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Seroprevalence of vaccine-preventable diseases among young children in the United Arab Emirates

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SUMMARY

Objectives: In the United Arab Emirates (UAE), many vaccine-preventable diseases are notifiable and are often reported despite high estimated immunization coverage. The serological assessment of immunity against these infections (serosurveillance) complements disease surveillance (notification). This study aimed to assess the yet unmeasured serological immunities to nine vaccine-preventable infections among vaccinated Emirati children.

Methods: This cross-sectional study involved children who attended the Well-Child Care Programme of the Ambulatory Healthcare Services (Al-Ain, UAE) between July 2014 and September 2015. Serological testing was performed in 227 Emirati children (49% females); subjects were aged (mean ± standard deviation) 45 ± 14 months (median 43, range 23–71 months).

Results: The seroprevalence rates varied markedly among the studied vaccine-preventable diseases, ranging from 39.2% (pertussis) to 98.3% (rubella). Other high seroprevalence rates were noted for measles (98.2%) and poliovirus (92%). The seroprevalence rate for mumps was 82.8%, for varicella was 68.3%, for diphtheria was 86.4%, for tetanus was 89.9%, and for *Haemophilus influenzae* type B was 84.1%.

Conclusions: A large number of the studied children had low seroprevalence rates against pertussis, varicella, and mumps. Studies are needed to explore whether modifying the national immunization programme could improve these low seroprevalence estimates.

1. Introduction

Despite the advances in vaccine preparations and scheduling, many children are still susceptible to common communicable diseases. The Health Authority of Abu Dhabi, United Arab Emirates (UAE) was notified of 268 cases of chickenpox, 39 cases of measles, 20 cases of mumps, and four cases of pertussis in children ≤4 years of age in the first two quarters of 2015; unfortunately, the vaccination status of these children was not reported.[1] Disease surveillance (notification data) is central to detecting outbreaks and providing timely information on the trends of vaccine-preventable diseases. However, such data may be incomplete and biased by variations in case definitions and classifications. Serosurveillance data, on the other hand, measures immunity that results from vaccination or past infection. These data are very useful for mathematical modelling to determine the potential for future outbreaks and the need for public health interventions such as modifications to the vaccination programmes or conducting vaccination campaigns.[2]

Immune responses to vaccines are influenced by several factors, including genetic predisposition. Inherited differences in molecules involved in immune signalling have been suggested to explain the variation in response to vaccines among various populations.[3] Other potential factors include nutritional status, congenital or acquired defects in immunity, inter-current infection, and vaccine-related variables (e.g., preparation, interactions, and administration sequence).[4] Individuals who are immune to an infectious disease are not only protected themselves, but also do not spread the disease. When a critical proportion of the population becomes immune, the herd immunity threshold is reached, halting disease transmission in the population.[5] For this, vaccination coverage above 95% among susceptible groups is necessary, in addition to the need for a surveillance system that would identify the groups at risk of contracting these vaccine-preventable infections. An effective

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vaccination programme would ideally aim to increase the number of individuals with positive serological immunity, reaching or exceeding the herd immunity threshold, which ranges from 66% (*Haemophilus influenzae* type B (Hib)) to 83% (measles), for each vaccine-preventable infection.[5,6]

The UAE has adopted the World Health Organization (WHO) Expanded Programme on Immunization (EPI) since 1978. The UAE-EPI includes childhood, school, adult, Hajj and Umrah, and traveller vaccines. Childhood vaccine coverage was estimated at 99% in 2014.[7] In brief, since 2011, a hexavalent vaccine (diphtheria–tetanus–acellular pertussis (DTaP), hepatitis B virus (HBV), inactivated poliovirus (IPV), and Hib) has been given at 2 and 4 months, and a pentavalent vaccine (DTaP–HBV–Hib) and oral poliovirus vaccine at 6 months. The tetravalent (DTaP–Hib) and oral poliovirus vaccines are given at 18 months. Tdap (tetanus, diphtheria, and pertussis) and oral poliovirus are given in grade 11. The measles–mumps–rubella (MMR) vaccine is given in two doses at 12 months and in grade 1. In February 2015, the Health Authority of Abu Dhabi updated the immunization schedule and introduced a second MMR dose at 18 months; the dose given in grade 1 will continue until the children who received two doses at 12 and 18 months are enrolled in grade 1. Varicella vaccine is given at 12 months and in grade 1. Oral poliovirus vaccine is also given in grade 1. Rubella and human papillomavirus vaccines are given to females only in grade 9 and 11, respectively. The varicella vaccine was added to the childhood vaccines in 2010 and to the school vaccines (grade 1) in 2012. Pneumococcal conjugate vaccine is given at 2, 4, 6, and 18 months. Rotavirus vaccine was added in 2013 at 2 months and 4 months. In addition, several childhood campaigns have been conducted in the region (e.g., the oral poliovirus vaccine campaign in January 2015).[8]

