Combating Measles in Nigeria: Epidemiological Trends, Drivers, Barriers and Public Health Interventions

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Measles remains a significant public health challenge in Nigeria, contributing to substantial morbidity and mortality among children despite the availability of effective vaccines. This narrative review aims to synthesize current literature on the epidemiological trends, drivers, barriers, and public health interventions related to measles control in Nigeria. A comprehensive search was conducted across Google Scholar, Scopus, and PubMed for articles published between 2008 and 2024. The search strategy utilized keywords such as “measles,” “Nigeria,” “epidemiology,” “vaccination,” and “public health interventions.” Articles were selected based on predetermined inclusion and exclusion criteria, focusing on studies that specifically addressed measles and its control measures in Nigeria. The review highlights fluctuating measles incidence with periodic outbreaks exacerbated by low immunization coverage, population displacement, and rapid urbanization. Suboptimal vaccination rates for both the first (MCV1) and second (MCV2) doses leave many children vulnerable. Barriers to effective control include misinformation, vaccine hesitancy, insecurity in conflict-affected regions, and logistical challenges in vaccine distribution. Public health interventions, including enhanced immunization campaigns, community engagement, and integrated health services, are essential for improving vaccination coverage and combating measles. Achieving effective measles control in Nigeria requires sustained commitment, adequate funding, and international collaboration to ensure the health and well-being of Nigerian children.

INTRODUCTION

Measles is a highly contagious viral disease caused by a virus from the Paramyxoviridae family [1, 2]. It spreads through respiratory droplets from coughing, sneezing, or close contact and can remain airborne or on surfaces for up to two hours. The virus has an incubation period of 7 to 18 days, with symptoms such as fever, rash, cough, coryza, and conjunctivitis [3-5]. Complications, including pneumonia, encephalitis, and diarrhea, can arise, particularly in malnourished children or those with vitamin A deficiency [6-8]. Despite the availability of a safe vaccine, measles remains a leading cause of death in children under five, especially in low-income countries [9, 10].

Global efforts have significantly reduced measles-related deaths, with vaccination campaigns preventing millions of fatalities between 2000 and 2015 [11]. However, in countries like Nigeria, measles continues to pose a major public health challenge. In 2013, only 42% of Nigerian children aged 12 to 23 months had received the measles vaccine, with significant regional disparities in coverage [12]. While the Southern regions reported higher coverage rates (62%-74%), Northern regions, affected by conflict and displacement, recorded much lower rates (22%-48%) [13]. This disparity in immunization coverage highlights the complex barriers to measles control in Nigeria [14-18].

Nigeria has seen fluctuating rates of measles incidence, often driven by factors such as low immunization coverage, population displacement due to conflict, and rapid urbanization [19, 20]. These outbreaks strain the healthcare system, exposing children to severe health risks. Suboptimal vaccination rates, particularly for the second dose of the measles-containing vaccine (MCV2), contribute to the continued spread of the virus [21, 22]. Conflict zones like Borno and Adamawa further complicate control efforts, as displaced populations have limited access to healthcare [23]. The burden of measles in Nigeria highlights the challenges of disease prevention and control within the context of a developing country[24, 25].This review explores the epidemiology of measles in Nigeria, examining the factors driving its persistence and identifying key barriers to effective control. It also outlines the public health interventions needed to combat measles and reduce its impact on vulnerable populations. Addressing these challenges requires a comprehensive approach, focusing on strengthening routine immunization, improving healthcare access, and ensuring adequate outbreak response systems [26, 27].

METHODOLOGY

This narrative review aims to synthesize existing literature on measles in Nigeria, focusing on epidemiological trends, drivers, barriers, and public health interventions. The methodology involved a systematic search and selection of relevant articles from three major databases: Google Scholar, Scopus, and PubMed. The search was limited to studies published between 2008 and 2024 to ensure the inclusion of the most recent and pertinent data.

Search Strategy:

A comprehensive search strategy was developed using a combination of keywords and Medical Subject Headings (MeSH) terms related to measles, including "measles," "Nigeria," "epidemiology," "vaccination," "public health interventions," "drivers," and "barriers." Boolean operators such as AND and OR were employed to refine the search results. The search was conducted in May, 2024.

