Epidemiology of measles in Taiwan: dynamics of transmission and timeliness of reporting during an epidemic in 1988–9

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SUMMARY

We analysed nation-wide reported measles cases during the 1988–9 epidemic and found that longer duration and wider spread were two major characteristics of the outbreak. All the 22 county/city index cases were reported with a delay of > 4 days and 64% were aged 5–14 years. This epidemic occurred mainly among 5–14-year-old school-children (59%), infants under 1 year (19%), and pre-school children (18%). The overall attack rate was 0·63 cases per 10000 population, with the highest attack rate (7·4 cases per 10000 population) occurring in infants. Among 280 confirmed cases < 15 months of age, 9-month-old infants (42 cases) had a higher risk of measles and peaked at 10 months (49 cases). This epidemic started in March 1988 among 5–9-year-old children in the northern suburban area, then spread to Taipei City and neighbouring counties or cities. It continued to spread from the northern to southern and western areas during the summer vacation and New Year holidays. Multiple logistic regression analysis showed that the delay of measles reporting was strongly associated with the cases infected early in the epidemic (OR = 6·9, P < 0·001) and reported from teaching hospitals (OR = 2·6, P < 0·001). The reappearance of high attack rates among 5–9-year-old children in the 1985 and 1988–9 measles epidemics in Taiwan indicated the persistence of pockets of susceptible individuals even after mass immunization.

INTRODUCTION

Measles in Taiwan was very widespread, with epidemics occurring every 2 years, before mass immunization programmes were implemented in 1978 [1]. Since then, measles mortality has decreased significantly and only one fatal case was reported in 1983. However, the virus persists in Taiwan and measles outbreaks continue to occur periodically (Fig. 1) [2]. Live attenuated measles vaccine was introduced to Taiwan in 1968. Mass immunization programmes with one dose of vaccine for all 9–36-month-old infants and children were instituted in the capital city (Taipei) in 1977, and the programme was extended to the whole Taiwan area for all children

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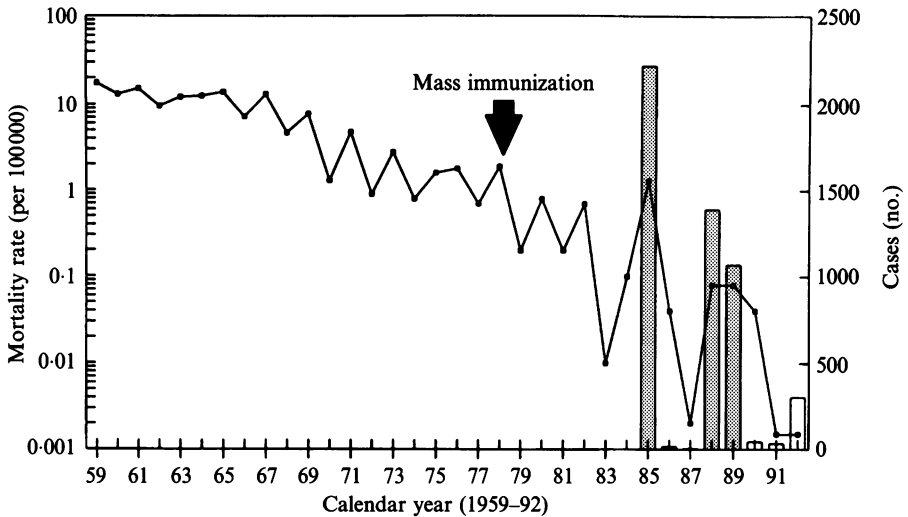
Fig. 1. The annual number of reported measles cases and measles mortality rates among individuals 0–19 years old in Taiwan, 1959–92. Measles became a reportable disease in 1985. Mortality rates were calculated from the number of individuals 0–19 years old as a denominator, because only 3 fatal cases occurred among adults > 19 years of age during 1959–89.■; Mortality rate; ▨, reported cases.

15–21 months of age in 1978. The recommended ages for vaccination have been changed several times since 1978: (a) 2 doses at 9 and 15 months of age in May 1984; (b) one dose at 12 months in January 1988 together with a 2-dose strategy if measles epidemics occurred; and (c) 2 doses at 9 and 15 months of age in May 1988 after the island-wide measles outbreak. These frequent changes have confused many local health personnel and parents about the optimal age of measles immunization.

