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Taiwan's Strategy Toward Measles Elimination

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Abstract

Background: Sustaining measles elimination in the post-elimination era presents increasing challenges due to global resurgence and waning vaccine-induced immunity. We aimed to evaluate epidemiological trends, vaccination strategies, and population immunity associated with achieving and maintaining measles elimination in Taiwan. **Methods:** We conducted a comprehensive analysis of national surveillance data from 1991 to 2024, including case notifications, viral genotypes, vaccination coverage rates (VCR), and surveillance performance indicators. Three population-based seroprevalence surveys conducted between 2002 and 2020 were reviewed to assess age-specific immunity. Descriptive analyses were performed to characterize long-term epidemiological and immunological trends. **Results:** Since 1993, annual measles cases have remained below 50, with non-imported incidence consistently <1 per million. Coverage for both MMR1 and MMR2 has exceeded 95% since 1998, with MMR1 coverage >97% since 2009. Genotyping evidence confirms interruption of endemic transmission since 2006. Seroprevalence surveys revealed declining antibody levels among adolescents and young adults, with seropositivity as low as 36.7% in specific cohorts. Despite this, transmission following importations has remained limited, with minimal secondary spread. **Conclusions:** Taiwan has successfully sustained measles elimination through high vaccination coverage, robust surveillance, and targeted interventions. Although serological evidence indicates waning immunity, epidemiological data suggest preserved population-level protection, likely mediated by immunological memory. Targeted booster strategies for high-risk groups may be more appropriate than universal additional dosing in post-elimination settings.

Keywords: measles elimination; MMR Vaccine; seroprevalence; waning immunity; immunization program; genotypes; Taiwan

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1. Introduction

Measles remains one of the most contagious vaccine-preventable diseases despite the availability of a safe and effective vaccine. Although global vaccination efforts have substantially reduced morbidity and mortality, recent resurgences highlight the fragility of measles elimination, particularly amid declining routine immunization coverage and increased international travel. Prior to the introduction of the measles vaccine in 1963 and subsequent widespread immunization efforts, major epidemics occurred approximately every two to three years, resulting in an estimated 2.6 million deaths annually [1]. Nearly all children get measles by age 15 [2]. During 2000–2023, an estimated 60.3 million measles deaths were averted by vaccination [3].

Taiwan introduced a live-attenuated measles vaccine (MV) in 1968 and, in 1978, implemented a routine immunization program providing MV to infants at 9 and 15 months of age. However, suboptimal early coverage led to periodic outbreaks, with three major outbreaks in 1985 (n=2,219), 1988 (n=1,386), and 1989 (n=1,060). In response, the Department of Health (reorganized as the Ministry of Health and Welfare in 2013) launched a comprehensive national program from 1991 to

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1996 to eradicate poliomyelitis, measles, congenital rubella syndrome (CRS), and neonatal tetanus (NT). In the ensuing years, the immunization and surveillance programs have been strengthened and fully integrated into the health care system. Under the program, measures were implemented to strengthen surveillance systems, case investigation, vaccination coverage, vaccine cold-chain management, physician and healthcare worker education, and diagnostic technology. Measles had been effectively controlled. In 2010, the national measles elimination program was reformulated to align with the World Health Organization (WHO) Western Pacific Regional Office (WPRO) guidelines, which set a target for regional measles elimination [4,5].

This study provides a comprehensive evaluation of Taiwan's strategy for measles elimination, drawing on over three decades of integrated epidemiological, immunological, and virological data. In addition, we examine the implications of waning vaccine-induced immunity in a post-elimination setting.

2. Materials and Methods

2.1. Surveillance and Immunization Data Collection

Measles is a notifiable disease in Taiwan, requiring reporting within 24 hours and laboratory confirmation. Epidemiological and laboratory data were obtained from the Taiwan Centers for Disease Control (Taiwan CDC). All specimens for reporting suspected cases will be sent to the Center for Diagnostics and Vaccine Development of Taiwan CDC for Disease Control for laboratory testing. The Measles and rubella laboratory testing algorithm are shown in Figure 1. Vaccination records were retrieved from the National Immunization Information System (NIIS), a centralized database covering childhood immunizations nationwide.

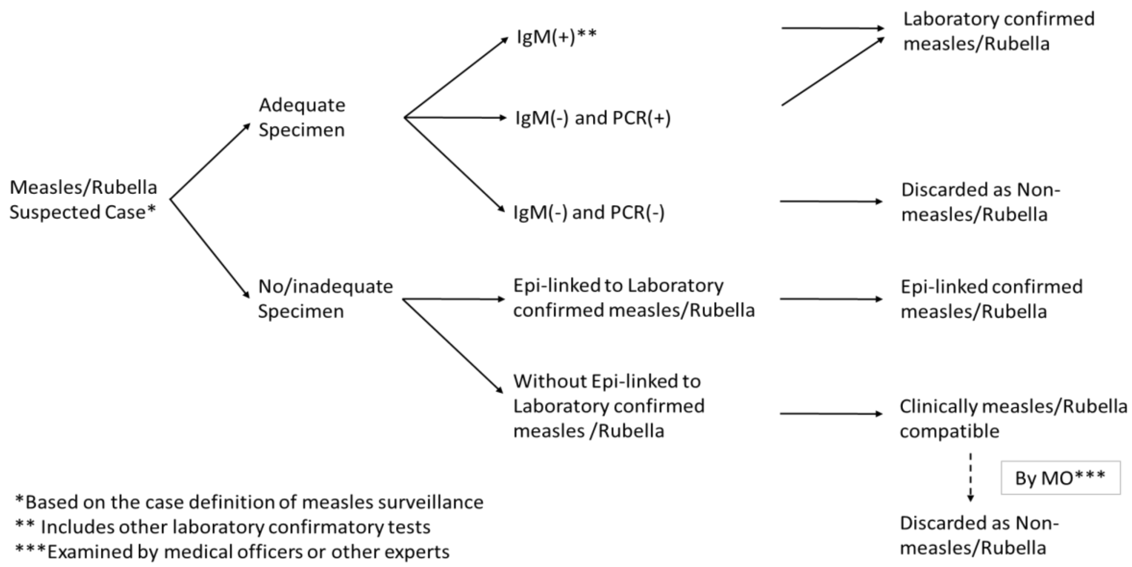

Figure 1. Measles and rubella diagnostic and case classification algorithm.

