JIDC | THE JOURNAL OF INFECTION IN DEVELOPING COUNTRIES

Coronavirus Pandemic

Impact of the COVID-19 pandemic on the measles elimination status in Armenia

Naira Melkonyan[1], Mary Ter-Stepanyan[1], Arman Badalyan[1], Hasmik Hovhannisyan[1]

[1] *Epidemiology Department, Faculty of Public Health, Yerevan State Medical University, Yerevan, 0025, Armenia*

Abstract

Introduction: The coronavirus disease 2019 (COVID-19) pandemic led to a decrease in immunization rates and measles surveillance, resulting in re-establishment of endemic measles transmission in many countries where measles was previously eliminated.

Methodology: We conducted a retrospective study to evaluate the impact of the pandemic on the measles elimination status in Armenia. We studied the prevalence of measles from 2000 to May 2024 and predicted the trend for the coming months. We assessed trends in coverage levels of the mumps-measles-rubella (MMR)1 and MMR2 vaccines in Armenia between 2003 and 2023. The performance indicators of measles surveillance at the national and subnational levels before, after, and during the pandemic (2013-May 2024) were studied.

Results: Endemic transmission of measles in Armenia was interrupted in 2008, and was sustained for many years; however, it was re-established in 2023. A total of 988 measles cases were recorded between February 2023 and May 2024. During the pandemic (2020–2022), MMR1 and MMR2 vaccine coverage decreased from the target level to 94%. Case-based measles surveillance was significantly weakened. Discarded case rate was 0.7 in 2020 and 2021, and 0.9 in 2022. After the pandemic, this indicator improved, reaching 33.3 in 2023 and 17.3 in 2024. The mean values of the numbers of discarded cases were 118 (95% CI, 73–163) in 2013–2019, and 23 (95% CI, 20–26) in 2020–2022 ($p < 0.05$).

Conclusions: The measles elimination status of Armenia was lost due to immunity gaps and weakening of measles surveillance during the pandemic.

Key words: pandemic; vaccination; measles; elimination; surveillance.

J Infect Dev Ctries 2025; 19(4):482-489. doi:10.3855/jidc.20558

(Received 06 July 2024 – Accepted 04 November 2024)

Introduction

Measles is a highly contagious, serious airborne vaccine-preventable disease of humans. Each person with measles can infect 12–18 other people in a totally susceptible population. Approximately 30% of measles cases involve one or more complications [1–3]. It has been recently discovered that the measles virus can damage the pre-existing immunological memory, leading to immunosuppression of the organism [4–6].

According to estimates by the World Health Organization (WHO), before the introduction of measles vaccine in 1963, major epidemics occurred every 2–3 years with an estimated 30 million cases and more than 2 million deaths occurring globally each year due to measles, and more than 95% of the population had been infected with the measles virus by the age of 15 years [7].

Taking into account the burden of measles, WHO adopted a measles elimination strategy in 1998 [8]. Accelerated immunization activities in WHO countries prevented 56 million deaths between 2000–2021 [3].

The coronavirus disease 2019 (COVID-19) pandemic has led to new challenges due to disruption in surveillance and routine immunization services. The suspension of immunization services, and the decline in immunization rates and surveillance, resulted in millions of children becoming vulnerable to vaccine-preventable diseases like measles [9–12].

Data from WHO showed that almost 40 million children worldwide had missed a measles vaccine dose in 2021, and 22 million infants missed at least one dose of measles vaccine through routine immunization in 2022. Routine vaccination coverage with one dose of measles vaccine globally was 81% in 2021 and 83% in 2022, which was the lowest rate since 2008. This led to major outbreaks in more than 22 countries [3,13].

According to data from WHO, 171,156 and 280,933 measles cases were reported in the 6 WHO regions, in 2022 and 2023 respectively. This means that there was a 64% increase in confirmed cases in 2023, compared to 2022. The epidemiological situation of measles has also complicated in the European region in recent years. A total of 942 measles cases were registered in 2022, and 58,114 cases in 2023; thus, the number of cases increased 60 times [14,15].

The WHO Strategic Advisory Group of Experts on Immunization adopted the measles and rubella new strategic framework 2021–2030, which envisions “a world free from measles and rubella” [16]. Elimination of measles is defined as the interruption of endemic measles transmission in a country for a period of at least 12 months, in the presence of a well-performing surveillance system [17]. Surveillance is one of the key strategies to achieving elimination of measles and maintenance of this status in the post-elimination period [18,19].