Recent measles epidemics in Taiwan occurred in 1985, 1988 and 1989 with 2219, 1386 and 1060 reported cases, respectively. The 1985 epidemic resulted in 97 deaths (mortality rate = 1·70 deaths per 100000 persons under age 15 years), whereas the 1988–9 epidemic caused only 12 deaths [3]. The 1988 epidemic started in the northern suburban area of Taiwan in March, but health authorities did not receive any reports until April. In order to prevent measles more effectively, the Advisory Committee of Immunization Practices (ACIP) in Taiwan decided to change the measles immunization schedule to 2 doses at 9 and 15 months of age as noted above. However, reported cases continued to increase and reached 2 peaks, the first in July 1988 and the second in January 1989, with 275 and 364 reported cases, respectively.

Epidemiological data of island-wide measles cases in Taiwan over the last 40 years have not hitherto been analysed, except for mortality analyses and a few local outbreak investigations [1, 2, 4]. Moreover, the effectiveness of the measles reporting system in Taiwan has not been evaluated since this disease became reportable in 1985. Therefore, we conducted this study with the following specific aims: (1) to characterize the epidemiology of measles during its outbreak in 1988–9 in Taiwan; (2) to explore the dynamics of measles transmission and (3) to evaluate the effectiveness of the passive surveillance system for measles. Our

findings may have strategic implications for eliminating measles from Taiwan and possibly for global eradication.

MATERIALS AND METHODS

Surveillance and reporting forms

Measles surveillance in Taiwan has been based on passive reporting since 1985. Physicians mail the report forms to their County or City Health Bureau. The Department of Health (DOH) receives these reports from all the local health bureaux each month. The information collected on the report form includes age, sex, date of onset and clinical manifestations. The report form for measles has been simplified twice from 1985 to 1989. New forms have excluded important information, such as immunization history, source of exposure and location of infection since 1987. In 1988–9, there were 2446 reported measles cases from which 2332 (95·3%) forms were available for analysis.

Epidemiological analysis

Reported measles cases were classified as confirmed or suspected. A 'confirmed case' was defined as having at least one of the following three criteria: (a) serological confirmation with positive measles IgM; (b) Koplik's spots on buccal mucosa; (c) fever, a generalized maculopapular rash, and at least one of the following signs or symptoms: cough, coryza, or conjunctivitis. The third criterion is similar to that of the CDC in the United States except the duration of rash (lasting for 3 or more days) [5], because patients in Taiwan often visit physicians once only without follow up. Reported cases that did not meet any of these criteria were classified as 'suspected cases'. An index case was defined as the first reported confirmed case in each county or city. In order to explore the possible differences between confirmed and suspected cases, factors such as sex, age, hospitalization, source of reporting, stage of epidemic, and delays in reporting were compared. Only confirmed cases were used to calculate cohort-specific attack rates by different immunization strategies. Reporting sources were classified as private clinic, public health station, private hospital, public hospital, teaching hospital and others (military hospital and unknown). Three epidemic stages were defined as follows: (1) starting period (Jan.–April 1988, prior to the first peak); (2) prevalent period (May 1988–March 1989); and (3) declining period (April–Dec. 1989). The reporting delay was defined as the number of days from the date of disease onset to the date that local health bureaux received the report.

Dynamics of measles transmission

Only confirmed cases were used to explore the dynamics of measles transmission. The spatial diffusion of this epidemic was analysed by month of onset with spot maps of cities and counties. Taiwan was divided into 23 administrative districts in 1989, including 2 national cities (Taipei and Kaohsiung), 5 provincial cities and 16 counties. Taipei and Kaohsiung Cities were the economical centres of northern and southern Taiwan, respectively. Taipei City, with the highest number of confirmed cases (478), was selected to examine the spread of measles among different age groups. In addition, Taipei City and Taidung County, where obvious

double peaks of measles cases appeared, were chosen to explore the difference in age distribution between the first and the second peaks.

Evaluation of measles reporting

Reporting delays were grouped as follows: 0–1 day, in compliance with DOH regulations; 2–4 days, which is a critical period for public health action to prevent the third generation of measles cases; 5–9 days and > 9 days (the incubation period of measles). All reported cases were analysed by multiple logistic regression analysis to explore factors associated with the timeliness of reporting, such as hospitalization, sources of reporting, and stages of epidemic. For the multivariate model, reporting delays were regrouped into: 0–9 days and > 9 days.

Statistical analysis

The associations between two categorical variables were tested for statistical significance by chi-square test, Mantel–Haenszel chi-square test for trend, or Fisher's exact test for the number of any category < 5 using SAS software. The multiple logistic regression with categorical variables was analysed with Categorical Model (CATMOD) in SAS software.