2.2. Data analysis

To monitor trends in measles immunity across different age groups and provide a robust evidence base for refining vaccination policies, three important seroprevalence surveys were conducted between 2002 and 2020.

- The first survey (2002–2007): Utilized residual sera from a cohort study titled "Prevalence Survey of Triple-High Status" (participants aged ≥15 years).
- The second survey (2007–2008): Employed a multi-stratified design to sample the general population, ranging from infants (< 1 year) to seniors (≥65 years).
- The third survey (2019–2020): Utilized residual blood samples from the "Taiwan National Immunity Longitudinal Survey" (participants aged 3–59 years).

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Findings from these periodic surveys were collated and analyzed to assess population-level immunity. Furthermore, we analyzed epidemiological and immunization data from all notified measles cases maintained by the Communicable Diseases Division of Taiwan CDC and NIIS. Data retrieved for each case included age, gender, occupation, date of symptom onset, date of diagnosis, clinical symptoms, and travel history. Laboratory test results were also integrated into the dataset. All data collation and statistical analyses were performed using Microsoft Excel.

3. Results

3.1. Long-Term Epidemiological Trends

From 1993 to 2024, measles incidence remained consistently low, and the annual number of measles cases remained below 50—except in 2019, when a resurgence of global measles activity led to multiple imported cases and subsequent clusters in healthcare settings and restaurants (Figure 2). A total of 534 confirmed cases were reported, including 342 (64%) non-imported cases and 192 (36%) imported cases. Most of the imported cases were either infected in Southeast Asia countries (53.7%) or China (27.5%). Prior to 2016, imported cases primarily originated from Mainland China. However, after 2016, the majority of infections shifted to Southeast Asian countries. Notably, there have been no imported cases from China recorded since 2020.

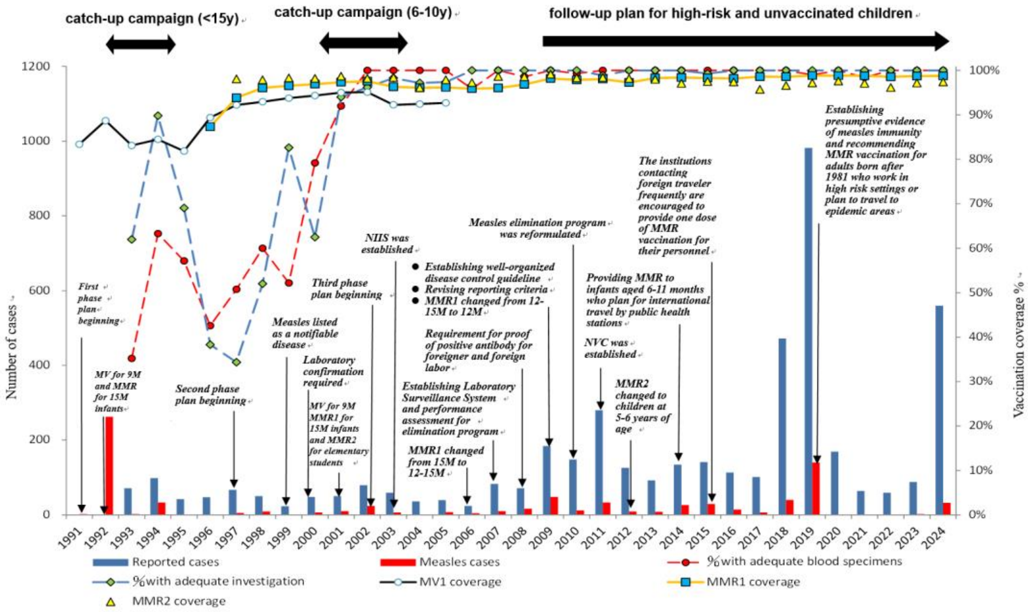

Figure 2. Trends of measles cases and the measles control program in Taiwan from 1991 to 2024.

From 2001 to 2024, a total of 478 confirmed cases were reported, including 39.5% imported cases. Most domestic cases were epidemiologically linked to importations (Figure 3). Over the past seven years (2018–2024), there were 216 confirmed cases, including 131 (60.7%) non-imported cases and 85 (39.3%) imported cases. the top three countries of origin for imported cases have been Thailand (24 cases), Vietnam (23 cases), and the Philippines (9 cases). Most cases were among individuals born after 1981(Figure 4). They were predominantly young adults aged 20–39, as well as infants under 1 year old who were too young to be vaccinated. (Figures 4 and 5).

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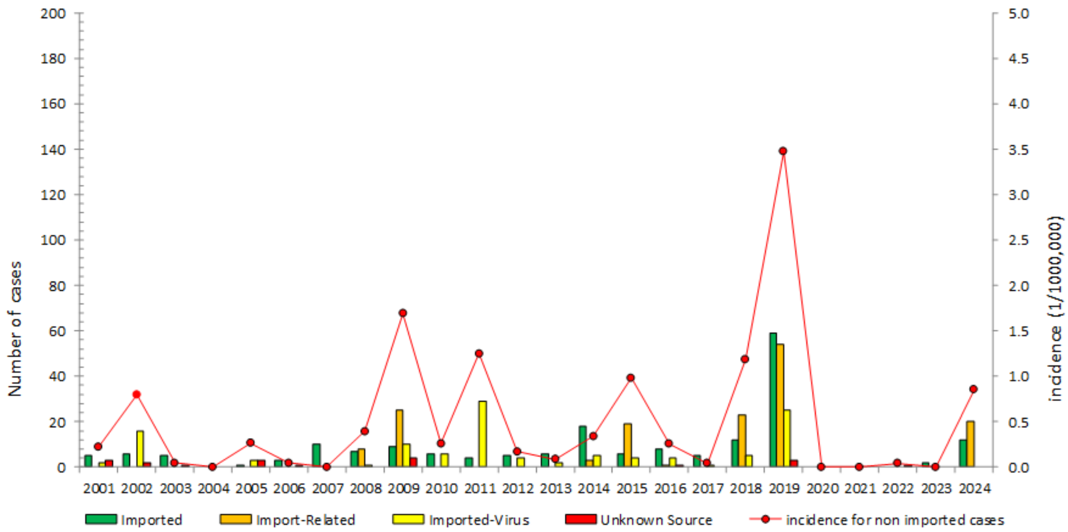

Figure 3. Trends in measles cases and the incidence of non-imported cases in Taiwan from 2001 to 2024.The average annual incidence rate for non-imported cases from 2001 to 2024 was 0.4 per 1 million, and all the annual incidence rates for non-imported cases were less than 1 per 1 million except for 2009, 2011, 2018, and 2019. * Imported-virus case: A case lacking an epidemiologic link to an imported case, but the infecting virus is proven to be an imported virus by genotyping.