Due to the high level of contagiousness of the measles virus, the herd immunity threshold is very high. At least 95% coverage with two doses of the measles vaccine is necessary to interrupt measles virus transmission [1].

In Armenia, the first dose of the measles monovaccine was introduced in 1967, and the second dose in 1986. The mumps-measles-rubella (MMR) combination vaccine was introduced in 2002. It is administered to children as routine vaccination with two doses at the age of 1 and 4–6 years. The measles elimination strategy was adopted in Armenia in 2002.

In this study, we aimed to assess the influence of the COVID-19 pandemic on the measles elimination status in Armenia.

Methodology

Prevalence of measles cases and immunoprophylaxis against measles in Armenia

In order to assess the measles elimination status of Armenia we studied the prevalence of measles. We used the National Center for Disease Control (NCDC) of Armenia database to collect data on the number of measles cases by month and calculated the measles incidence rates per million people from 2000 to May 2024.

An approximation method was used for the analysis. Dynamics of the number of measles cases was expressed by linear polynomial interpolation to make it more obvious and an approximation value was determined. Using the linear approximation method, we determined the trends for the coming months.

Using the NCDC database, we assessed trends of MMR1 and MMR2 vaccine coverage levels in Armenia from 2003 to 2023 to estimate the quality of measles immunoprophylaxis.

Measles surveillance performance and laboratory indicators

WHO has established measles surveillance performance and laboratory indicators to assess the quality of the measles surveillance system at the stage of elimination and in the post-elimination period. We considered the importance of case-based measles surveillance to evaluate the sensitivity of detection, notification, and investigation of suspected measles cases; and determined two main indicators: i) rate of discarded cases, ii) representativeness of reporting discarded cases.

Rate of discarded cases (D) was the rate of suspected measles cases investigated and discarded as non-measles cases following testing from an accredited laboratory (rate per 100,000 population). Discarded case rate (D) was calculated by the following formula: $D = X/P \times 100{,}000$, where X = number of suspected cases that had been investigated and discarded as a non-measles case, P = national population (target level ≥ 2/100,000 population).

Representativeness of reporting discarded cases (R) was the percentage of subnational administrative units (Yerevan city and provinces of Armenia) that reported at least 2 discarded non-measles cases per 100,000 population per year (calculated as percentage). It was determined by the formula: $R = Y/Z \times 100$, where Y = number of subnational administrative units that achieved a rate of discarded cases of ≥ 2 per 100,000 population, Z = number of subnational administrative units (target level ≥ 80%).

We assessed the trends of these indicators at the national and subnational levels before, after, and during the COVID-19 pandemic (2013 to May 2024).

All measles suspected cases were investigated by the enzyme linked immunosorbent assay (ELISA) method provided in the reference laboratory of NCDC.

Statistical analysis

Descriptive statistics were calculated, including the population mean value ($\mu \pm \sigma$) with 95% confidence interval (CI) for continuous parameters. The numbers of discarded cases were calculated for the ‘before period’ (2013–2019) and for the period during the COVID-19 pandemic (2020–2022) using Microsoft Office Excel. t test (two tailed, independent samples) was used to compare the mean values of the numbers of discarded cases to assess the impact of the COVID-19 pandemic on measles surveillance performance. A p value less than 0.05 was considered statistically significant.

Percentage changes in the mean of discarded cases in the period 2020–2022 were compared to the mean for the period 2013–2019; and the mean of discarded cases in the period 2020–2022 was compared to the number of discarded cases in 2023 and 2024 to assess trends and restoration case-based measles surveillance.

Ethical compliance

This research did not involve human subjects or animal experiments and did not require ethical approval.

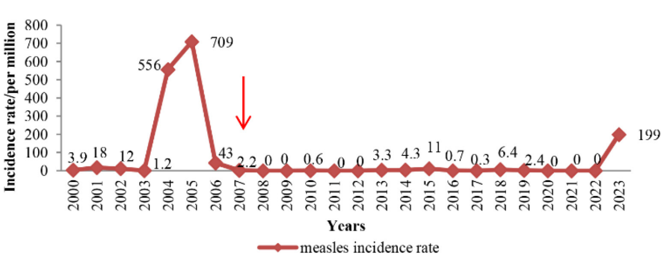
Results

WHO has established the key criteria for monitoring progress towards elimination and maintenance of this status as follows: i) disease incidence of measles, ii) measles vaccination coverage, and iii) measles surveillance and laboratory performance indicators.