RESULTS

Comparison between confirmed and suspected cases

Among 2332 available reported cases, 1324 (57%) were classified as confirmed cases by the presence of Koplik's spots (1016, 77%), CDC-compatible clinical criteria (273, 20%) and measles specific IgM antibody (35, 3%). Compared with the suspected measles cases, the confirmed measles cases had higher percentage of children under 10 years old (72 vs 63%, $P < 0.001$, Mantel–Haenszel chi-square test), a higher hospitalization rate (23·4 vs 17%, $P < 0.001$, chi-square test) and a higher percentage of reporting delay > 9 days (44·8 vs 33·4%, $P < 0.001$, Mantel–Haenszel chi-square test). In addition, the proportions of confirmed cases that were reported from private, public and teaching hospitals were 26·1, 14·9 and 15·3% respectively; significantly higher than those of suspected cases (21·6, 8·6 and 9·2%) ($P < 0.001$, chi-square test). In total, private clinics accounted for the majority (46%) of reported cases. Confirmed and suspected cases did not differ in sex ($P = 0.83$) and stages of epidemic ($P = 0.36$, chi-square test) (Table 1).

Index case

The 22 index cases were mostly male ($N = 13$, 59%), children aged 5–14 years ($N = 14$, 64%) and reported from private clinics ($N = 7$, 32%) or public hospitals ($N = 7$, 32%). In addition, all of the index cases were reported to local health bureaux with a delay > 4 days (range = 6–159 days, median = 10 days, mode = 9 days, mean = 35 days), which is a critical period for prevention of the third generation of cases.

Attack rates

The overall attack rate was 0·63 cases/10000 people, with the highest cohort-specific attack rate (7·43 cases/10000 people) occurring among infants < 1 year of

Table 1. *Comparison of epidemiological characteristics and reporting conditions between confirmed and suspected reported measles cases in Taiwan, 1988–9**

Variables	Confirmed ($N = 1324$) No. (%)	Suspected ($N = 1008$) No. (%)	P value (D.F., χ^2)
Age (years)			< 0.001†
< 1	233 (17·6)	142 (14·1)	(1, 19·5)
1–4	221 (16·7)	135 (13·4)	
5–9	499 (37·7)	360 (35·7)	
10–14	244 (18·4)	230 (22·8)	
$\geqslant 15$	49 (3·7)	65 (6·5)	
Unknown	78 (5·9)	76 (7·5)	
Hospitalization			< 0.001
Yes	311 (23·5)	170 (16·9)	(2, 74·8)
No	505 (38·1)	566 (56·2)	
Unknown	508 (38·4)	272 (27·0)	
Sources of reporting			< 0.001
Private clinic	525 (39·7)	537 (53·3)	(5, 76·1)
Health station	32 (2·4)	53 (5·3)	
Private hospital	345 (26·1)	218 (21·6)	
Public hospital	197 (14·9)	87 (8·6)	
Teaching hospital	203 (15·3)	93 (9·2)	
Others	22 (1·7)	20 (2·0)	
Stages of epidemic*			0·362
Starting	32 (2·4)	16 (1·6)	(3, 3·2)
Prevalent	1204 (90·9)	930 (92·3)	
Declining	84 (6·3)	61 (6·0)	
Unknown	4 (0·3)	1 (0·1)	
Delay time (days)			< 0.001†
0–1	4 (0·3)	3 (0·3)	(1, 17·4)
2–4	65 (4·9)	80 (7·9)	
5–9	379 (28·6)	270 (26·8)	
$\geqslant 10$	593 (44·8)	337 (33·4)	
Unknown	283 (21·4)	318 (31·5)	

* Stages of epidemic were classified as follows: (1) starting period (Jan.–April 1988, prior to the rise of the first peak); (2) prevalent period (May 1988–March 1989) and (3) declining period (April–Dec. 1989).

† Mantel–Haenszel chi-square test; D.F., degrees of freedom.

age. The other cohort-specific attack rates were 2·24 cases/10000 people among children born April 1976–June 1983 (with immunization strategy of one dose of measles vaccine at 15–21 months of age) and 1·64 cases/10000 people among children born July 1983–March 1987 (with immunization strategy of 2 doses of measles vaccine at 9 and 15 months of age). The cohort born before mass immunization had the lowest attack rate (0·06 cases/10000 people) during this epidemic (Table 2).

Age distribution

Among the 1246 confirmed cases with known age, 40% ($N = 499$) occurred among 5–9-year-old school-children, 19·6% ($N = 244$) in 10–14 year, 18·7%

Table 2. *Cohort-specific attack rates of confirmed measles and the number of fatal cases by different immunization strategies during the 1988–9 measles epidemic in Taiwan*

Birth cohorts* (year/month)	Supposed immunization strategies	Death no.	Confirmed cases†	
			No. (%)	AR(1/10000)‡
1987/4+				
Age < 1	Not eligible	3	233 (18·5)	7·43
Age > 1	One dose at 12 months	2	71 (5·6)	1·15
1983/7–87/3	Two doses at 9 and 15 months	1	237 (18·8)	1·64
1976/4–83/6	One dose at 15–21 months	4	629 (49·9)	2·24
< 1976/4	No mass immunization	2	91 (7·2)	0·06
Total		12	1261 (100·0)	0·63

* Sixty-three confirmed measles cases with unknown birthday were not included for analysis.
† Only the confirmed cases were used to calculate the cohort-specific attack rates (AR).
‡ The cohort-specific population was estimated by the statistics in Dec. 1988.