As no serosurveillance data are available in the UAE for vaccine-preventable diseases despite the continuing occurrence of some of these infections, this study was undertaken to assess the prevalence of antibodies against these diseases among vaccinated Emirati children.

2. Methods

2.1. Study participants and data collection

This cross-sectional study involved an unselected cohort of 231 children who attended the Well-Child Care Programme of the Ambulatory Healthcare Services (Al-Ain, Abu Dhabi) between July 2014 and September 2015. This programme (birth to 6 years of age) was first established in the Emirate of Abu Dhabi in March 2013. The programme delivers preventive care as set by the Health Authority of Abu Dhabi policies and international guidelines. It provides care at 34 centres in the entire Emirate of Abu Dhabi, where 70% of patients are Emirati. A primary aim of this programme is to enhance culturally relevant preventive measures that include clinical assessment, immunization, nutrition, preventive measures, and screening. No specific sampling method was used, as all children presenting to these services during the study period and who were eligible for enrolment in the study were included if the parents consented.

Inclusion criteria were: (1) children 23 months to 6 years of age, and (2) an up-to-date immunization status. Exclusion criteria were acute or chronic medical illnesses, and regular medications other than acetaminophen or ibuprofen. The immunization status was verified by reviewing the clinic vaccination logbooks, individual patient immunization cards, and electronic records. No history of prior infection with a vaccine-preventable illness was collected.

Blood was collected and processed to measure the immune responses to nine selected vaccine-preventable diseases: diphtheria, tetanus, pertussis, poliovirus, Hib, measles, mumps, rubella, and varicella. All negative or equivocal results were repeated at least once for confirmation.

2.2. Laboratory testing

An ELISA was used to measure IgG antibody titres in the sera of the participating children. All tests were performed and interpreted according to the manufacturers' instructions at a single laboratory (the Central Reference Laboratory of the Ambulatory Healthcare Services). Missing serology results were due to inadequate serum volume to run all the tests in a blood sample.

For Hib, anti-polyribosylribitolphosphate IgG antibodies were measured (RE56351; IBL International, Hamburg, Germany). A failure to seroconvert following Hib vaccination was considered an inability to react to this polysaccharide antigen. Immunoreactions to non-typeable *Haemophilus influenzae* are not detected by this test. Antibody concentrations <0.15 μg/ml corresponded to insufficient protection (negative), 0.15–1.0 μg/ml equivocal, and >1.0 μg/ml sufficient immunity (positive). For poliovirus (RE56921; IBL International), titres <8 U/ml were negative, 8–12 U/ml equivocal, and >12 U/ml positive. Antibodies against *Bordetella pertussis* (BOPG0030), measles (MEAG0330), mumps (MUMG0340), varicella zoster virus (VZV) (VZVG0490), *Corynebacterium diphtheriae* toxin (CORG0090), *Clostridium tetani* toxin (TETG0430), and rubella (RUBG0400) were measured using NovaLisa test kits (Dietzenbach, Germany). For pertussis, measles, mumps, and VZV, titres <9 NTU (NovaTec units) were negative, 9–11 NTU equivocal, and >11 NTU positive. For diphtheria and tetanus, titres <0.01 IU/ml were negative, 0.0–0.1 IU/ml equivocal, and >0.1 IU/ml positive. For rubella, titres <10 IU/ml were considered negative, 10–15 IU/ml equivocal, and >15 IU/ml positive.