Prevalence of measles cases in Armenia at the stage of elimination

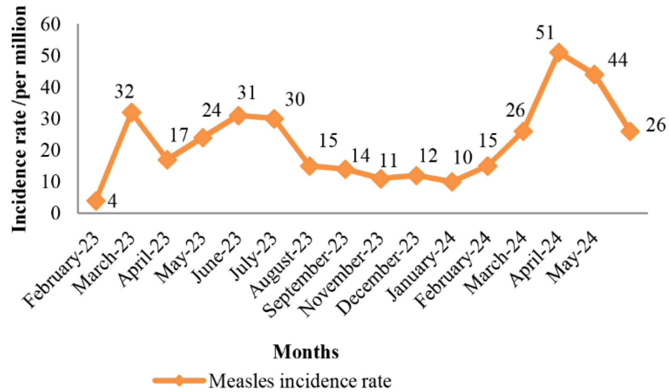
Measles prevalence study showed that there were large outbreaks of measles in 2004 and 2005 in Armenia; measles incidence was 556 (n = 1783) and 709 (n = 2281), respectively (per million people). In 2006 and 2007, the incidence of measles decreased to 43 (n = 137) and 2.2 (n = 7), respectively. In those years, most of the measles cases were registered in the age group 6–27 years. Taking into account the tense epidemiological situation, supplementary immunization activity (SIA) with measles and rubella vaccine was performed in this age group in Armenia in 2007, providing 96% coverage. No endemic cases of measles were reported since 2008. All identified cases were classified as imported cases or importation-related cases. In 2008, the endemic transmission of measles was interrupted and this status was sustained for several years (up to 2023). The measles incidence rates per million people are presented in Figure 1.

Figure 1. Dynamics of the measles incidence rates per million people in Armenia (2000–2023).



Arrow indicates the time 2007 when supplementary immunization activity with measles and rubella vaccine was carried out in Armenia. After that, the endemic transmission of measles was interrupted. All cases were classified as imported or import-related.

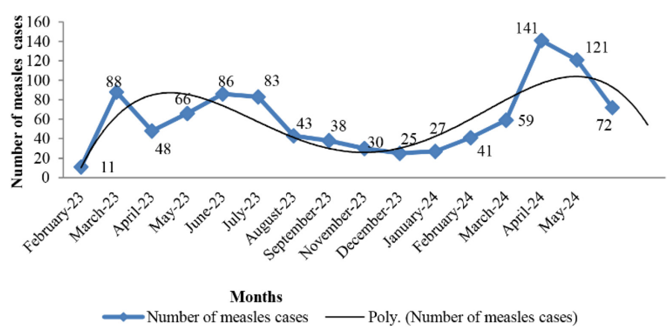
Figure 2. Dynamics of the measles incidence rates per million people in Armenia from February 2023 to May 2024.



Measles cases were imported in February 2023, leading to the spread of endemic cases. The incidence of measles cases is demonstrated in Figure 2. Several cases of measles have been recorded since February 2023, without interruption. The incidence of measles increased in the last months of 2023 and has continued during 2024. A total of 554 measles cases were recorded in 2023, and 434 cases were recorded from January to May 2024. Out of them (n = 988), 57% were children and 43% were adults, and 82% of the cases were hospitalized. There was 1 fatal case.

Figure 3 shows the trend of the number of measles cases by month, which is expressed by polynomial interpolation with an approximate value. The highest number of cases were in March (n = 88) and June (n = 86) of 2023, and in March (n = 141) and April (n = 121) of 2024. The polynomial interpolation diagram predicted marked decrease in the number of measles cases in the coming months (approximation value: R^2 = 0.6379).

Figure 3. The number of the measles cases in Armenia from February 2023 to May 2024.



Black line: Dynamics of the number of measles cases was expressed by linear polynomial interpolation. We have determined the trend for the coming months. Approximation value was R2 = 0.6379. Marked decrease of the number of measles cases was predicted for the coming months, based on the polynomial interpolation diagram.