Inclusion and Exclusion Criteria:

Articles were included in this review based on the following criteria:

- **Inclusion Criteria:**
    - Studies focusing on measles epidemiology in Nigeria.
    - Articles discussing public health interventions aimed at measles control.
    - Research addressing barriers and drivers of vaccination uptake.
    - Peer-reviewed articles published between 2008 and 2024.
- **Exclusion Criteria:**
    - Articles not written in English.
    - Publications that did not specifically address measles or relevant public health issues.

Data Extraction and Analysis:

Data were extracted from selected articles, including study design, key findings, and conclusions. The extracted data were organized thematically to identify patterns and gaps in the existing literature. This review highlights the trends in measles incidence, the sociocultural and economic factors influencing vaccination uptake, and the effectiveness of various public health interventions implemented in Nigeria.

Ethical Considerations:

As this narrative review utilized publicly available literature, no ethical approval was required. All relevant studies and data sources were appropriately cited to maintain academic integrity.

RESULTS AND DISCUSSION

Understanding the Virology of Measles

Measles is a highly contagious viral disease caused by the measles virus (MeV), which belongs to the genus Morbillivirus within the family Paramyxoviridae[28]. The virus (Figure 1) is an enveloped virus, meaning it has a lipid membrane derived from the host cell. This envelope is crucial for the virus's ability to enter host cells[29, 30]. The virus has a single-stranded, negative-sense RNA genome approximately 15,894 nucleotides in length. This genome is non-segmented and encodes all the necessary proteins for viral replication and assembly. The genome encodes six structural proteins: 1) Nucleocapsid (N) protein which encapsulates the RNA genome, forming a nucleocapsid. 2) Phosphoprotein (P) and 3) Large (L) protein: These form the RNA-dependent RNA polymerase complex essential for transcribing and replicating the viral RNA. 4) Matrix (M) protein which plays a role in virus assembly and release, aiding in the budding of new virions from the host cell. 5) Fusion (F) protein: Facilitates the fusion of the viral envelope with the host cell membrane, allowing entry of the viral genome into the host cell and 6) Hemagglutinin (H) protein: which binds to cellular receptors on the host cell surface, which is a critical step for viral attachment and subsequent entry. Its replication begins with attachment. The H protein binds to specific receptors on the host cell surface, such as CD150 (SLAM) found on immune cells and Nectin-4 found on epithelial cells[31].

This binding is the first step in the infection process. Upon binding, the F protein mediates the fusion of the viral envelope with the host cell membrane, allowing the viral nucleocapsid to enter the host cell cytoplasm[32]. Inside the host cell, the RNA-dependent RNA polymerase transcribes the negative-sense RNA genome into positive-sense mRNA, which is then translated into viral proteins. Concurrently, the genome is replicated to produce new viral RNA. Newly synthesized viral proteins and RNA genomes are assembled into new virions in the host cell cytoplasm. The assembled virions bud off from the host cell membrane, acquiring their envelope in the process and thereby completing the replication cycle[33].

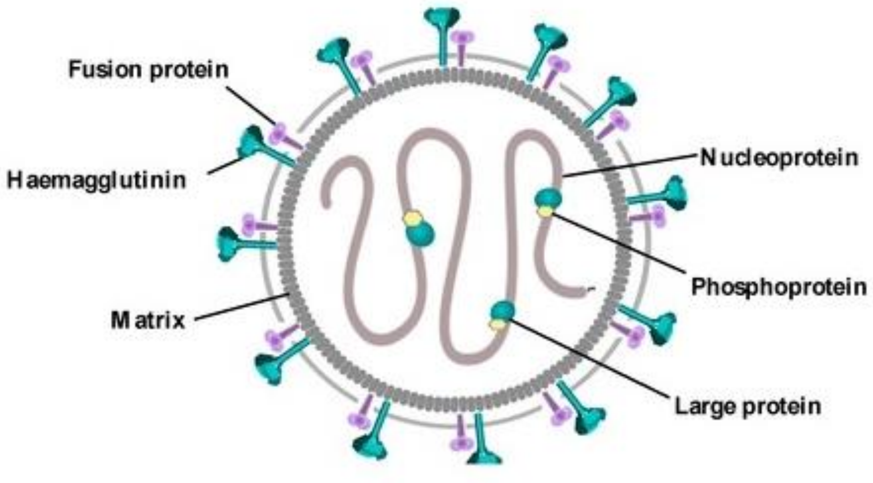

Figure 1: Schematic diagram of measles virus[28]

After entering the respiratory tract, the measles virus infects local epithelial cells and then spreads to regional lymphoid tissues. This leads to a systemic spread via the bloodstream (viremia), allowing the virus to disseminate to various organs, including the skin, respiratory tract, and immune system. The systemic spread results in the hallmark symptoms of measles: high fever, cough, coryza (runny nose), conjunctivitis, and a maculopapular rash[34].