2.3. Statistical analysis

The collected data were entered and analysed using IBM SPSS Statistics version 20.0 (IBM Corp., Armonk, NY, USA). For the purpose of the study, all positive and negative serology results excluded the equivocal or grey zone results. A descriptive analysis was performed on the percentage of children with positive serology results for each vaccine and was calculated with 95% confidence intervals (CI). These were also calculated across four age bands (23–35 months, 36–47 months, 48–59 months, and 60–72 months). The number and percentage of children who had negative serology to one or more vaccines was also calculated. Pearson's Chi-square test was used to compare the seropositivity prevalence rates; if the expected frequency was less than five, Fisher's test was used instead. Statistical significance was defined by a two-sided p-value of less than 0.05.

3. Results

Of the 231 children initially recruited, four were excluded (two non-Emiratis who returned from living abroad and had never been immunized, as stated by their parents, and two other children who had insufficient serum). The remaining 227 children (49% females) were enrolled. Their age (mean ± standard deviation) was 45 ± 14 months (median 43, range 23–71 months).

The immunization history was verified in 217 children (217/227, 95.6%) by reviewing the vaccination documentation (e.g., clinic logbooks, electronic records, and immunization cards). The parents of 10/227 (4.4%) children could not be reached to confirm the immunization status.

The prevalence (mean; 95% CI) of positive serological immunity varied markedly among the studied vaccines (Table 1). It was

highest for rubella (98.3%; 95.5, 99.5) and measles (98.2%; 95.5, 99.5) and lowest for varicella (68.3%; 61.8, 74.3) and pertussis (39.2%; 32.8, 45.8). For individual vaccines, the prevalence of positive serological immunity also varied with the age of the children (Table 2).

For the 227 children, information on negative serology was unavailable on all vaccine serology in 19 (8%). For the remaining 208 children, 43 (19%) had no seronegative results and 165 (81%) were seronegative for at least one vaccine.

Seronegativity to only one vaccine occurred in 101 (44.5%) children. This included 67 to pertussis (50% of all pertussis seronegativities), 19 to varicella (26% of varicella seronegativities), 12 to mumps (31% of mumps seronegativities), two to diphtheria (33% of diphtheria seronegativities), and only one to tetanus (11% of tetanus seronegativities). The remaining 80 (35%) children had seronegativity to more than one vaccine. Forty-three (20.6%) children had seronegativity to two vaccines; 24 (55%) combinations were pertussis plus varicella, nine (21%) were pertussis plus mumps, and 10 (24%) were other combinations. Seventeen (8%) children had seronegativity to three vaccines, and three (1.4%) had seronegativity to four vaccines (One to pertussis, varicella, mumps and measles; one to pertussis, varicella, mumps and rubella; and one to pertussis, varicella, diphtheria and tetanus). One child (0.5%) had seronegativity to five vaccines (diphtheria, pertussis, measles, mumps, and varicella).

When negative serological immunity occurred to several vaccines simultaneously in a child, pertussis, varicella, mumps, tetanus, diphtheria, and measles were the most likely to be involved. When the proportion of children with seronegativity to one to four vaccines was compared amongst the age groups, it was not statistically different (Chi-square test $p = 0.72$).

4. Discussion

This cross-sectional serosurveillance study estimated the level of immunity against nine childhood vaccines in Emirati children. The serological immunity rates below the recommended herd immunity threshold for pertussis, mumps, and varicella[5] are consistent with the observed endemics of pertussis, varicella, and mumps in the region despite excellent childhood vaccination coverage.[1] Reassuringly, the serological immunity rates exceeded the herd immunity threshold for measles, poliovirus, rubella, and Hib, mirroring the near-absence of reported cases of these infections.[5]

Similar findings have been reported in other population-based seroepidemiological studies. A report from Singapore described serological immunity in children aged 1–17 years in 2008–2010; immunity to measles was 83.1%, to mumps was 71.8%, and to rubella was 88.5%.[9] In another study involving Austrian children aged 4–8 years, the immunity to tetanus was 96%, to measles was 90%, to diphtheria was 81%, to mumps was 72%, to rubella was 63%, and to pertussis was 27%. The authors concluded that the low levels of antibodies after vaccination against pertussis, rubella, and mumps should be considered when recommending new vaccination schedules.[10]

In the present study, antibodies against measles virus were found in 98.2% of the enrolled children, none had equivocal results, and 1.8% of children had negative measles serology. As stated by the World Health Organization (WHO), the proportion of susceptible individuals should not exceed 5% for young adults above the age of 14 years in order to achieve an interruption in the transmission of measles; the seropositivity rate of the studied children fulfils this requirement.[11] This is in contrast to an earlier observation of only 54% of Emirati medical students having positive measles antibodies. The low measles seroprevalence rate among the medical students cohort probably reflects early vaccination against measles with a waning immune response produced by vaccination over time as opposed to natural exposure to the virus.[12,13]

The overall prevalence of antibodies to rubella virus in this study was 98.3%. The elimination of rubella and the prevention of congenital rubella syndrome require that the percentage of susceptible women of childbearing age is less than 5%, as recommended by the WHO. The present study finding of 98.3% of the studied children having antibodies to rubella virus is in line with this requirement.[14] However, it remains to be seen whether this high rate is maintained in the older age groups.