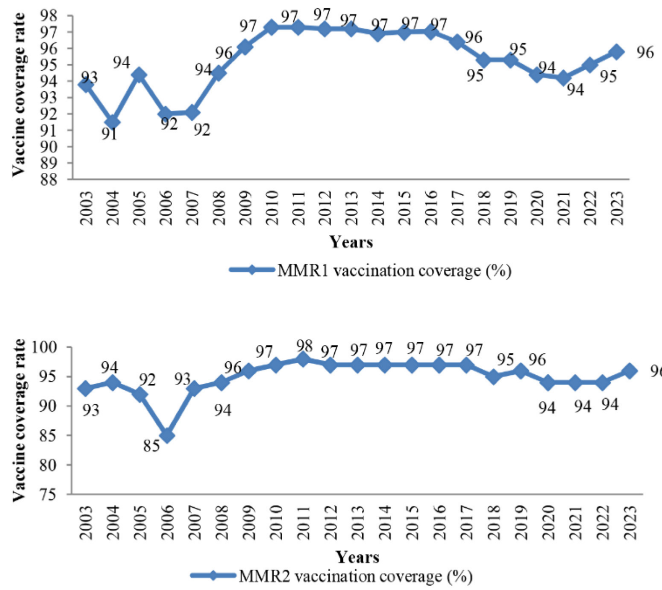
Trend of the coverage of measles vaccine before and during the COVID-19 pandemic

The target level of vaccine coverage with both doses had been achieved at the national level (96.1% and 96.3%, respectively) since 2009. The high coverage level of MMR1 and MMR2 vaccines (96–97.7%) was maintained for several years. However, since 2018, vaccine coverage with both doses decreased compared to previous years, and this declined further from the target level during the COVID-19 pandemic (2020–2022) reaching 94% at the national level. In 2022, MMR1 vaccination coverage at the first subnational level was within the range of 91.2–97.1%. In 2023, the target level of coverage with MMR1 and MMR2 routine vaccinations was restored (95.8% and 96%). The variation in the coverage rates of MMR1 and MMR2 vaccines in Armenia from 2003 to 2023 is presented in Figure 4.

Trends in the measles surveillance performance in Armenia

Standard indicators established by WHO are used to assess the quality of measles surveillance. These indicators measure the timeliness and completeness of reporting, laboratory investigation rate, rate of discarded cases, representativeness of reporting discarded cases, and whether the origin of infection is known. Table 1 summarizes the measles surveillance indicators in Armenia between 2013 and May 2024. All indicators were improved and reached the target levels for the years up to 2020. The values of the measles surveillance indicators decreased during the years of the COVID-19 pandemic (2020–2022). This was particularly evident in case-based measles surveillance at both the national and subnational levels.

Figure 4. Dynamics of MMR1 and MMR2 vaccine coverage rates in Armenia (2003-2023).



MMR: mumps, measles, rubella.

The rate of discarded cases decreased to 0.7 in 2020 and 2021, and 0.9 in 2022 (4.5 in 2019). Discarded case rate was not provided at the target level in subnational units. The timeliness of reporting was also not provided for these years. Due to the measles outbreak since 2023,

Table 1. Measles surveillance performance and laboratory indicators in Armenia (2013–May 2024).

Parameter	Targets	Annual measles surveillance performance indicators											
		2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024 Jan–May
Timeliness of reporting	≥ 80%	92	83	92	58	75	83	100	75	75	67	100	100
Completeness of reporting	≥ 80%	100	100	100	75	92	100	100	100	100	100	100	100
Laboratory investigation rate	≥ 80%	68.2	100	100	100	100	100	100	100	100	100	100	100
Rate of discarded cases	At least 2 discarded measles cases should be reported annually per 100,000 population	4	1.06	4.8	3.17	1.98	8.1	4.5	0.7	0.7	0.9	33.3	17.3
Representativeness of reporting discarded cases	At least 2 discarded measles cases per 100,000 population in ≥ 80% of subnational units	64	64	91	82	72.7	90.9	83	0	0	0	82	85
Origin of infection known	≥ 80%	63.2	100	94	100	100	84	86	-	-	-	100	100

the sensitivity of measles surveillance was increased and performance indicators were improved. Discarded case rate was 33.3 in 2023, and 17.3 in 2024. Between 2023 and May 2024, the origin of infection of all measles cases was identified through an epidemiologic survey. Out of a total of 988 cases, 420 cases were imported or importation-related, and 568 cases were endemic.

To assess the influence of the COVID-19 pandemic on the quality of the case-based measles surveillance, we compared the population mean values of the number of discarded cases between 2013–2019 and 2020–2022, and determined that the mean values of discarded cases were 118 (95% CI, 73–163) and 23 (95% CI, 20–26), $p < 0.05$, respectively. During the pandemic (2020–2022), the number of the reported suspected cases was reduced by 81% compared to the 2013–2019 period. In 2023 and 2024, identification of suspected cases was significantly improved and increased by 3921% (925 cases) and 1991% (481 cases), respectively, compared to the 2020–2022 period (Table 2).