($N = 233$) in infants under < 1 year old and 17·7% ($N = 221$) in 1–4-year-old pre-school children (Table 1). The age distribution of 12 fatal cases was 3 in infants < 1 year old, 3 in 1–4 years, 2 in 5–9 years, 3 in 10–14 years and 1 in 15–19 years. The youngest confirmed case was a newborn infant. The oldest one was 66 years old. Among the 280 confirmed cases < 15 months of age, measles cases rose significantly at 9 months old ($N = 42$) and peaked at 10 months old ($N = 49$). Their distribution was 9·3% in 0–6 months, 28·9% in 7–9 months, 45% in 10–12 months and 16·8% in 13–15 months.

Dynamics of transmission

Two peaks appeared during the 1988–9 measles epidemic. The first confirmed case was a 10-year-old girl who developed measles on 12 March 1988 in Taipei County. This case was not reported to the local health bureau until 10 April 1988. Since then, the reported number rose dramatically and reached the first peak of 185 confirmed cases in June and July. Although the reported cases gradually decreased after July, the epidemic recurred in December 1988 and produced a second, higher peak of 187 confirmed cases in January 1989. Reported cases waned gradually over the next 5 months (the number of cases were 112, 67, 39, 18 and 15 in each following month of Feb.–June). After June 1989, only sporadic cases were reported (Fig. 2).

This island-wide epidemic spread geographically by a combination of neighbourhood and age-related transmission. The outbreak first emerged in the northern suburban area (Taipei County) in March 1988. It then spread to Taipei City (the capital of Taiwan, which has a population density of 9868 persons/km²) in April and diffused concurrently to the neighbouring counties/cities located in eastern (Ilan, 209 persons/km²) and northern Taiwan (Keelung, 2626 persons/km²). Ilan County and Keelung City reported their first confirmed cases in April and May respectively, whereas the southeasternmost, rural county (Taidung, 74 persons/km²) began reporting measles cases in July. The first peak of this epidemic reached in June 1988 with 89% (164/185) of the cases reported from
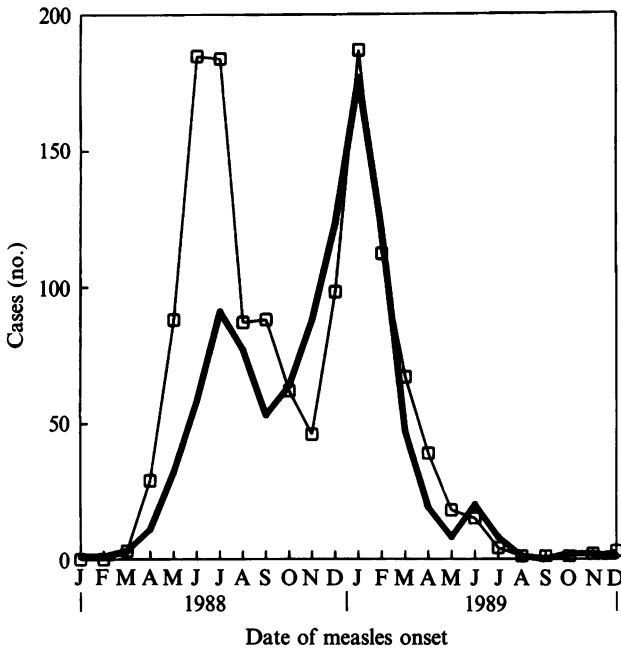
Fig. 2. Month distribution of reported measles during the 1988–9 epidemic in Taiwan. The school winter and summer vacations in Taiwan are in February and July–August, respectively. The 'confirmed case' was defined as having at least one of the following 3 criteria: (1) serological confirmation with positive measles IgM; (2) Koplik's spots on buccal mucosa; (3) fever, a generalized maculopapular rash, and at least one of the following signs or symptoms: cough, coryza, or conjunctivitis. □, Confirmed cases; +, suspected cases.