Since the introduction of the MMR vaccine and despite adequate vaccination coverage, cases of mumps are still reported every year.[1] This may be attributed to a loss of immunity against the mumps virus over time as a result of reduced immunogenicity induced by the mumps vaccine component of the MMR in relation to the other two components (measles and rubella).[13,15–17] However, immunity to the mumps virus is complex and interpretation is complicated: although a high population seropositivity rate against the virus is an important factor in outbreak prevention, the minimum protective titres are unknown, which may therefore explain why seronegativity does not necessarily equate with susceptibility.[17,18]

In this study, the total percentage of varicella (VZV) seropositivity was 68.3%, somewhat lower than in other reports, perhaps because of the use of a different assay method for detecting anti-VZV antibodies, in addition to the absence of a 'gold standard' method for detecting anti-VZV IgG.[19] As equivocal results were nil in this study, these differences in the seroprevalence rates cannot be attributed to their exclusion from the positive, as in other reports.[20]

IgG antibodies to *B. pertussis* were detected in 39.2% of the children and did not vary much with age. The young age of the

Table 1
Serological immunity against the nine studied vaccines in 227 fully vaccinated children[a]

	Measles	Mumps	Rubella	Diphtheria	Tetanus	Pertussis	Poliovirus	Hib	Varicella
Positive	98.2 [95.5; 99.5] (223)	82.8 [77.2; 87.4] (188)	98.3 [95.5; 99.5] (223)	86.4 [81.1; 90.5] (196)	89.9 [85.1; 93.4] (204)	39.2 [32.8; 45.8] (89)	92.0 [87.7; 95.2] (209)	84.1 [78.7; 88.6] (191)	68.3 [61.8; 74.3] (155)
Equivocal	0 [NA] (0)	0 [NA] (0)	1.3 [0.2; 3.8] (3)	7.9 [4.7; 12.2] (18)	2.2 [0.7; 5.0] (5)	0 [NA] (0)	4.0 [1.8; 7.3] (9)	10.1 [6.5; 14.8] (23)	0 [NA] (0)
Negative	1.8 [0.4; 4.4] (4)	17.2 [12.5; 22.7] (39)	0.4 [0.1; 2.4] (1)	2.6 [0.9; 5.6] (6)	4.0 [1.8; 7.3] (9)	58.6 [51.8; 65.0] (133)	4.0 [1.8; 7.3] (9)	0 [NA] (0)	31.7 [25.7; 38.2] (72)
No data	0 [NA] (0)	0 [NA] (0)	0 [NA] (0)	3.1 [1.2; 6.3] (7)	3.9 [1.8; 7.3] (9)	2.2 [0.7; 5.0] (5)	0 [NA] (0)	5.8 [3.0; 9.5] (13)	0 [NA] (0)

NA, not applicable; Hib, *Haemophilus influenzae* type B.
[a] Values are presented as the percentage, [95% confidence interval], and (*n*).

Table 2
Positive serology against the nine studied vaccines in 227 fully vaccinated children[a]