Discussion

The data indicate that endemic transmission of measles was interrupted in Armenia in 2008. After that, endemic measles cases were registered up to 2023. Large measles outbreaks were recorded in our neighboring countries (Georgia, Russian Federation, and Turkey) and other European countries from 2014 to 2018 [20,21]. During this time, Armenia recorded only imported or importation-related cases, and no endemic transmission. This elimination status was sustained in Armenia for many years, and was an outstanding achievement for our country. This measles elimination was the result of a high coverage level of two doses of the measles vaccine and a high quality of measles surveillance system. The COVID-19 pandemic led to a global decrease in the coverage of measles vaccinations and a weakening of the measles surveillance system. Previous studies have shown that the immunization process was disrupted during the pandemic, resulting in a dramatic increase in morbidity and mortality from vaccine-preventable diseases. Many alarming predictions of similar challenges have followed the COVID-19 pandemic [22–24]. Extensive measles outbreaks have occurred in many countries, including Armenia, since 2022 [3,15]. The first imported measles case in this period was registered in February 2023, which spread and resulted in endemic cases. Endemic cases were recorded in Armenia since March 2023. Since the chain of transmission of the virus was continuing uninterrupted for a period of 12 months (from March 2023 to March 2024), Armenia lost the elimination status. Endemic measles transmission was re-established due to immunity gaps in the population and weaknesses in sensitivity of the measles surveillance program. MMR1 and MMR2 vaccine coverage decreased to 94% at the national level, from 2020 to 2022.

Two doses of measles attenuated live vaccine are essential for effective protection from measles. The two doses of the MMR vaccine are about 97% effective, and one dose is about 93% effective [25]. Therefore, high coverage with the measles vaccine is an effective tool for interrupting the transmission of the virus [17]. A study on the measles outbreak in the United States concluded that when there is a decline of the MMR vaccine coverage to 85%, a large outbreak in the population is likely in the presence of an imported case. Between 2001 and 2023, 88% of outbreaks larger than 50 cases have occurred within these settings. The measles vaccine is very effective; however, even with 97% coverage, there is some chance of an outbreak due to extreme contagions [26]. Therefore, the best protection against measles is to get vaccinated. The measles vaccine coverage in Armenia was restored at the national level in 2023. The coverage level increased to 95.8% for MMR1 and 96% for MMR2, as a result of catch up of routine vaccinations.

The data indicate that case-based measles surveillance weakened in Armenia during the pandemic. The rate of discarded cases significantly decreased at the national and subnational levels. This means that the vigilance of medical professionals was weakened and suspected measles cases and real positive cases may have been missed. A high-quality measles

Table 2. Measles discarded cases in Armenia (2013–May 2024).

Years	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024 Jan–May
Discarded cases	**122**	**33**	**145**	**96**	**60**	**239**	**133**	**20**	**22**	**26**	**925**	**481**
Population mean of the number of discarded cases (μ ± σ) 95% CI	2013–2019 118 (95% CI, 73–163)							2020–2022 23 (95% CI, 20–26)				
	Statistical significance* $p < 0.05$											
Percentage changes in the mean values of discarded cases	Percentage changes in the means of discarded cases in 2020–2022 compared to the mean in 2013–2019 – 81%							Percentage changes in the means of discarded cases in 2020–2022 compared to the numbers of discarded cases in 2023 and 2024 3921% 1991%				

* *t*-test was used to compare the mean values of the numbers of discarded cases between 2013–2019 and 2020–2022.

surveillance system with adequate sensitivity and specificity to detect, notify, and investigate suspected cases and outbreaks in a timely manner; classify cases by source (imported or importation-related); and as confirmed or discarded is important to undertake appropriate anti-epidemic actions to prevent further transmission. In Armenia, the measles surveillance activated and discarded case rate increased to 33.3 in 2023 and 17.3 in 2024, compared to previous years (0.7–0.9).