Taipei City and Taipei County. The virus continued to circulate in these areas and was transmitted to the central metropolitan area (Taichung City, 4469 persons/km²) in June and the southern metropolitan areas (Tainan City, 3801 persons/km² and Kaohsiung City, 8868 persons/km²) in July. Concurrently, measles cases mushroomed in 16 of 23 cities/counties during July 1988, the school summer vacation. After September, measles activity decreased gradually and only sporadic cases occurred in northern and southern areas. However, the disease recurred in December and reached the second peak in January 1989 in Taipei City and western counties (Fig. 3). Apparently, Taipei areas with the highest population density had measles cases from the beginning to the end of the epidemic. However, the Central Mountain Range, located longitudinally across Taiwan island, forced the virus diffused from northern to eastern, southeastern, central and finally southwestern areas. Infected individuals in Taipei and Kaohsiung Cities facilitated measles virus island-wide transmission continuously.

The dynamics of measles transmission among different age groups in Taiwan demonstrated that the disease spread from younger (5–9 years of age) to older school-children ($\geq$ 10 years of age) and pre-school children ($\leq$ 4 years of age) in both the urban (Taipei City) (Fig. 4) and suburban areas (Taipei County, data not shown). In addition, more cases occurred among infants (22·2 %) and children older than 10 years (32·7 %) in the second wave than that of the first wave (18·4
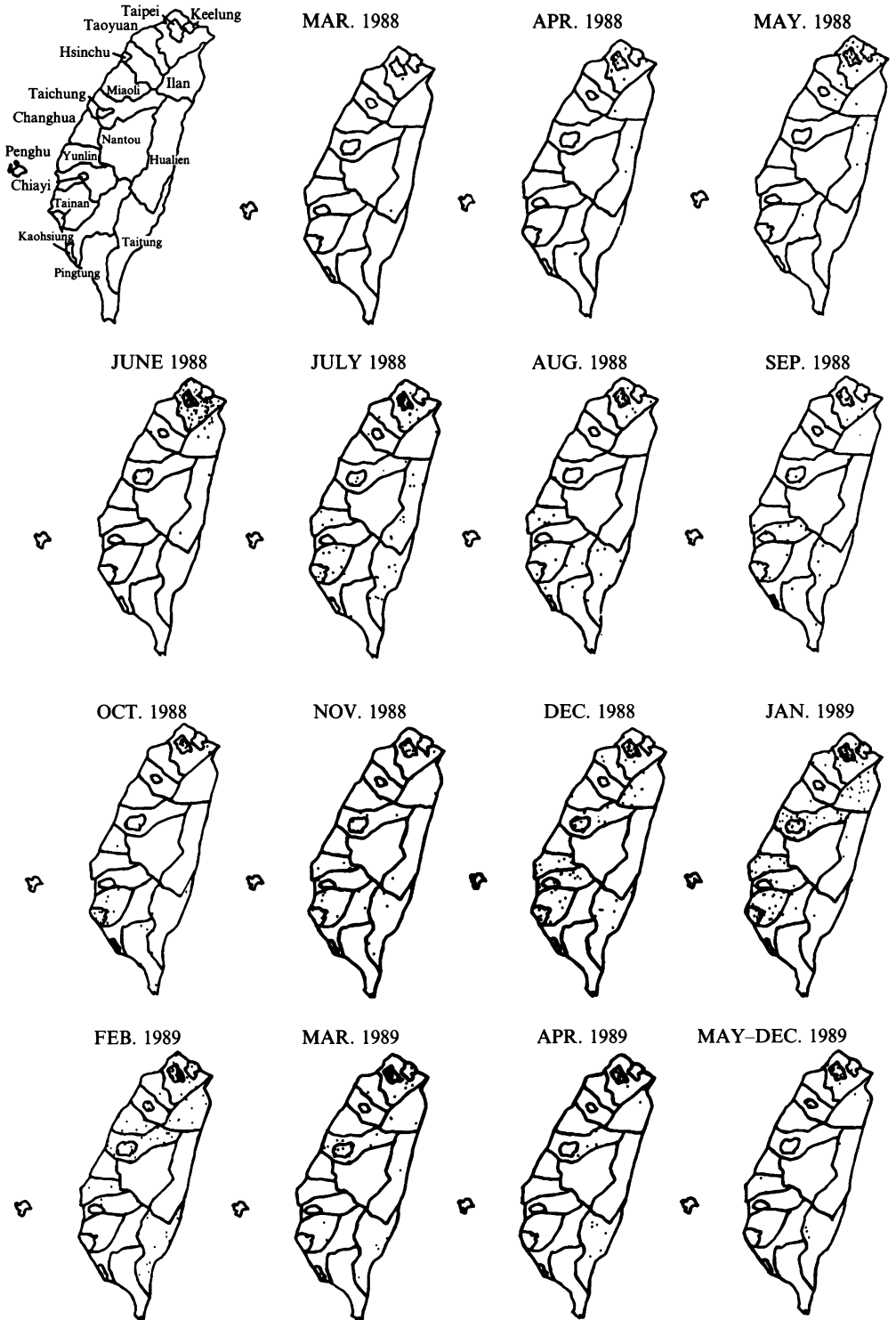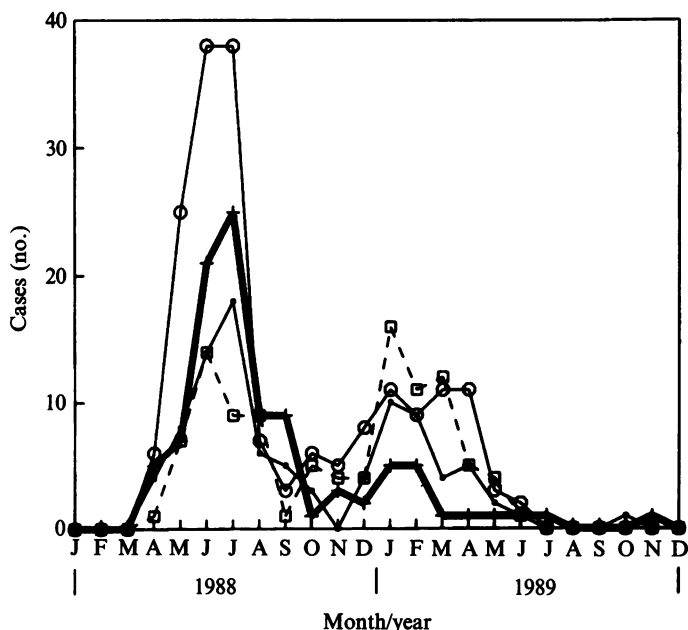
Fig. 3. For legend see opposite.