Age in months	Measles	Mumps	Rubella	Diphtheria	Tetanus	Pertussis	Poliovirus	Hib	Varicella
23–35 (n=69)	98.5 (68) [92.1; 99.9]	89.8 (62) [80.2; 95.8]	98.5 (68) [92.1; 99.9]	92.7 (64) [83.9; 97.6]	89.8 (62) [80.2; 95.8]	40.6 (28) [28.9; 53.0]	88.4 (61) [78.4; 94.8]	88.4 (61) [78.4; 94.8]	71.0 (49) [58.8; 81.3]
36–47 (n=63)	96.3 (61) [88.9; 99.6]	73.0 (46) [60.3; 83.4]	98.4 (62) [91.4; 99.9]	92.0 (58) [82.4; 97.3]	89.9 (56) [78.4; 95.4]	47.6 (30) [34.8; 60.6]	93.6 (59) [84.5; 98.2]	80.9 (51) [69.0; 89.7]	74.6 (47) [62.0; 84.7]
48–59 (n=47)	100 (47) [92.4; 100]	82.9 (39) [69.1; 92.3]	97.8 (46) [88.7; 99.9]	80.8 (38) [66.7; 90.8]	89.3 (42) [76.8; 96.4]	34.0 (16) [20.8; 49.3]	91.5 (43) [79.6; 97.6]	89.3 (42) [76.8; 96.4]	59.6 (28) [44.2; 73.6]
60–72 (n=48)	97.9 (47) [88.9; 99.9]	85.4 (41) [72.2; 93.9]	97.9 (47) [88.9; 99.9]	75.0 (36) [60.4; 86.3]	91.6 (44) [80.0; 97.7]	31.2 (15) [18.6; 46.2]	95.8 (46) [85.7; 99.4]	77.1 (37) [62.6; 87.9]	64.6 (31) [49.4; 77.8]
Equivocal or unknown serology	(0)	(0)	(3)	(25)	(14)	(5)	(9)	(36)	(0)
Total (N=227)	98.2 (223) [95.5; 99.5]	82.2 (188) [77.2; 87.4]	98.2 (223) [95.5; 99.5]	86.3 (196) [8.1; 90.5]	89.8 (204) [85.1; 93.4]	39.2 (89) [32.8; 45.8]	92.1 (209) [87.7; 95.2]	84.4 (191) [78.7; 88.6]	68.2 (155) [61.7; 74.2]

Hib, Haemophilus influenzae type B.
[a] Values are presented as the percentage (number of children) and [95% confidence interval].

participants with narrow band ages in this study makes it unlikely that this low rate could be related to differences by age in the kinetics of pertussis toxin (PT) antibodies,[21] or to the waning immune response once the protection of primary vaccination has been lost.[22]

The limitations of this study include the single nationality and the narrow age band of the enrolled children attending the health care system of a single city. As this cannot be considered a random or a representative sample of the population of children, the extrapolation of the study findings to other settings requires careful consideration. Another limitation is that, as no history of clinical infection with these vaccine-preventable diseases was included in the survey, it is not possible to attribute the finding of a positive serology result to the administration of the corresponding vaccine or to the infection itself. Similarly, no clinical outcomes were studied in order to correlate the findings with the protective effect of these vaccines.

In summary, many fully vaccinated children may still be susceptible to pertussis, varicella, and mumps, and this remains a challenge to the immunization programme. National immunization programmes need to be guided by population-based serosurveillance studies before recommending the usage of more immunogenic vaccines and/or improved schedules of administration. Immunizations tailored to particularly susceptible (e.g., boosters of varicella and measles vaccines for medical students) or high-risk groups (boosters of pertussis vaccine for young infants) may also be necessary. The efficacy of such endeavours with regard to carriage and herd immunity in the community will require ongoing evaluation.

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Conflict of interest: The authors declare that they have no conflict of interest.