Clinical Manifestations and Consequences of Measles Virus Infection

Measles typically begins with an incubation period of 7 to 14 days, followed by the onset of prodromal symptoms, including high fever, cough, runny nose (coryza), and red, watery eyes (conjunctivitis) [1]. Within 2 to 4 days of symptom onset, a characteristic red, blotchy rash appears, starting on the face and neck before spreading downward to the rest of the body. Small white spots, known as Koplik's spots, may also appear inside the mouth 1 to 2 days before the rash [3].

While measles is self-limiting in many cases, severe complications can occur, particularly in malnourished children and immunocompromised individuals. Common complications include diarrhea and pneumonia, the latter being a leading cause of measles-related deaths [4]. More severe consequences include encephalitis (inflammation of the brain), which can lead to permanent neurological damage or death in approximately 0.1% of cases [5]. Subacute sclerosing panencephalitis (SSPE), a rare but fatal long-term complication, can develop years after infection, causing progressive neurological deterioration. Other potential consequences include blindness, particularly in individuals with vitamin A deficiency, and severe dehydration from diarrhea [7]. Addressing the clinical manifestations and consequences of measles is critical for highlighting the importance of timely vaccination and effective public health interventions.

Measles vaccination

Measles vaccination is a crucial public health intervention to prevent the spread of this highly contagious viral disease [3]. The measles vaccine, often given as part of the MMR (measles, mumps, rubella) or MMRV (measles, mumps, rubella, varicella) vaccine, is highly effective and safe. The World Health Organization (WHO) recommends two doses: the first at 9-12 months and the second at 15-18 months or during school entry. One dose provides 85-95% protection, while two doses increase effectiveness to 97-99% [11]. Measles vaccination efforts have significantly reduced global measles cases and deaths, preventing over 20 million deaths between 2000 and 2015 [14]. However, coverage gaps persist, particularly in low-income countries. Achieving 95% vaccination coverage is necessary for herd immunity, which protects vulnerable populations such as infants and immunocompromised individuals by preventing the widespread transmission of the virus [15]. Expanding vaccination coverage remains a priority for measles control worldwide.

Immune response to measles virus

The immune response to measles virus (MeV) is a complex interplay between the innate and adaptive immune systems, which together orchestrate a robust defense against the virus (Figure 2) [35]. Upon MeV infection, the host's immune system detects the virus through pattern recognition receptors (PRRs) such as Toll-like receptors (TLRs) and retinoic acid-inducible gene I (RIG-I)-like receptors. PRRs are crucial in recognizing pathogen-associated molecular patterns (PAMPs) on MeV. TLRs, located on the cell surface and within endosomes, detect viral components such as single-stranded RNA (ssRNA). RIG-I-like receptors, present in the cytoplasm, also recognize viral RNA]. The engagement of these receptors by MeV PAMPs triggers signaling pathways that lead to the activation of transcription factors like NF-κB and IRF3.Production of Cytokines is another important immune response to MeV. Upon activation, infected cells produce and secrete type I interferons (IFNs) and other pro-inflammatory cytokines. Type I IFNs (IFN-α and IFN-β) are pivotal in the antiviral response, as they induce an antiviral state in both infected and neighboring cells by upregulating the expression of interferon-stimulated genes (ISGs). These ISGs encode proteins that inhibit viral replication and modulate the immune response. Cytokines such as IL-6 and TNF-α also contribute to the inflammatory milieu, recruiting immune cells to the site of infection [36].