Fig. 4. Age-specific monthly distribution of reported confirmed measles in Taipei City ($N = 478$). Age (years): ■, < 1; +, 1–4; ○, 5–9; □, ⩾ 10.

Table 3. *Age distribution of reported measles by epidemic wave in Taipei City and Taidung County during 1988–9 epidemic in Taiwan*

	Age distribution (years)				
	< 1	1–4	5–9	⩾ 10	Total
Areas	No. (%)	No. (%)	No. (%)	No. (%)	No. (%)
Taipei City*	94 (19·7)	98 (20·5)	183 (38·3)	103 (21·5)	478 (100)
1st wave†	58 (18·4)	80 (25·3)	128 (40·5)	50 (15·8)	316 (66)
2nd wave†	36 (22·2)	18 (11·1)	55 (34·0)	53 (32·7)	162 (34)
Taidung County‡	20 (25·3)	14 (17·7)	36 (45·6)	9 (11·4)	79 (100)
1st wave†	8 (20·5)	9 (23·1)	19 (48·7)	3 (7·7)	39 (49)
2nd wave†	12 (30·0)	5 (12·5)	17 (42·5)	6 (15·0)	40 (51)

* $\chi^2 = 26\cdot7$, degree of freedom = 3, $P < 0\cdot001$, chi-square test.

† The epidemic waves were classified as: (1) January–November 1988 and (2) December 1988–December 1989.

‡ $P = 0\cdot4$, Fisher's Exact Test (2-tail).

and 15·8%, respectively) in Taipei City ($P < 0\cdot001$, chi-square test). Taidung County which has much lower population density also had a similar trend without statistical significance because of small sample size ($P = 0\cdot4$, Fisher's Exact test) (Table 3).

Fig. 3. The geographical distribution of monthly confirmed measles case numbers during the 1988–9 measles epidemic in Taiwan. The Central Mountain Range, which occupies about half of the island, stretches north to south a distance of 205 miles, and east to west a maximum width of 50 miles. Numerous peaks rise to between 12 000 and 13 000 ft. Therefore, the dynamics of measles transmission in eastern Taiwan is different from the western areas.

Table 4. *Factors associated with delay of measles reporting during the 1988–9 measles epidemic in Taiwan*

| Variables* | Delay time (days)† | | | | Logistic‡ regression | |
	0––9 (N = 801) No.	(%)	≥ 10 (N = 930) No.	(%)	OR(95% CI)	P
Hospitalization						
No	410	(51·2)	383	(41·2)	1·0 referent	
Yes	105	(13·1)	245	(26·3)	1·9 (1.3–2·6)	< 0·001
Unknown	286	(35·7)	302	(32·5)	0·9 (0·8–1·1)	0·37
Reporting sources						
Private clinic	471	(59·5)	389	(42·6)	1·0 referent	
Health station	27	(3·4)	21	(2·3)	1·0 (0·6–1·8)	0·98
Private hospital	120	(15·2)	262	(28·7)	2·1 (1·6–2·8)	< 0·001
Public hospital	117	(14·8)	99	(10·8)	0·7 (0·5–1·0)	0·09
Teaching hospital	56	(7·1)	142	(15·6)	2·6 (1·8–3·8)	< 0·001
Stages of epidemic§						
Starting	6	(0·7)	22	(2·3)	6·9 (2·5–19·3)	< 0·001
Prevalent	740	(92·4)	858	(92·3)	1·6 (1·0–2·4)	0·04
Declining	55	(6·9)	50	(5·4)	1·0 referent	

* Twenty-seven cases without data on medical settings were excluded.