References

1. Hosani FA, Mulla MA, Abdulla A, Shehhi BA, Jaafar K, Khudhair A, et al. Communicable Diseases Bulletin quarterly summary report: 2nd quarter. Abu Dhabi: Health Authority - Abu Dhabi; 2015, http://www.haad.ae/HAAD/LinkClick.aspx?fileticket=kCGuarfuxNk%3d&tabid=1177 (Accessed on July 17, 2016)
2. Weir R, Jennings L, Young S, Brunton C, Murdoch D. National serosurvey of vaccine preventable diseases. Wellington, New Zealand: Ministry of Health; 2009.
3. Kimman TG, Vandebriel RJ, Hoebee B. Genetic variation in the response to vaccination. *Community Genet* 2007;**10**:201–17.
4. Siegrist CA. The challenges of vaccine responses in early life: selected examples. *J Comp Pathol* 2007;**137**(Suppl 1):S4–9.
5. Fine PE. Herd immunity: history, theory, practice. *Epidemiol Rev* 1993;**15**:265–302.
6. Theodoratou E, Johnson S, Jhass A, Madhi SA, Clark A, Boschi-Pinto C, et al. The effect of *Haemophilus influenzae* type b and pneumococcal conjugate vaccines on childhood pneumonia incidence, severe morbidity and mortality. *Int J Epidemiol* 2010;**39**(Suppl 1):i172–85.
7. World Health, Organization. Vaccine-preventable diseases: monitoring system 2015 global summary. Geneva: WHO; 2015.
8. Health Authority - Abu Dhabi Immunization Schedule for 2015-2016. http://www.haad.ae/HAAD/LinkClick.aspx?fileticket=9nWVMFujBTc%3D&tabid=183 (Accessed on July 17, 2016).
9. Ang LW, Lai FY, Tey SH, Cutter J, James L, Goh KT. Prevalence of antibodies against measles, mumps and rubella in the childhood population in Singapore, 2008-2010. *Epidemiol Infect* 2013;**141**:1721–30.
10. Paulke-Korinek M, Fischmeister G, Grac A, Rendi-Wagner P, Kundi M, Mohsenzadeh-Rabbani A, et al. Persistence of antibodies in 4-8 year old Austrian children after vaccination with hexavalent DTaP–HBV–IPV/Hib and MMR vaccines. *Vaccine* 2011;**29**:5130–6.
11. World Health, Organization. A strategic framework for the elimination of measles in the European Region. In: The Expanded Programme on Immunization in the European Region of the WHO. Geneva: WHO; 1999.
12. Sheek-Hussein M, Hashmey R, Alsuwaidi AR, Al Maskari F, Amiri L, Souid AK. Seroprevalence of measles, mumps, rubella, varicella-zoster and hepatitis A–C in Emirati medical students. *BMC Public Health* 2012;**12**:1047.
13. Amela C, Pachón I, de Ory F. Evaluation of the measles, mumps and rubella immunisation programme in Spain by using a sero-epidemiological survey. *Eur J Epidemiol* 2003;**18**:71–9.
14. World Health, Organization. Eliminating measles and rubella and preventing congenital rubella infection. In: WHO. European Region strategic plan 2005-2010. Copenhagen: WHO. Regional Office for Europe; 2005.
15. Mossong J, Putz L, Schneider F. Seroprevalence of measles, mumps and rubella antibodies in Luxembourg: results from a national cross-sectional study. *Epidemiol Infect* 2004;**132**:11–8.
16. Domínguez A, Plans P, Costa J, Torner N, Cardenosa N, Batalla J, et al. Seroprevalence of measles, rubella, and mumps antibodies in Catalonia, Spain: results of a cross-sectional study. *Eur J Clin Microbiol Infect Dis* 2006;**25**:310–7.
17. Eriksen J, Davidkin I, Kafatos G, Andrews N, Barbara C, Cohen D, et al. Seroepidemiology of mumps in Europe (1996-2008): why do outbreaks occur in highly vaccinated populations? *Epidemiol Infect* 2012;**141**:651–66.
18. Theeten H, Hutse V, Hens N, Yavuz Y, Hoppenbrouwers K, Beutels P, et al. Are we hitting immunity targets? The 2006 age-specific seroprevalence of measles, mumps, rubella, diphtheria and tetanus in Belgium. *Epidemiol Infect* 2011;**139**:494–504.
19. Chris Maple PA, Gunn A, Sellwood J, Brown DW, Gray JJ. Comparison of fifteen commercial assays for detecting varicella zoster virus IgG with reference to a

time resolved fluorescence immunoassay (TRFIA) and the performance of two commercial assays for screening sera from immunocompromised individuals. *J Virol Methods* 2009;**155**:143–9.
20. Nardone A, de Ory F, Carton M, Cohen D, van Damme P, Davidkin I, et al. The comparative sero-epidemiology of varicella zoster virus in 11 countries in the European region. *Vaccine* 2007;**25**:7866–72.
21. Cattaneo LA, Reed GW, Haase DH, Wills MJ, Edwards KM. The seroepidemiology of *Bordetella pertussis* infections: a study of persons ages 1-65 years. *J Infect Dis* 1996;**173**:1256–9.
22. Rendi-Wagner P, Tobias J, Moerman L, Goren S, Bassal R, Green M, Cohen D. The seroepidemiology of *Bordetella pertussis* in Israel—estimate of incidence of infection. *Vaccine* 2010;**28**:3285–90.