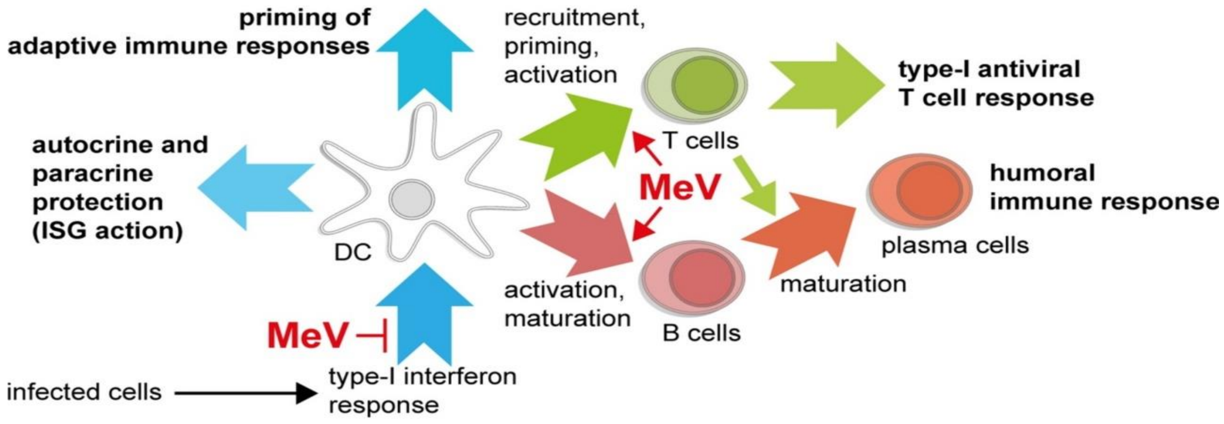

Figure 2: Immune response to measles virus[35]

Furthermore; natural killer (NK) cells are among the first responders in the innate immune response to MeV [35]. IFNs and other cytokines activate NK cells, enhancing their cytotoxic activity against infected cells. NK cells recognize and kill infected cells through mechanisms such as the release of perforin and granzymes, as well as antibody-dependent cellular cytotoxicity (ADCC).The adaptive immune response is primed by antigen-presenting cells (APCs) such as dendritic cells (DCs), which process and present MeV antigens via major histocompatibility complex (MHC) molecules. DCs migrate to lymphoid tissues, where they interact with T cells, providing the necessary co-stimulatory signals for T cell activation [37].

CD4+ helper T cells (Th cells) and CD8+ cytotoxic T lymphocytes (CTLs) are crucial for controlling MeV infection. The CD4+ Helper T Cells produce cytokines that support the activation and proliferation of B cells, CD8+ T cells, and other immune cells[36]. Th cells differentiate into various subsets (e.g., Th1, Th2) based on the cytokine environment. Th1 cells, characterized by their production of IFN-γ, are particularly important for antiviral responses. They assist in the activation and proliferation of CTLs, which recognize and kill infected cells via MHC class I molecules presenting viral peptides. The CD8+ Cytotoxic T Cells on the other hand recognize and kill infected cells presenting viral peptides on MHC class I molecules. This cytotoxic activity helps eliminate reservoirs of viral replication within the host. After infection or vaccination, memory B cells persist and can rapidly produce antibodies upon re-exposure to the virus. Memory CD4+ and CD8+ T cells provide a swift and robust response to subsequent infections, preventing disease recurrence[35].

The humoral immune response is characterized by the activation and differentiation of B cells into plasma cells, which produce specific antibodies against MeV antigens, particularly the hemagglutinin (H) and fusion (F) proteins [34]. These antibodies neutralize the virus, preventing it from entering host cells and facilitating its clearance by immune cells through mechanisms such as opsonization and ADCC. Type I IFNs not only limit viral replication within the infected cells (autocrine action), but also protect neighboring uninfected cells (paracrine action) by inducing the expression of ISGs. These ISGs enhance the antiviral state of cells, reinforcing the overall immune response against MeV [37].

The live-attenuated measles vaccine induces a strong and durable immune response similar to natural infection, conferring long-term protection[38]. Vaccinated individuals develop both humoral and cellular immunity, which is critical for effective and lasting immunity. Transient Immunosuppression: Measles infection can cause transient immunosuppression, leading to increased susceptibility to secondary infections. This immunosuppression is due to: 1) Lymphopenia: Reduction in lymphocyte counts during acute infection, 2) Suppression of Immune Function: MeV can infect and impair the function of immune cells, including dendritic cells and T cells and 3) Immune Evasion: MeV has evolved mechanisms to evade the immune system, such as inhibiting interferon signaling and modulating the host immune response to enhance its replication and spread.