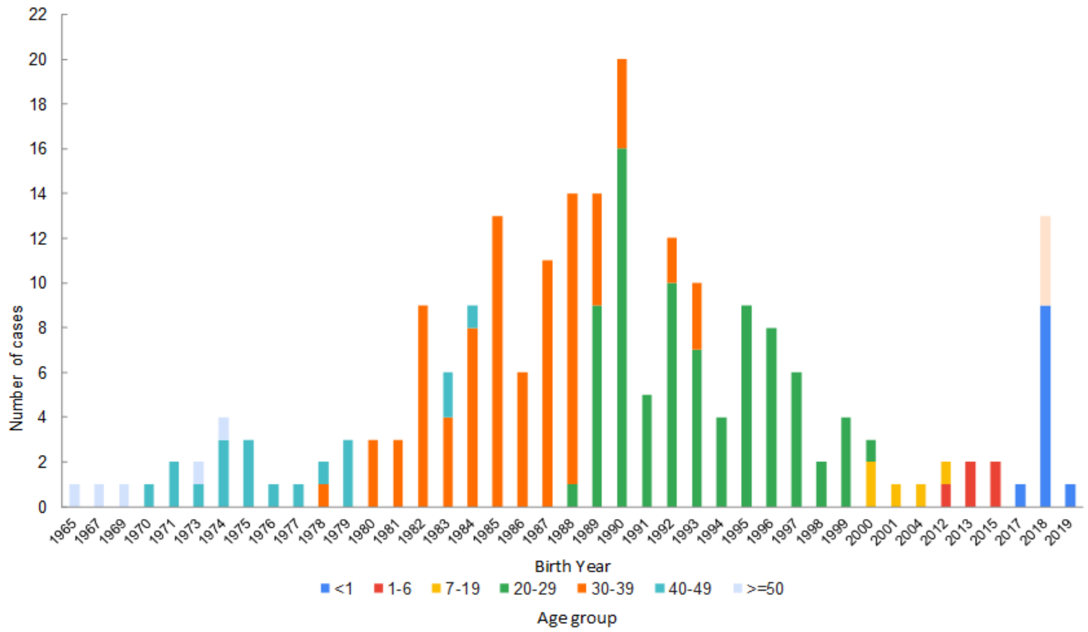

Figure 4. Distribution of measles cases by birth year and age from 2018 to 2024. Cases born or before 1982 accounted for only 13% of all cases; furthermore, only one case was born before 1966, and this individual was an immunocompromised patient with cancer.

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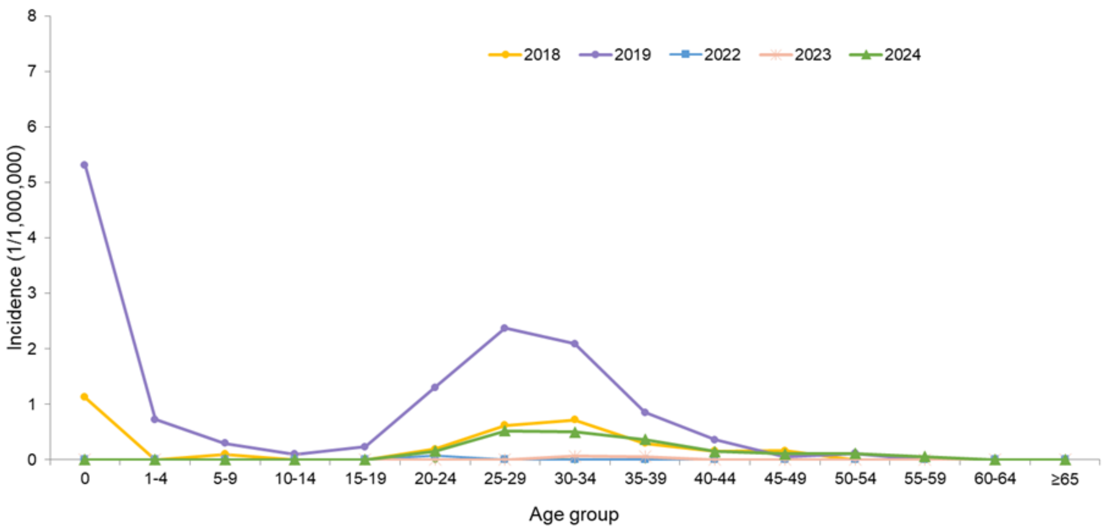

Figure 5. Age-specific Incidence of Measles Cases in Taiwan from 2018 to 2024*. In 2019, the average single-year population of the 25–29 age group was 1.9 times that of the age-0 cohort. The elevated infant measles incidence that year is attributed to a diminished birth cohort combined with an increase in imported cases and subsequent household clusters linked to severe regional outbreaks in neighboring countries. *There were no confirmed cases in 2020 and 2021.