Similar findings have been presented in previous studies. The South-East Asian region reported an 8% decline in the first dose of measles containing vaccine MCV1 coverage and an 11% decline in the second dose of measles containing vaccine (MCV2) coverage in 2021, compared with 2019. The sensitivity of the measles surveillance system decreased. A total of 49,201 suspected measles cases were reported in 2022 compared to 31,091 in 2020, and 69,207 in 2019. Among the measles outbreaks reported in the region in 2022, only half were responded with adequate immunization activities [27]. During 2019–2022, the number of Eastern Mediterranean region countries that met the national target for surveillance sensitivity (2 or more suspected cases per 100,000 population discarded as non-measles) declined from 14 (64%) in 2019 to 11 (50%) in 2022. Measles incidence decreased by 75%, from 29.8 in 2019 to 7.4 in 2020, increased by 30% to 9.6 in 2021, and further increased by 421% from 9.6 in 2021 to 50.0 in 2022 due to the outbreaks. These challenges have resulted from underperforming immunization programs, leading to measles immunity gaps [28]. The overall quality of measles surveillance declined during the COVID-19 pandemic in many countries in the African region. Only 11 countries (23%) met the targets for both principal surveillance performance indicators in 2020, compared to an average of 21 countries in the years 2014–2019. The annual discarded rate declined by more than 50% in 16 countries in 2020 compared to the average for 2014–2019 [29]. The COVID-19 pandemic also affected the measles elimination strategy in the European region. Vaccination coverage decreased in 2020 and 2021, compared to previous years: the total MMR1 and MMR2 vaccine coverage was 96% and 92% in 2019, 94% and 91% in 2020, 94% and 91% in 2021, respectively [30]. Sensitivity of the measles surveillance significantly declined during 2020–2022 and discarded case rate was 0.5–1.0; this increased by 4.1 in 2023. In 2023, measles cases were reported in 42 of the region's 53 member states. The rise in cases has accelerated in recent months, and this trend is expected to continue if urgent measures are not taken across the region to prevent further spread [31].

The measles epidemiologic situation was also tense before the COVID-19 pandemic in some regions. There were large measles outbreaks in 2018–2019, and measles transmission was considered to have been re-established in 6 countries that had previously achieved measles elimination status (Albania, Czechia, Lithuania, Slovakia, United Kingdom, and Uzbekistan), mostly as a consequence of anti-vaccination movements [32]. Since 2016, outbreaks have been recorded in 10 countries worldwide, where measles was previously eliminated, and endemic transmission was restored [13].

Thus, the COVID-19 pandemic affected the measles elimination strategy in WHO member countries, as well as in Armenia, which led to re-establishment of endemic transmission, and a high risk of loss of elimination status.

Conclusions

Our study shows that the transmission of the endemic measles cases was interrupted in Armenia in 2008. Armenia achieved elimination status and sustained it for several years. During the COVID-19 pandemic, the measles vaccine coverage decreased at the national and subnational levels. This resulted in immunity gaps for measles. Over the years, a susceptible mass of people had accumulated as a result of lack of vaccination, and this resulted in an outbreak from the imported case. Decrease in the sensitivity of measles surveillance was mainly a consequence of the insufficient identification of the suspected measles cases (significantly low discarded case rate). In such measles surveillance conditions, real measles cases were missed and led to transmission of endemic cases. Endemic transmission of the virus was continuing uninterrupted for a period of 12 months because there were gaps in immunity, and Armenia lost the elimination status. Considering the current challenges, the following measures are recommended to restore and sustain the measles elimination status:

1. Regular epidemiological analysis, monitoring of the changing transmission and epidemiology of measles;
2. Identification and correction of weaknesses in the surveillance systems, continuous maintenance of high-quality measles surveillance, in particular, increasing sensitivity in detecting suspected cases of measles;

3. Performing active surveillance in healthcare facilities, such as regular review of clinic logbooks for missed cases to improve case-based surveillance;
4. Genotyping of viruses to monitor virus transmission regionally for understanding the epidemiology of an outbreak or a sporadic case to assess whether an outbreak is ongoing or the result of a new importation;
5. Identifying the immunity gaps in population subgroups for targeted immunization strategies, and correction of weaknesses in the immunization process;
6. Raising communities' and healthcare professionals' awareness of measles and the importance of vaccination.

Limitations

The study did not include the surveillance indicator of viral characterization. This indicator is the percentage of laboratory-confirmed outbreaks (chains of transmission) or sporadic cases from which samples were obtained and sequenced in an accredited or proficient laboratory (target level is (V1, V2) ≥ 80% for outbreaks). Data on the genotype of the measles virus were not available. The origin of the infection (imported, import-related, or endemic) was determined by epidemiologic investigation.

Acknowledgements

We thank the National Center for Disease Control and Prevention of the Ministry of Health, Republic of Armenia for providing access to the database. The authors received no financial support for the research, collection, analysis and interpretation of data, writing, and publication of this article.

Authors' contributions

NM: methodology, data curation, investigation, writing original draft, software, formal analysis; MT-S: review and editing, project administration, supervision; AB: methodology, formal analysis, conceptualization, writing, review, and editing; HH: review and editing.