Understanding the immunology of measles is crucial for developing effective vaccines and therapeutic strategies[39]. The robust immune response elicited by the measles virus, particularly the generation of long-lasting immunity, is a cornerstone of measles control and eradication efforts. The live-attenuated measles vaccine is highly effective in inducing a strong and long-lasting immune response. Vaccination programs aim to achieve high coverage to maintain herd immunity, thereby preventing outbreaks. The vaccine works by mimicking natural infection, inducing both humoral and cellular immunity without causing disease[35, 40].

Current Epidemiological Trends of measles in Nigeria

Nigeria has experienced several measles outbreaks over the years, with children under five being the most affected[9, 14-21, 41]. The trend typically shows a cyclical pattern, where cases spike every 2-3 years, highlighting gaps in herd immunity [10, 13, 23, 36]. Data from the Nigeria Centre for Disease Control (NCDC) indicates that these outbreaks are not evenly distributed, with certain states and regions being more affected due to various socio-economic and environmental factors[42].According to the World Health Organization (WHO), the country reported over 28,000 measles cases in 2019, a significant increase from previous years. The most affected states include Borno, Yobe, and Adamawa, regions with high levels of insecurity and displaced populations, which complicate vaccination efforts[11, 12]. The resurgence of measles in Nigeria can be attributed to several factors. Firstly, gaps in routine immunization coverage have left many children vulnerable[43]. While the national immunization rate for the first dose of the measles-containing vaccine (MCV1) hovers around 54%, the coverage for the second dose (MCV2) is even lower, indicating a substantial immunity gap. Additionally, the COVID-19 pandemic disrupted vaccination campaigns and routine immunization services, exacerbating the problem[17-20]. Despite global efforts to eradicate measles, Nigeria still records significant outbreaks. The introduction of the Measles and Rubella Initiative (M&RI) in 2001 aimed to reduce measles mortality by 95% by 2015 compared to 2000 levels. While progress has been made, the goal of complete eradication remains elusive[21].In March 2024, Borno (304), Yobe (157), Bauchi (115), Osun (115), Lagos (110), Adamawa (102), and Katsina (91) collectively represented 44.2% of the 1986 suspected cases reported (Table 1)[42].

Among the suspected cases, 599 (30.16%) were confirmed (172 lab-confirmed, 406 epidemiologically linked, and 21 clinically compatible), 325 (16.36%) were discarded, and 1062 (53.47%) were pending classification. Suspected cases were reported from 436 Local Government Areas (LGAs) across 34 States and the Federal Capital Territory (FCT). Fourteen deaths were recorded from confirmed cases. From January to March 2024, Borno (2897), Yobe (345), Bauchi (319), Katsina (276), Osun (276), Lagos (269), and Ogun (255) accounted for 60.38% of the 7,842 suspected cases reported. Among the suspected cases,

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Table 1: Distribution of key measles surveillance variables by states, March, 2024[42].