3.2. Vaccination Policy and Coverage Rates

Taiwan has had a routine measles vaccination schedule for infants and children since 1978, with two doses of MV given at 9 months and 15 months. In 1991, the eradication program was initiated, and a regulation requiring the examination of immunization records for all elementary school entrants was established to monitor vaccination status and improve vaccination coverage rates. In 1992, one dose of MV was given at 9 months of age, and one dose of measles-mumps-rubella vaccine (MMR) was administered at 15 months of age. To improve coverage rates and ensure that people born after 1976 have received at least 2 doses of measles-containing vaccine (MCV) by age 1, two catch-up campaigns were implemented. From 1992 to 1994, the campaign targeted junior high school students through preschool children (1976 to 1990 birth cohort), while the campaign of 2001 to 2004 was aimed at elementary school students (1990 to 1994 birth cohort). Since 2001, the second dose of the measles-mumps-rubella vaccine (MMR2) has been routinely administered to elementary school students. In 2006, the first dose of the measles-mumps-rubella vaccine (MMR1) was changed from 15 months to 12-15 months. However, there were some unvaccinated children aged 1 to 2 years old infected with measles and induced some clusters during 2008 and 2009. The time for administering the MMR1 was revised from 12 to 15 months of age to 12 months of age since 2009. In 2012, the age for the MMR2 was changed to 5 to 6 years old. (Figure 2)

Between 1998 and 2024, immunization coverage for MMR1 by age 2 years was consistently high, at 95.9% or higher. Regarding MMR2, coverage rates ranged from 96.1% to 99.1% among primary school entrants (aged 6–7 years) from 1997 to 2011, and from 95.7% to 98.2% among children aged 5–6 years from 2012 to 2024. (Figure 2)

3.3. Quality of Epidemiological and Laboratory Surveillance Systems [6]

Prior to 1999, measles was classified as a reportable rather than a notifiable disease in Taiwan. To enhance detection sensitivity, the Taiwan CDC implemented a dual active and passive surveillance framework. In 1991, a "zero-reporting system" was established, targeting clinical sites specialized in pediatrics, internal medicine, and family medicine. Local health authorities conducted weekly telephone inquiries to monitor suspected cases of acute flaccid paralysis, measles, rubella, and neonatal tetanus. These active surveillance data were cross-referenced with the passive

Notifiable Disease Surveillance System. Following a period of stable epidemiological control, the zero-reporting measure was discontinued in 2015.

In 2007, Taiwan CDC began using the Laboratory Surveillance System—originally designed for influenza and enterovirus—to screen patients with symptoms such as rash, fever, cough, coryza, or conjunctivitis. Between 2007 and 2024, this proactive system identified only 2 confirmed measles cases, reflecting low community transmission. Taiwan has a high-quality surveillance system that is sensitive enough to detect imported and import-related cases.

Since 2000, laboratory confirmation has been mandatory for all suspected measles cases. Standardized specimen collection (throat swabs, urine, and whole blood) for virologic testing was formalized in 2002. During the third phase of the measles eradication program (2002–2006), there were significant improvements in the rates of adequate specimen collection and epidemiological investigation (Figure 2). To maintain high surveillance quality, the Taiwan CDC established performance indicators to assess local health departments' performance. In accordance with the WHO Western Pacific Regional Office (WPRO) guidelines for monitoring measles elimination [7], surveillance quality indicators from 2020 to 2024 were evaluated. Although the annual reporting rates of discarded non-measles cases fell below the target threshold between 2020 and 2023—a decline primarily attributed to reduced clinical suspicion and reporting activity following two years of zero cases and subsequent minimal incidence (1–2 cases)—all other surveillance performance indicators consistently exceeded established targets**.** (Table 1)

Table 1. Performance of indicators to monitor progress toward measles elimination from 2020 to 2024 in Taiwan.

Indicators	**Parameters**	
	Target	**2020-2024**
Incidence		
Incidence of all measles cases per million total population (exclude imported cases)	< 1	0.00 – 0.85
Population immunity		
National MCV1 coverage	≥ 95%	98.6% – 98.8%
National MCV2 coverage	≥95%	96.2% – 97.6%
Quality of the surveillance system		
Epidemiologic surveillance indicators		
% of suspected cases reported within 24 hours	≥80%	96.9% –100.0%
Annual reporting rate of discarded non-measles cases per 100,000 population at the national level*	≥2 per 100,000	0.39 – 2.35
% of suspected cases with adequate investigation	≥80%	100%
Laboratory indicators		
% of suspected cases with adequate blood specimen	≥80%	96.7% – 100%
% of blood specimens received at the TCDC laboratory within five days of collection	≥80%	100%
% of specimens with results reported within four days of receipt at the designated laboratory	≥80%	99.0% – 100%
% of outbreaks with specimens collected for virus detection	≥80%	100%
% of virus detection and genotyping completed within two months of receipt at the lab	≥80%	100%

Abbreviations: MCV, measles-containing vaccines; TCDC, Taiwan Centers for Disease Control. *The specimens obtained from reported measles and rubella cases undergo testing for both diseases as part of routine laboratory surveillance. Therefore, the numbers of suspected cases were combined for calculation.

3.4. Seroprevalence Survey

The measles seroprevalence surveys conducted between 2002 and 2007 revealed that natural infection cohorts born before 1976 maintained high seropositivity rates (93.3–98.5%), the 1976-1986

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birth cohorts had a lower measles seropositive rate (81.7-84.7%) than that of the 1969-1975 cohorts (93.3-94.0%) (Table 2). These findings suggest that vaccine-induced immunity may last for a shorter period than that acquired through natural infection. Longitudinal observation of the 1976–1986 cohort showed a 3% decline in seropositivity rate over a five-year period. Notably, the 2007–2008 study found that the seropositivity rate in the 1982–1987 cohort dropped to 50.6%, while the equivocal rate rose to 30.6% (Table 2). The declining seropositive rate in vaccinated cohorts might be due to a lack of natural booster infections and waning immunity [8].

Table 2. Measles seroprevalence study conducted in Taiwan from 2002 to 2020.