† Six hundred and one cases without data on delay time were not analysed, including 221 (37%) which lacked the data on disease onset, 339 (56%) which lacked data on reporting dates by health bureaux and 41 (7%) lacked both sets of data.

‡ Multiple logistic regression with the following equation: Ln(odds ratio of delay reporting) = $-1\cdot55+0\cdot63$ (hospitalization = yes) $-0\cdot11$ (hospitalization = unkown) $+0\cdot01$ (health station) $+0\cdot74$ (private hospital) $-0\cdot30$ (public hospital) $+0\cdot97$ (teaching hospital) $+1\cdot93$ (starting stage) $+0\cdot45$ (prevalent stage).

§ Stages of epidemics were classified as follows: (1) starting period (Jan.–April 1988, prior to the rise of the first peak); (2) prevalent period (May 1988–March 1989) and (3) declining period (April–Dec. 1989).

Timeliness of measles reporting

Among 1731 reported cases with documented dates of measles onset and reporting, the mean, median, mode and range of the reporting delay were 14, 10, 8 and 0–213 days, respectively. The hospitalized cases [odds ratio (OR) = 1·9, $P < 0\cdot001$], private hospital (OR = 2·1, $P < 0\cdot001$), teaching hospitals (OR = 2·6, $P < 0\cdot001$), the starting stage (OR = 6·9, $P < 0\cdot001$) and prevalent stage (OR = 1·6, $P = 0\cdot04$) of the epidemic had significant associations with the longer reporting delay (≥ 10 days) in multiple logistic regression analysis (Table 4).

DISCUSSION

Measles is a suitable model with which to explore the dynamics of transmission, the mechanism of virus circulation and for developing effective control and eradication strategies for specifically human diseases transmitted via air-borne spread [6–10]. The recent global resurgence of measles epidemics in several developed countries in 1988–91 reinforces the importance of timely measles surveillance and the need to investigate the dynamics of measles transmission

after mass immunization [11–15]. This study illustrates a longer duration of epidemics in Taiwan compared to the pre-vaccination era. The spread of measles in Taiwan started from a suburban area (Taipei County) to a metropolitan city (Taipei City), and then spread to other regional cities and rural areas. It also showed that the epidemic spread from younger (5–9 years of age) to older school-children and then to pre-school children. In addition, the delay in reporting of index cases, the fact that about 10% of primary school-children remained susceptible in spite of a mass immunization programme and past epidemics [14, 16], the low vaccine coverage (73–89%) [17], and a high attack rate among infants facilitated the longer persistence of this island-wide epidemic.

Two characteristics of measles epidemiology, seasonality and age distribution, have changed over 10 years of mass immunization in Taiwan. The peak season of measles epidemics during 1959–81 in May disappeared in the 1984–5 and 1988–9 outbreaks [1, 2]. The 1988–9 epidemic started in March after school opened in late February, similar to the findings of Fine and Clarkson in England and Wales [18]. The different peak month of June–July 1988 and January 1989 coincided with the summer vacation and New Year holidays and spread measles island-wide. Furthermore, mass immunization programmes tend to raise the age of susceptibles from preschool to school-children [19–20]. More cases appeared among 10–14-year-old children in 1988–9 (20%) than in 1976–85 (1·2%) [2] and signified that the problems of a 'honeymoon period' after mass immunization occurred in Taiwan [20]. Infants had a significantly increased risk of measles infection after 9 months of age, implying the urgent need to immunize them at 9 or 6 months once a measles outbreak occurs [21]. The strategy of 2 doses of measles vaccine at 9 and 15 months during 1984–7 should theoretically reduce the attack rate among those children < 5 years of age, but low coverage rate (50%) for the second dose may still increase the overall risk of measles among this birth cohort [22]. A booster dose of measles vaccine (or MMR) among school-children to improve both individual protection and herd immunity is widely applied to many countries [23]. Its optimal age should be determined by seroepidemiological data, particularly the duration of measles neutralization antibody and the protective level. In addition, the spreading of this island-wide epidemic started from younger school-children (5–9 years of age) to older population (⩾ 10 years old) and preschool children (⩽ 4 years of age), consistent with our previous serosurvey in a rural community [14]. It is very likely that the high contact rate among younger school-children was associated with the initiation of the outbreak, particularly in an urban city [24]. In addition, the school holidays certainly facilitated transmission to wider areas. These findings demonstrate the urgent need to establish a school-based surveillance system, to implement school immunization requirements [25] and to investigate the possible role of declining immunity in the effective control of vaccine-preventable diseases in Taiwan.