States	# Suspected cases	# Confirmed cases (%)	Classification of confirmed cases			% of confirmed cases aged 9-59 months	% of confirmed cases that are "zero doses"
			Lab. confirmed	Epid. linked	Clin. Compatible		
NORTH	**5,591**	**3,895 (69.7%)**	**864**	**2001**	**1030**	**69.3%**	**87.3%**
Adamawa	224	69 (30.8%)	68	0	1	26.3%	95.0%
Bauchi	327	153 (46.8%)	78	32	43	55.1%	90.6%
Benue	109	54 (49.5%)	54	0	0	33.9%	95.1%
Borno	2,899	2,812 (97.0%)	113	1936	763	73.7%	85.2%
FCT, Abuja	34	19 (55.9%)	19	0	0	33.3%	88.9%
Gombe	122	62 (50.8%)	59	3	0	62.9%	89.3%
Jigawa	246	49 (19.9%)	49	0	0	56.5%	97.2%
Kaduna	115	65 (56.5%)	63	0	2	54.7%	100.0%
Kano	95	18 (18.9%)	18	0	0	61.3%	91.5%
Katsina	301	48 (15.9%)	47	0	1	63.3%	92.3%
Kebbi	161	29 (18.0%)	29	0	0	61.8%	79.0%
Kogi	57	14 (24.6%)	14	0	0	35.5%	80.6%
Kwara	170	57 (33.5%)	57	0	0	30.0%	93.3%
Nasarawa	74	31 (41.9%)	31	0	0	40.0%	63.3%
Niger	78	30 (38.5%)	30	0	0	65.0%	81.5%
Plateau	44	15 (34.1%)	14	0	1	36.7%	96.7%
Sokoto	83	45 (54.2%)	45	0	0	61.3%	100.0%
Taraba	30	13 (43.3%)	13	0	0	31.0%	19.0%
Yobe	346	287 (82.9%)	38	30	219	56.7%	94.9%
Zamfara	76	25 (32.9%)	25	0	0	84.7%	99.6%
SOUTH	**2,251**	**139 (6.2%)**	**139**	**0**	**0**	**34.7%**	**22.1%**
Abia	77	10 (13.0%)	10	0	0	35.4%	56.3%
Akwa Ibom	97	7 (7.2%)	7	0	0	25.7%	11.4%
Anambra	147	5 (3.4%)	5	0	0	35.0%	50.0%
Bayelsa	100	11 (11.0%)	11	0	0	38.3%	10.6%
Cross River	89	17 (19.1%)	17	0	0	37.1%	13.3%
Delta	77	3 (3.9%)	3	0	0	46.4%	17.9%
Ebonyi	36	0 (0.0%)	-	0	0	63.2%	47.4%
Edo	74	8 (10.8%)	8	0	0	38.9%	8.3%
Ekiti	185	2 (1.1%)	2	0	0	13.3%	6.7%
Enugu	133	5 (3.8%)	5	0	0	59.1%	59.1%
Imo	80	3 (3.8%)	3	0	0	8.3%	66.7%
Lagos	279	4 (1.4%)	4	0	0	45.9%	5.4%
Ogun	257	14 (5.4%)	14	0	0	18.9%	13.5%
Ondo	132	9 (6.8%)	9	0	0	31.6%	14.0%
Osun	282	10 (3.5%)	10	0	0	25.0%	10.0%
Oyo	178	27 (15.2%)	27	0	0	28.6%	8.3%
Rivers	28	4 (14.3%)	4	0	0	21.4%	28.6%
TOTAL	**7,842**	**4,034 (51.4%)**	**1,003**	**2001**	**1030**	**67.2%**	**83.4%**

4034 (52.35%) were confirmed (1003 lab-confirmed, 2001 epi-linked, and 1030 clinically compatible), 654 (8.51%) were discarded, and 3,154 (40.21%) were pending classification. The age group 9 - 59 months constituted 2710 (67.2%) of all confirmed cases. Thirty-three deaths (Case Fatality Rate = 0.81%) were recorded among confirmed cases. Of the 4034 confirmed cases, 3,364 (83.4%) did not receive any dose of measles vaccine ("zero doses"). In March 2023, eight LGAs across seven states (Abia - 2; Rivers - 1; Plateau - 1; Bauchi, Sokoto, Gombe & Kaduna - 1) each recorded an outbreak. Cumulatively, a total of 184 LGAs across 35 states experienced at least one measles outbreak this year (Figure 3). Only the Federal Capital Territory (FCT) and Osun States did not report any confirmed measles outbreak this year. There were more cases reported in the northern region of the country compared to the southern region (Figure 4).