Year of serum sample obtained	2002				2007			2007-2008				2019-2020			
Source of the study population	Prevalence Survey of Triple-High Status (≥15 years old)							Population in Taiwan				National Immunity Longitudinal Survey			
Sampling method	Stratified random sampling (Cohort study)							Stratified random sampling				Simple random sampling			
Antibody test	ELISA (Kit brand: Siemens Enzygnost)							ELISA (Kit brand: Siemens Enzygnost)				ELISA (Kit brand: Euroimmun)			
	Birth cohort	Case number	P^a	E^b	Case number	P^a	E^b	Age group	Case number (Birth cohort)	P^a	E^b	Age group	Case number (Birth cohort)	P^a	E^b
								>65	251 (~1942)	98.8%	1.2%				
								56-65	250 (1942-52)	100%	0%				
	1958-68	204	98.0%	1.0%	204	98.5%	1.0%	46-55	267 (1952-62)	97.8%	1.5%	55-59	190 (1959-65)	97.4%	1.6%
	1969-75	300	94.0%	5.0%	300	93.3%	4.0%	36-45	263 (1962-72)	95.8%	3.0%	50-54	201 (1964-70)	93.0%	2.0%
												45-49	210 (1969-75)	89.1%	1.4%
	1976-86	300	84.7%	10.3%	300	81.7%	10.0%	26-35	245 (1972-82)	87.3%	8.2%	40-44	211 (1974-80)	81.0%	5.2%
												35-39	203 (1979-84)	66.5%	9.4%
								21-25	255 (1982-87)	50.6%	30.6%	30-34	197 (1984-89)	48.2%	10.2%
								17-20	408 (1987-91)	53.9%	23.3%	25-29	201 (1989-95)	41.8%	11.4%
								13-16	302 (1991-95)	56.6%	19.2%	20-24	209 (1994-2000)	54.6%	6.7%
								9-12	421 (1995-99)	63.2%	22.1%	15-19	210 (1999-2005)	36.7%	8.1%
								5-8	409 (1999-2002)	71.9%	17.1%	10-14	215 (2004-2010)	64.7%	8.4%
								1-4	446 (2002-2006)	78.9%	7.0%	5-9	213 (2009-2014)	84.0%	5.2%
								<1	35 (2006~)	2.9%	0%	3-4	140 (2014-20017)	92.9%	0.7%
								Total	**3,552**	**74.7%**		**Total**	**2,400**	**70.1%**	

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[a] P=Positive (Siemens Enzygnot: >300 mIU/mL ; Euroimmun: ≥ 275 IU/L). [b] E=Equivocal (Siemens Enzygnost: 150~300 mIU/mL ; Euroimmun:200~<275 IU/L).

A recent seroprevalence survey conducted between 2019 and 2020 found an overall measles seropositivity rate of approximately 70% (1,683/2,400). Age-specific analysis revealed a U-shaped distribution of antibody prevalence. Seropositivity rates for ages 10-39 years were consistently below 80%, with the nadir in the 15–19 age group (36.7%). Conversely, the highest seropositivity was identified in the 55–59 age group (97.4%), followed by the 3–4 and 50–54 age groups (both at 93%). (Table 2)

3.5. Genotyping Evidence

Genotyping of isolated measles viruses in Taiwan from 2001 to 2024 is summarized in Table 3. Between 2001 and 2017, genotype H1 was the most prevalent, identified in 56.1% (120/214) of all detected viruses. Although H1 was detected annually (except in 2004 and 2011), 88.7% (86/97) of genotype H1 cases identified from 2006 to 2017 were linked to known imported cases. During this period, 11 cases (one in 2008, three in 2012, four in 2015, and three in 2016) had no traceable source. Their viral sequences were closely related to lineages circulating endemically in China [9–11], indicating that genotype H1 was not an endemic genotype in Taiwan after 2006. Other genotypes, including D3, D4, D5, D8, D9, G3, and B3, were detected sporadically and were primarily associated with imported cases, with no evidence of sustained annual transmission. [11]

Table 3. Genotypes of Measles Virus in Taiwan from 2001 to 2024.

Year	Measles Virus Genotypes							
	H1	D3	D4	D5	D8	D9	G3	B3	All
2001	5(3)[a]	0	0	0	0	0	0	0	5(3)
2002	14(3)	1(1)	0	1	0	0	0	0	16(4)
2003	1(1)	2(2)	0	1(1)	0	1(1)	0	0	5(5)
2004	0	0	0	0	0	0	0	0	0
2005	3	0	0	1(1)	0	0	0	0	4(1)
2006	3(3)	0	0	0	0	0	0	0	3(3)
2007	3(3)	0	0	3(3)	0	1(1)	0	0	7(7)
2008	8(7)	0	0	1(1)	0	2(2)	0	0	11(10)
2009	30(30)	0	0	0	1(1)	0	10	0	41(31)
2010	3(3)	0	0	0	0	7(1)	0	0	10(4)
2011	0	0	2(2)	0	0	27(1)	0	0	29(3)
2012	5(2)	0	0	0	3(2)	0	0	0	8(4)
2013	5(5)	0	0	0	2	0	0	0	7(5)
2014	5(5)	0	0	0	4(4)	1(1)	0	12(7)	22(17)
2015	27(23)	0	0	0	0	0	0	0	27(23)
2016	7(4)	0	0	0	6(5)	0	0	0	13(9)
2017	1(1)	0	0	0	4(4)	0	0	1	6(5)
2018	0	0	0	0	35(31)	0	0	3(2)	38(33)
2019	0	0	0	0	102(82)	0	0	34(27)	136(109)
2020	0	0	0	0	0	0	0	0	0
2021	0	0	0	0	0	0	0	0	0
2022	0	0	0	0	0	0	0	0	0
2023	0	0	0	0	2(2)	0	0	0	2(2)
2024	0	0	0	0	12(7)	0	0	20(18)	32(25)
Total	120(93)	3(3)	2(2)	7(6)	171(138)	39(7)	10	70(54)	422(303)

a: The numbers in parentheses were associated with imported cases supported by epidemiological evidence.

Since 2018, measles virus genotypes B3 and D8 have been the only strains circulating in Taiwan. In 2018, 35 cases of genotype D8 were confirmed, 31 of which were import-related, while three cases were identified as genotype B3 (including two import-related cases). Although the 2019 epidemic was characterized by multiple importations and subsequent secondary transmission, strict border controls during the COVID-19 pandemic (2020–2021) resulted in zero confirmed cases, indicating no endemic transmission. Following this period, two imported D8 cases were reported in 2023. In 2024, 20 cases of genotype B3 were confirmed (18 of which were import-related), alongside 12 cases of genotype D8. Of the D8 cases, seven were import-related, and five formed a local cluster. Sequence analysis of the five local cluster cases revealed that they differed from the D8 sequences of the 2023 cases and were identical to those of cases imported from Thailand and Cambodia during the same period.