A long duration and widespread infection were common characteristics of the 1988–9 measles epidemic in Taiwan as well as several other countries during 1988–91 [11–15]. The epidemic diffused from the northern suburban area, where 14% of population were migratory in 1989 [26], to a metropolitan city and then out to other regional cities and rural areas. Interestingly, the majority of the migratory population in Taipei County came from those areas with poor economic

status. Cliff and colleagues also found that measles dispersed from the capital to regional centres and then to the neighbouring hinterlands in most of 16 epidemics in Iceland during 1904–74 [6]. Children from migratory families often missed their immunizations and became the 'dead-corners' of prevention and the 1989–90 measles epidemic in the United States started in such families in Los Angeles, Chicago and Houston [11]. Low vaccine coverage among migratory families was also responsible for the 1982 epidemic of poliomyelitis in Taiwan [27] and the 1989–90 outbreaks of poliomyelitis in mainland China, despite high overall immunization coverage [28]. In addition, widely distributed susceptible pockets plus high population density and frequent hometown visits during holidays may explain this longer and wider epidemic. The slow diffusion of this island-wide outbreak from suburban areas with many migratory families to other areas suggests the importance of monitoring this high risk group and the possibility of effective outbreak control if target populations could be defined immediately and be immunized in time.

Passive surveillance is often associated with delayed and low reporting [29–31]. Because measles is highly contagious and the virus is particularly communicable during catarrhal stage (about 7 days post exposure or 3 days before onset of rash) [32], an index case may cause two further generations of cases by the fourth day after onset of rash. All the index cases in this study were reported to local health bureaux with a delay > 4 days, indicating the ineffectiveness of current reporting systems in detecting outbreaks within the critical 4 day period. Delay in case reporting is also common with other infectious diseases surveillance systems such as shigellosis with a delay of 11 days, a length sufficient to generate secondary and tertiary transmission cycles [29]. Teaching hospitals had the worst reporting delay, possibly because of referral of severe cases from primary medical clinics. Here we could not differentiate the delay of measles reporting due to delay in visiting a physician from that due to a delay of reporting. However, 7 cases were reported to local health bureaux by facsimile within one day of onset of the disease. We believe that integrating the 'sentinel physician' and 'sentinel school-nurse' reporting systems with a network of facsimile could improve the timeliness of infectious diseases surveillance.

National data on disease notification are valuable for evaluating the effectiveness of control programmes and monitoring their future trends, even if such systems are incomplete [33–36]. Completeness of measles reporting in Taiwan is poor, with a physician reporting rate of 6% and sensitivity of 4% in rural areas [14]. In Keelung (a provincial city), none of 20 serologically-confirmed cases was reported to the health bureau [16]. However, the low reporting rate did not distort the major characteristics of this epidemic, because there were multiple sources of reporting from different types of medical institutes. Many cases were classified as 'suspected cases' due to missing medical information on the reporting forms. In addition, the fact that suspected cases were significantly older than confirmed cases (Table 1) and a rubella epidemic concurrently occurred in 1988–9 [14] so that that we used only confirmed cases for analysing epidemiologic characteristics. The low reporting rate, missing data on the reporting forms, and similar symptoms of measles and rubella indicate the need for active investigation of reported cases to collect detailed medical information, ascertain more linked cases, and conduct

serological testing that would differentiate atypical measles from other exanthematous diseases [37, 38].

Measles is a useful indicator with which to evaluate the effectiveness of immunization programmes. The worldwide emergence of large-scale measles epidemics in many developed countries during 1988–91 is alarming. New findings have changed our understandings of measles, including the occurrence of subclinical infection [14, 38, 39] at immunized individuals may transmit the virus [38–40], the lack of life-long immunity in certain individuals [41–42], the genetic variability of the virus [43] and the significance of air-borne transmission [44–46]. Future measles control, in Taiwan and globally, should include: (1) increasing the timeliness and completeness of surveillance, (2) prospective immunological evaluation of vaccinees, (3) reassessment of the roles of immunized and asymptomatic individuals in the dynamics of transmission, and (4) utilization of local seroepidemiological data as well as residual maternal antibody levels for optimizing age and doses of immunization programmes.

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