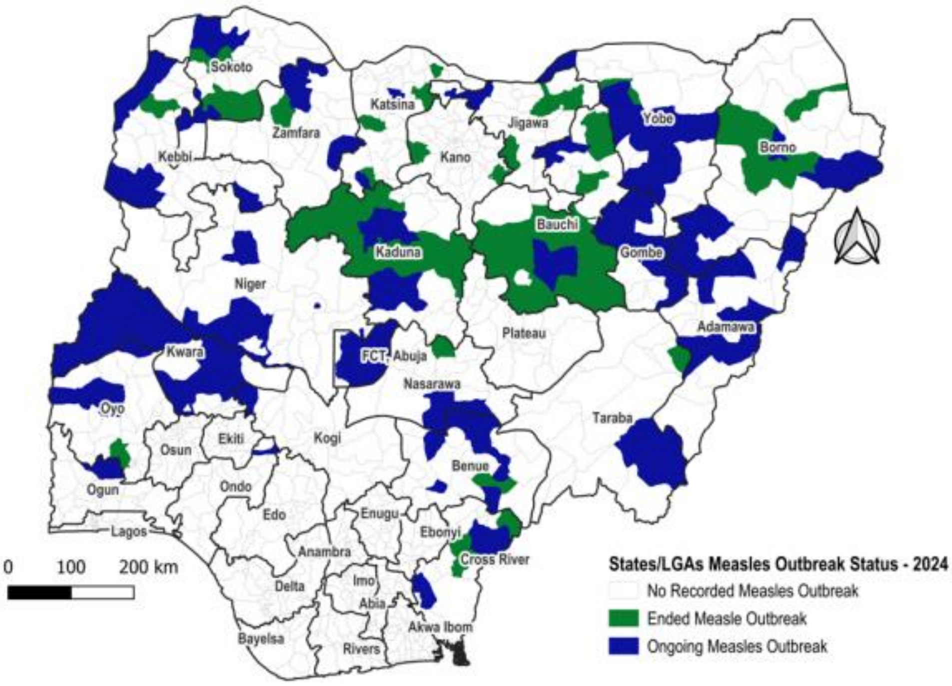

Figure 3: Distribution of measles outbreak by LGAs/States in Nigeria, Jan - Mar 2024 [42].

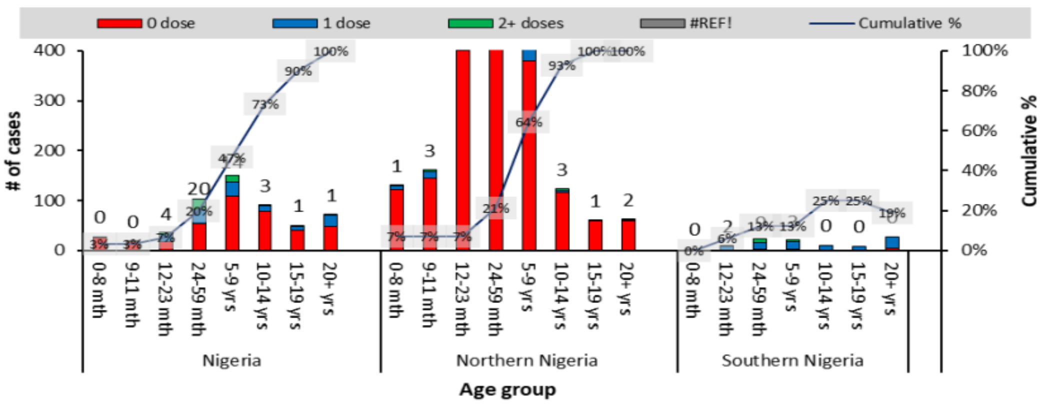

Figure 4: Vaccination status and age distribution laboratory confirmed measles cases in Nigeria (Northern vs Southern zone), Jan - Mar, 2024 [42].

Drivers of measles transmission in Nigeria

The cyclical pattern of measles outbreaks in Nigeria, characterized by spikes in cases every 2-3 years, is driven by several interconnected factors: Key drivers contributing to the persistence and spread of measles in Nigeria include (Figure 5):

1. High Contagiousness of Measles:

Measles is one of the most contagious diseases known, with a basic reproduction number (R0) of 12 to 18. This means that, in a population without immunity, one person with measles can infect 12 to 18 other people. The virus can spread through respiratory droplets when an infected person coughs or sneezes, and it can remain airborne and on surfaces for up to two hours, infecting those who come into contact with these droplets or surfaces[5, 6, 41].

2. Population Density:

High population density greatly facilitates the spread of measles. In crowded conditions, such as in urban slums, schools, and healthcare facilities, the measles virus can easily spread from person to person due to close contact and shared airspace. Rapid urbanization and population growth have created densely populated areas where infectious diseases can spread more easily[28, 43].