4. Discussion

Taiwan introduced the measles vaccine into its routine childhood immunization program in 1978. In the early stages, suboptimal vaccination coverage led to periodic outbreaks every 2 to 3 years. However, measles was brought under effective control by 1993—only 15 years after the program's inception. This milestone was primarily attributed to the 1991 implementation of the "Four-Phase Plan to Eradicate Poliomyelitis, Measles, Congenital Rubella Syndrome (CRS), and Neonatal Tetanus (NT)." Through this meticulously designed framework, Taiwan consistently developed and executed robust prevention and control strategies.

A pivotal policy established in 1991 mandated immunization record verification for all elementary school entrants. By implementing systematic reviews of routine vaccination histories and catch-up mechanisms for kindergarten and primary school students, Taiwan has maintained consistently high coverage rates for measles and other essential childhood vaccines. Furthermore, two important MMR vaccination catch-up campaigns targeting school-aged children were conducted between 1992–1994 and 2001–2004. These initiatives significantly increased measles vaccination rates and national herd immunity. Given that school enrollment in Taiwan exceeds 99.9%, school-based mass vaccination campaigns have proven highly effective. For instance, the MMR vaccination campaign conducted from 2001 to 2004, which targeted students in the 1st through 5th grades, achieved a coverage rate exceeding 98% for each grade level. Both MMR1 and MMR2 coverage rates have remained above 95% since 1998. By utilizing these two targeted campaigns, the eradication program enabled birth cohorts from 1976 to 1994 to rapidly achieve high vaccination rates and comprehensive immunity. This strategic approach successfully closed the immunity gaps present in earlier cohorts. Consequently, from 1995 to 2008, annual incidence rates for non-imported cases remained below 1 per million.

In Taiwan, a significant proportion of foreign spouses originates from China and Southeast Asia. Frequent cross-border travel by these families increases the risk of measles virus exposure among unvaccinated children. During 2008–2009, severe measles outbreaks were reported in several neighboring countries, including China, Cambodia, Malaysia, the Philippines, and Vietnam. Following these regional surges, Taiwan recorded 16 imported cases during this period, primarily from China (n=7) and Vietnam (n=6). Notably, six of these cases involved children aged 0–4 years born to foreign spouses. These infections occurred either in infants below the eligible vaccination age or in children who traveled to high-endemicity regions prior to receiving their scheduled MCV. Upon returning to Taiwan, one infant (<1 year) and two toddlers (1-year-old) subsequently initiated hospital-based clusters. To mitigate transmission risks in children aged 1–6 years, the administration age for the MMR1 was standardized to 12 months in April 2009, narrowing the previous 12–15-month window. Furthermore, the Taiwan CDC integrated the NIIS with National Immigration Agency records to enhance the surveillance of unvaccinated children. Under this integrated framework, the

NIIS automatically alerts local health agencies when a child without a documented MMR record arrives in Taiwan. Public health nurses then conduct active follow-up and vaccination outreach. Through these strategic applications of the NIIS [12], MMR1 coverage has consistently exceeded 97% since 2009 (Figure 2), resulting in a significant decline in the annual measles case count among the 1–6 age cohort. (Table 4)

Table 4. Annual distribution of measles cases among children aged 1–6 years from 2009 to 2024. a: Documented completing one dose of MMR vaccination b: Foreign child c: Foreign national father refused MMR vaccination for the child.

Age (years)	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
1	7	2	1	1	0	4	1 [b]	1 [c]	1	0	3	0	0	0	0	0
2	5	0	0	0	0	1 [a]	0	0	0	0	0	0	0	0	0	0
3	1	0	0	0	0	0	0	0	0	0	2(1 [a],1 [b])	0	0	0	0	0
4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	2	0	0	0	0	0	0	0	0	1 [a]	1 [a]	0	0	0	0	0
6	1	0	1	0	0	0	0	0	0	0	1 [b]	0	0	0	0	0
Total cases	**17**	**2**	**2**	**1**	**0**	**5**	**1**	**1**	**1**	**1**	**7**	**0**	**0**	**0**	**0**	**0**

Genotypic analysis from 2001 to 2024 further corroborates these findings (Table 3). Genotype H1 cases, mostly originating from China, were detected annually between 2001 and 2017 (excluding 2004 and 2011). Epidemiological evidence since 2006 indicates that the majority of genotype H1 cases were import-related. Following China's intensified elimination efforts, its national incidence has declined sharply since 2017. Correspondingly, genotype H1 has not been detected in Taiwan since 2018, replaced by genotypes D8 and B3 from Southeast Asia. This genotyping evidence confirms the interruption of endemic transmission after 2006. According to the WHO verification criteria [4,6,13], Taiwan has successfully sustained measles elimination.

Synthesizing these lines of evidence, Taiwan achieved effective control and elimination shortly after the vaccine's introduction, significantly earlier than many neighboring countries. However, this success has led to a lack of "natural boosting" from the circulating wild-type virus. The 2007–2008 seroprevalence survey revealed that antibody levels waned over time in post-1981 vaccination-era cohorts. The seropositivity rate reached its nadir in the 21–25 age group—approximately 15 years after the MMR2—at only 50%, with an additional 30.6% falling into the equivocal range. In contrast, the naturally infected cohorts born before 1972 maintained seropositivity rates above 95%. For those born between 1972 and 1982, the seropositivity rate remained near 90% (Table 1), likely because they were either infected naturally during the early stages of the vaccination program or received natural boosting from lingering outbreaks. These findings align with studies from other highly immunized or eliminated countries, showing significantly higher seroprevalence in older, naturally infected populations and notable waning immunity in young adults born after the implementation of national vaccination programs [8,14–17].