Corresponding author

Melkonyan Naira, MD, PhD.
Department of Epidemiology, Faculty of Public Health, Yerevan State Medical University,
2 Koryun St. Yerevan, 0025, Armenia.
Tel: +37491375860
Email: nmelkonyan01@gmail.com

Conflict of interests

No conflict of interests is declared.

References

1. WHO (2017) Measles vaccines: WHO position paper — April 2017. Weekly Epidemiological Record No 92: 205–228. Available: https://www.who.int/publications/i/item/who-wer9217-205-227. Accessed: 28 April 2017.
2. Guerra MF, Bolotin S, Lim G, Heffernan J, Deeks SL, Li Y, Crowcroft NS (2017) The basic reproduction number (R0) of measles: a systematic review. Lancet Infect Dis 17: e420–e428. doi: 10.1016/S1473-3099(17)30307-9.
3. WHO (2024) Official WHO updates — measles. Available: https://www.who.int/news-room/fact-sheets/detail/measles. Accessed: 12 July 2024.
4. Morales GB, Muñoz MA (2021) Immune amnesia induced by measles and its effects on concurrent epidemics. J R Soc Interface 18: 20210153. doi: 10.1098/rsif.2021.0153.
5. Mina MJ, Kula T, Leng Y, Li M, Vries RD, Knip M, Siljander H, Rewers M, Choy DF, Wilson MS, Larman HB, Nelson AN, Griffin DE, Swart RL, Stephen J, Elledge SJ (2019) Measles virus infection diminishes preexisting antibodies that offer protection from other pathogens. Science 366: 599–606. doi: 10.1126/science.aay6485.
6. Laksono BM, Vries RD, Verburgh RJ, Visser EG, Jong A, Fraaij PL, Ruijs WL, Nieuwenhuijse DF, Ham HJ, Koopmans MP, Zelm MC, Osterhaus AD, Rik L. de Swart RL (2018) Studies into the mechanism of measles-associated immune suppression during a measles outbreak in the Netherlands. Nat Commun 9: 1–10. doi: 10.1038/s41467-018-07515-0.
7. Vassantachart MJ, Yeo HA, Vassantachart AY, Jacob SE, and Golkar L (2019) Art of prevention: the importance of measles recognition and vaccination Int J Womens Dermatol 6: 89–93. doi: 10.1016/j.ijwd.2019.06.031.
8. WHO (2003) Strategic plan for measles and congenital rubella infection in the European Region of WHO. Copenhagen. Available: https://iris.who.int/bitstream/handle/10665/107526/E81567.pdf. Accessed: 19 March 2014.
9. Shet A, Carr K, Danovaro-Holliday MC, Sodha SV, Prosperi C, Wunderlich J, Wonodi C, Reynolds HW, Mirza I, Gacic-Dobo M, O'Brien KL, Lindstrand A (2022) Impact of the SARS-CoV-2 pandemic on routine immunization services: evidence of disruption and recovery from 170 countries and territories. Lancet Glob Health 10: e186–194. doi: 10.1016/S2214-109X(21)00512-X.
10. Zar HJ, Dawa J, Fischer GB, Castro-Rodriguez JA (2020) Challenges of COVID-19 in children in low-and middle-income countries. Paediatr Respir Rev 35: 70–74. doi: 10.1016/j.prrv.2020.06.016.
11. Pan American Health Organization (PAHO), WHO (2020) Summary of the status of national immunization programs during the COVID-19 pandemic. Available: https://www.paho.org/en/documents/summary-status-national-immunization-programs-during-covid-19-pandemic-july-2020. Accessed: 28 July 2020.
12. WHO (2021) Measles outbreaks strategic response plan 2021-2023. Available: https://www.who.int/publications/i/item/9789240018600. Accessed: 31 August 2022.
13. WHO (2022) Nearly 40 million children are dangerously susceptible to growing measles threat. Available: https://www.who.int/news/item/23-11-2022-nearly-40-million-children-are-dangerously-susceptible-to-growing-measles-threat. Accessed: 10 January 2023.

