regarding long-term immunity against mumps after vaccination. While the declining seroprevalence of mumps since the last MMR vaccination evident from our study suggests waning immunity, the decreased level of mumps IgG antibody or lack of mumps IgG antibody does not necessarily imply the loss of clinical protection. Other studies have found that vaccine recipients with undetectable antibody levels had lymphoproliferative responses to mumps antigen [35, 36].

### Rubella

The overall prevalence of rubella IgG antibody in children and adolescents aged 1–17 years (88.5%,

95% CI 86.6–90.2) was above the threshold of 83–85% for herd immunity against rubella [15]. Compared to a previous study [10], the seroprevalence in children aged 1–14 years has increased from 84% in 1998 to 90.0% in 2008–2010. Rubella seroprevalence was lower than in Australia (95.4% in children aged 2–14 years in 2002) [37], and comparable to New Zealand (89.7–90.5% in the 6–15 years group in 2009) [18] and England and Wales (84.3% in children aged 2–14 years in 2000) [37]. As is the case of measles and mumps, the seroprevalence of rubella declined from an average of 92.4% within 9 years post-vaccination to <80% in those who were last vaccinated  $\geq 10$  years ago.

The seroprevalence of rubella was the highest and that of mumps was the lowest. This was somewhat reflected in the age-specific incidence of these diseases. The incidence of rubella in children aged <15 years decreased from 6.6/100 000 in 2008 to 2.8/100 000 in 2010. The incidence of mumps in this age group decreased from 54.2/100 000 to 31.1/100 000 in 2010. On the other hand, the incidence of measles in children aged <15 years was 3.9/100 000 in 2010, which was more than three times that of 1.2/100 000 in 2008. The highest incidence of measles was in children aged <5 years, in particular, infants aged <12 months who are not included in the vaccination programme. With effect from 1 December 2011, the first dose of MMR vaccine was brought forward from age 15 months to age 12 months in order to protect unvaccinated children aged 12–15 months. Furthermore, to reduce the number of children which may not respond to the first dose of MMR vaccination, the second dose was brought forward from 6–7 years to between 15 and 18 months. With this change in the immunization schedule, children would have received two doses of MMR vaccine by age 2 years, thus reducing the pool of susceptibles in young children.

There are a number of limitations to our study. First, the NPSS is not representative of the childhood population in Singapore. It is based on laboratory-based design instead of population-based sampling so as to ensure an adequate sample size, since population-based sampling is known to suffer from lower response rates due to parental concern about collecting blood samples from their children. However, national serosurveys using sera from diagnostic laboratories have been performed in other developed countries, including the UK [38], Australia [39] and New Zealand [18]. A study conducted in school children in Victoria suggested that the

collection of a convenient sample of sera from diagnostic laboratories throughout Australia is an appropriate sampling strategy to measure population immunity, as the estimates of immunity to MMR, hepatitis B and varicella zoster virus obtained were similar to those of a three-stage random cluster survey [40].

Second, the findings from the NPSS may not be comparable to those of previous surveys in Singapore due to the different study designs, laboratory methods of antibody measurement and cut-off values in defining serostatus. Similarly, the seroprevalence of MMR in Singapore may not be directly comparable to that of other countries. Moreover, there are differences in the year of introduction of the MMR immunization programme, as well as schedules and strategies adopted in different countries. The VE may also vary in different populations or ethnic groups.

The success of the two-dose regimen of MMR vaccination introduced in 1998 was reflected in the steep decline in disease incidence and a considerably high seroprevalence of MMR in children aged 1–17 years between 2008 and 2010. Seroprevalence surveys should be periodically conducted to measure the level of immunity against MMR and other vaccine-preventable diseases and to identify susceptible population groups for protection. This complements the ongoing case surveillance for effective disease prevention and control.

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## DECLARATION OF INTEREST

None.

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