The existing literature indicates that declining antibody titers do not necessarily indicate a total loss of protection. While vaccine-induced antibodies may wane or become undetectable, robust immunological memory often persists [18,19]. Most vaccinated individuals can mount a protective immune response upon exposure to the measles virus. Although secondary vaccine failure (SVF) may occur occasionally due to waning immunity, it does not appear to play a significant role in sustained measles transmission [18]. Despite the 2007–2008 findings showing a drop in seropositivity among young adults, Taiwan's long-term epidemiological trends demonstrate that, since 1993, annual cases have remained extremely low and limited to cases imported from abroad (Figure 2). The absence of sustained community transmission suggests that the vaccinated cohorts retain enough immunological memory to maintain effective population-level immunity.

The global resurgence of measles during 2018–2019 led to a significant increase in imported cases in Taiwan. In 2018, an imported index case triggered a notable cluster involving airline crew members, passengers, and ground staff. This was followed by multiple importations in 2019, resulting in several healthcare-associated clusters. Crucially, epidemiological investigations revealed that many infected healthcare workers had documented two-dose MMR vaccination histories. These occurrences suggest that infection may occur despite prior vaccination, potentially due to high-dose exposure in clinical settings or waning vaccine-induced immunity.

While these outbreaks were primarily contained within institutional settings and limited to identified contacts, they prompted a critical re-evaluation of national policy. Drawing on domestic and international evidence on measles antibody decline associated with MMR2 response [8,15], the Taiwan Advisory Committee on Immunization Practices (ACIP) established revised operational criteria for measles and rubella immunity in 2019. Under these guidelines, an individual is considered immune if they meet at least one of the following criteria:

- Birth year prior to 1981 (provided the individual is not immunocompromised);
- Laboratory-confirmed history of measles or rubella infection;
- Serological evidence of positive measles/rubella antibody titers within the previous five years;
- Documented administration of two MMR doses (with a minimum interval of 28 days) after one year of age, provided the final dose was received within the last 15 years.

To safeguard healthcare infrastructure, the Taiwan CDC integrated the MMR vaccination status of healthcare workers born in or after 1981 into national hospital infection control audit standards. Hospitals were mandated to implement comprehensive catch-up programs, providing an additional MMR dose to healthcare workers who either lacked a two-dose history or had received their last dose more than 15 years prior. Furthermore, based on risk assessments derived from the 2018–2019 clusters, the Taiwan CDC identified high-risk groups for infection and transmission, including travelers to endemic areas, healthcare workers, childcare workers, and personnel with frequent professional contact with foreign nationals. A booster MMR dose is formally recommended for individuals in these high-risk categories born in or after 1981 who do not meet the immunity criteria.

To evaluate whether the birth-year threshold (born before 1981) for presumed measles immunity required revision, the Taiwan CDC conducted a second national seroprevalence survey in 2019–2020,12 years after the previous assessment. Age-specific analysis across both surveys revealed a consistent U-shaped distribution of antibody prevalence (Figure 6). Specifically, seropositivity peaked at approximately 2 years of age (the first MMR dose is administered at 12–15 months), followed by a gradual decline. While a transient increase in seropositivity was observed following the second MMR dose (administered at age 5 or 6–7), it subsequently declined with age. In the 2007–2008 and 2019–2020 surveys, antibody positivity increased significantly among individuals aged 26 and 36 years, respectively. These cohorts, representing the pre-1981 birth generations, exhibited markedly higher seropositivity than those born in the vaccination era; in both surveys, seropositivity exceeded 97% for individuals aged 55 and older (Table 1). However, the 2019–2020 survey identified a more pronounced decline in the adolescent population (aged 11–18) compared to the same age group in the 2007–2008 study. Notably, seropositivity reached a nadir of only 36% in the 17–18 age group, suggesting that vaccine-induced antibodies drop below 40% approximately ten years after the MMR2.

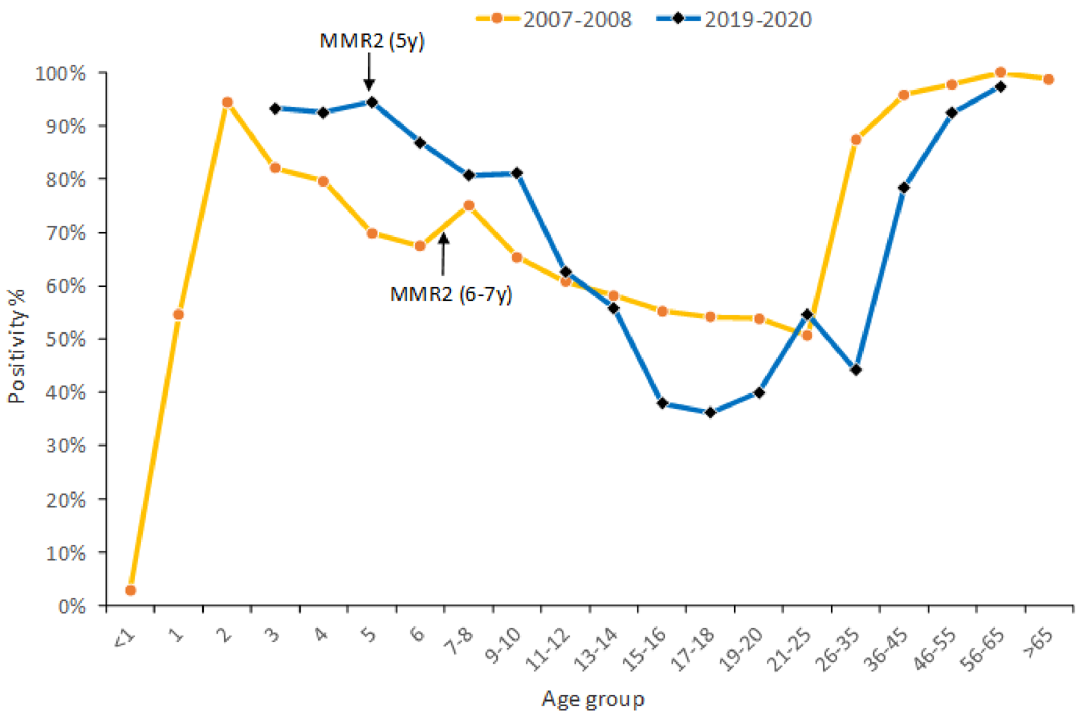

Figure 6. Comparison of seroprevalence of measles by age conducted in 2007-2018 and 2019-2020. Following the 2012 policy shift, the MMR2 vaccination schedule was advanced from primary school entry (ages 6–7) to age 5. Consequently, the MMR2 vaccination age was 6–7 years during the 2007–2008 survey period, whereas it was 5 years during the 2019–2020 survey.