14. PRO/EDR (2024) Measles-Americas: PAHO Available: https://promedmail.org/promed-post/?id=8714646. Accessed: 4 February 2024.
15. WHO (2024) Measles and rubella monthly update — WHO European Region. Available: https://www.who.int/europe/publications/m/item/measles-and-rubella-monthly-update---who-european-region---april-2024. Accessed: 22 May 2024.
16. WHO (2021), Measles and rubella strategic framework 2021–2030. Available: https://www.who.int/publications/i/item/measles-and-rubella-strategic-framework-2021-2030. Accessed: 8 November 2020.
17. WHO European Region (2024) Eliminating measles and rubella in the WHO European Region. Integrated guidance for surveillance, outbreak response and verification of elimination. Available: https://www.who.int/europe/publications/i/item/9789289060783. Accessed: 8 February 2024.
18. WHO (2017) Roadmap to elimination standard measles and rubella surveillance. Weekly Epidemiological Record 92: 97–105. Available: https://iris.who.int/handle/10665/254754. Accessed: 2 August 2022.
19. WHO (2012) Surveillance guidelines for measles, rubella and congenital rubella syndrome in the WHO European Region. Available: https://iris.who.int/handle/10665/260123. Accessed: 31 December 2024.
20. WHO EpiBrief (2015) A report on the epidemiology of selected vaccine-preventable diseases in the European Region, No. 1/2015. Available: https://iris.who.int/handle/10665/369102. Accessed: 12 Jun 2023.
21. WHO EpiData (2020) A monthly summary of the epidemiological data on selected vaccine-preventable diseases in the WHO European Region, No. 01/2020. Available: https://www.who.int/europe/publications/m/item/epidata-1-2020. Accessed: 9 February 2020.
22. Sun X, Samba TT, Yao J, Yin W, Xiao L, Lui F, Lui X, Zhou J, Kou Z, Fan H, Zhang H, Williams A, Lansana PM, Yin Z (2017) Impact of the Ebola outbreak on routine immunization in western area, Sierra Leone-a field survey from an Ebola epidemic area. BMC Public Health 17: 363. doi: 10.1186/s12889-017-4242-7.
23. Lassi ZS, Naseem R, Salam RA, Siddiqui F, Das JK (2021) The impact of the COVID-19 pandemic on immunization campaigns and programs: a systematic review. Int J Environ Res Public Health 18: 988. doi: 10.3390/ijerph18030988.
24. Melkonyan N, Badalyan A, Hovhannisyan H, Poghosyan K (2022) Impact of the COVID-19 pandemic on routine immunization services in Yerevan and vaccinations against COVID-19 in Armenia. J Infect Dev Ctries 16: 1687–1695. doi: 10.3855/jidc.17028.
25. Uzicanin A, Zimmerman L (2011) Field effectiveness of live attenuated measles-containing vaccines: a review of published literature. J Infect Dis 204 Suppl 1: S133–148. doi: 10.1093/infdis/jir102.
26. CDC (2024) Assessing measles outbreak risk in the United States. National Center for Immunization and Respiratory Diseases. Available: https://www.cdc.gov/ncird/whats-new/measles-outbreak-risk-in-us.html. Accessed: 4 April 2024.
27. Bahl S, Khanal S, Sangal L, Tabassum S, Ungchusak K, Andrus J (2023) Measles and rubella elimination: protecting children through immunization in South-East Asia Region (SEAR). Lancet Reg Health Southeast Asia 18: 100–303. doi: 10.1016/j.lansea.2023.100303.
28. CDCP (2024) Progress toward regional measles elimination-WHO, Eastern Mediterranean Region, 2019–2022. MMWR Weekly 73: 139–144. doi: 10.15585/mmwr.mm7307a1.
29. Masresha B, Luce R, Katsande R, Dosseh A, Tanifum P, Lebo E, Byabamazima Ch, Kfutwah A (2021) The impact of the COVID-19 pandemic on measles surveillance in the World Health Organisation African Region, 2020. Pan Afr Med J 39: 192. doi: 10.11604/pamj.2021.39.192.29491.
30. WHO (2022) Measles and rubella monthly update — WHO European Region. Vaccine-preventable diseases and immunization programme. Available: https://cdn.who.int/media/docs/librariesprovider2/euro-health-topics/vaccines-andimmunization/eur_mr_monthly-_update_en_october 2022.pdf?sfvrsn=8918475a_2&download=true. Accessed: 1 November 2022.
31. WHO EpiData (2024) A monthly summary of the epidemiological data on selected vaccine-preventable diseases in the WHO European Region, No. 01/2024. Available: https://www.who.int/europe/publications/m/item/epidata-1-2024. Accessed: 14 February 2024.
32. WHO (2022) Tenth meeting of the European Regional Verification Commission for Measles and Rubella Elimination. Available: https://iris.who.int/bitstream/handle/10665/363174/WHO-EURO-2022-6093-45858-66035-eng.pdf?sequence=1. Accessed: 16 February 2022.