Conversely, the 21–25 age group in the 2019–2020 survey did not follow the expected downward trend but instead showed an increase in seropositivity (Figure 6). This deviation is likely attributable to the Taiwan CDC's 2019 initiative, which recommended MMR booster vaccinations for adults born after 1981 who work in high-risk settings or plan travel to endemic areas. Furthermore, we observed that seropositivity among naturally infected individuals and vaccinated cohorts born before 1981 was lower in the 2019–2020 survey than in 2007–2008. This decline in both the "naturally infected" and "naturally boosted" cohorts suggests that antibody levels still wane over time in the absence of circulating wild-type virus, albeit at a slower rate than vaccine-induced immunity. Synthesizing epidemiological data from 2018–2024 (Figure 4) and evidence from the 2019–2020 survey, the Taiwan ACIP updated the criteria for measles immunity in 2025. The threshold of "Birth before 1981 (and not immunocompromised)" was formally adjusted to "Birth before 1966 (and not immunocompromised)".

While our 2019–2020 survey indicated an overall measles IgG seroprevalence of only 71% among individuals aged 3–65 years—with a notable waning of immunity in adolescents and young adults—these figures must be interpreted with caution. A primary consideration is the inherent limitation of enzyme-linked immunosorbent assays (ELISA) compared to the plaque reduction neutralization test (PRNT). Although ELISA was employed in both the 2007–2008 and 2019–2020 surveys, PRNT remains the gold standard for assessing measles immunity, as it directly measures the functional neutralizing capacity of antibodies. Previous studies have demonstrated that individuals testing negative or equivocal by ELISA often possess protective neutralizing antibodies when re-evaluated via PRNT, suggesting that ELISA-based surveys frequently underestimate true population-level protection [18–20]. Furthermore, the discrepancy between the two surveys may be exacerbated by the use of different commercial kits. Modern assays exhibit varying sensitivities in detecting low-titer vaccine-induced immunity, which wanes over time, compared with the robust titers following natural infection. Specifically, diagnostic performance near the cut-off (equivocal) range is inconsistent across brands [21]. While the 2007–2008 survey utilized the Siemens Enzygnost kit, the 2019–2020 study transitioned to the Euroimmun kit to minimize false-positive rates. However, this shift may have inadvertently led to an overestimation of the "equivocal" or “Negative” proportion. Furthermore, analysis of the age distribution of confirmed measles cases from 2023 to 2024 revealed that most cases occurred in the age group born after 1981 (the 30-41 age group accounted for 70%). Therefore, it can be inferred that the actual proportion of measles antibodies in different age groups in Taiwan is not as low as indicated by this study's results. Authors should discuss the results and their interpretation in light of previous studies and the working hypotheses. The findings and their implications should be discussed in the broadest context possible. Future research directions may also be highlighted.

5. Conclusions

Taiwan has successfully sustained measles elimination through high vaccination coverage, robust surveillance, targeted interventions, and molecular evidence confirming the interruption of endemic transmission. Although serological evidence indicates waning immunity, epidemiological data suggest preserved population-level protection, likely mediated by immunological memory. Consequently, individuals with two documented MCV doses are considered immune, even if antibody levels are below test thresholds for positivity [22], and a universal third dose of MMR remains unsupported by international consensus. Furthermore, evidence from hospital cluster investigations and a systematic review of individuals with secondary vaccination failure (SVF) indicates that the secondary attack rate from breakthrough infections is exceedingly low [23]. Nevertheless, the post-COVID-19 global measles resurgence and the persistence of imported cases necessitate vigilance. Targeted booster strategies for high-risk—specifically healthcare workers with over 15 years since their last dose—may be more appropriate. Future efforts will focus on longitudinal seroprevalence monitoring and evaluating the impact of supplemental dosing on mitigating breakthrough transmission risks.

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Informed Consent Statement: The data analyzed in this study consist exclusively of de-identified secondary data and publicly available information sourced from official government websites for statistical analysis. This study involves a comparative analysis of three distinct seroepidemiological surveys conducted by the Taiwan CDC. These surveys were implemented for public health surveillance and infectious disease control. Each original survey obtained independent IRB approval at the time of data collection. Findings from these surveys have been previously published in peer-reviewed international journals (e.g., *Vaccine*) or disseminated through official government reports, confirming their adherence to ethical standards. We maintain that the current analysis is exempt from additional IRB approval based on the following criteria: The research utilizes strictly de-identified secondary data. The authors had no direct contact with the study subjects, nor did they have access to identifiable biological specimens. According to the regulations set forth by the Ministry of Health and Welfare in Taiwan, public policy evaluations conducted by government agencies in the performance of their statutory duties are classified as human subjects research exempt from ethics committee review. As this study constitutes an evaluation of public policy effectiveness conducted under the mandate of the Taiwan CDC, it falls within the scope of research exempt from formal IRB oversight. This manuscript has undergone formal internal review and has been officially authorized for publication by the Taiwan CDC (Ref: **Official Document No. 1150200207**).

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Abbreviations

The following abbreviations are used in this manuscript:

VCR	Vaccination Coverage Rates
MV	Measles Vaccine
CRS	Congenital Rubella Syndrome
NT	Neonatal Tetanus
WHO	World Health Organization
WPRO	Western Pacific Regional Office
Taiwan CDC	Taiwan Centers for Disease Control
NIIS	National Immunization Information System
MMR	Measles-Mumps-Rubella Vaccine
MCV	Measles-Containing Vaccine
MMR1	The First Dose of The Measles-Mumps-Rubella Vaccine
MMR2	The Second Dose of The Measles-Mumps-Rubella Vaccine
SVF	Secondary vaccine failure
Taiwan ACIP	Taiwan Advisory Committee on Immunization Practices
ELISA	Enzyme-Linked Immunosorbent Assays
PRNT	Plaque Reduction Neutralization Test

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