3. Travel and Mobility:

Travel and mobility can facilitate the rapid spread of measles from areas with outbreaks to other regions with low immunity levels. Travelers can carry the virus across long distances, introducing it to susceptible populations, which can lead to new outbreaks. Frequent population movements, including internal displacement due to conflict or economic factors, exacerbate the spread of measles. These movements can reintroduce the virus into populations where immunity is low or waning, leading to periodic outbreaks. Migratory movements also complicate vaccination efforts, as mobile populations may miss routine immunizations. Ongoing conflicts, especially in the Northeast, have also led to large-scale displacement, creating pockets of susceptible populations. Internally displaced persons (IDPs) often have limited access to healthcare services, including vaccination[17, 43].

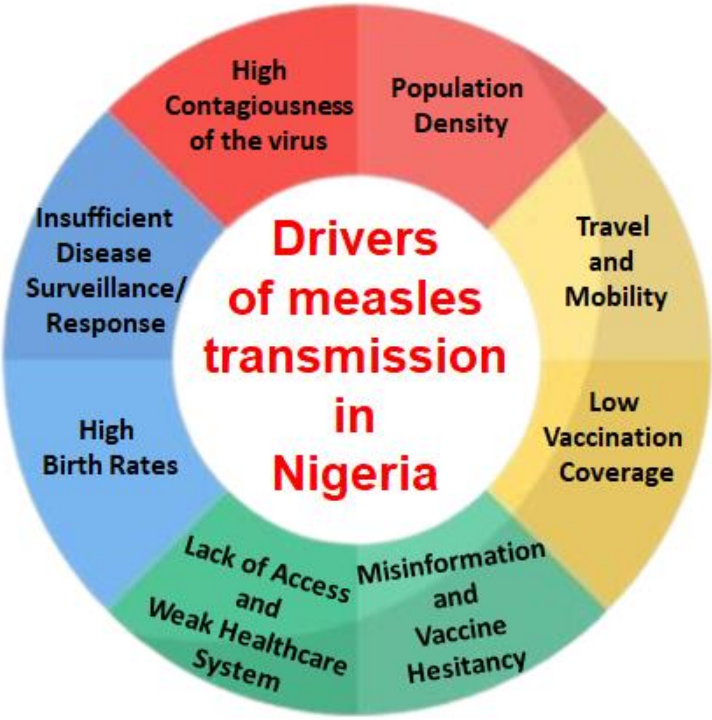

Figure 5: Drivers of measles transmission among the populace.

4. Low Vaccination Coverage:

A primary factor contributing to the cyclical outbreaks is the low vaccination coverage. For herd immunity against measles, about 95% coverage with two doses of the vaccine is required. In Nigeria, routine vaccination coverage often falls short of this threshold, leaving a significant portion of the population susceptible to the virus. The accumulation of unvaccinated cohorts over time can lead to outbreaks when the virus is introduced[7, 44].Areas with low vaccination coverage are particularly susceptible to the rapid spread of measles. Vaccination not only protects the individual who receives the vaccine but also contributes to herd immunity, which protects those who are not vaccinated or who cannot be vaccinated due to medical reasons[45]. When vaccination rates fall below a certain threshold, herd immunity is compromised, allowing the virus to spread more easily among unvaccinated individuals. Immunization rates in Nigeria have improved but remain suboptimal. According to the WHO[11, 12], only about 54% of children received the first dose of the measles-containing vaccine (MCV1) in 2020, far below the recommended 95% needed for herd immunity. Despite the efforts to increase immunization, coverage remains below the threshold needed to achieve herd immunity. Many children in Nigeria remain unvaccinated or under-vaccinated. The reasons for this include logistical challenges, vaccine supply issues, and inadequate health infrastructure, particularly in rural and conflict-affected areas[46-53].

5. Misinformation and Vaccine Hesitancy:

Misinformation about vaccines and vaccine hesitancy among certain segments of the

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population can lead to lower vaccination rates. This hesitancy, fueled by myths, cultural beliefs, or distrust in health interventions, can result in pockets of unvaccinated individuals who can contribute to the resurgence of measles[45, 46].Rumors and myths about vaccine safety and efficacy undermine public trust in immunization programs. Skepticism about vaccines fueled by misinformation and cultural beliefs plays a significant role in vaccine hesitancy, further hindering immunization efforts. Even in areas with initially high vaccination rates, the immunity in the population can wane over time, especially if booster campaigns are infrequent or if initial vaccination efforts do not reach enough of the population. This gradual decline in population immunity can lead to susceptibility to outbreaks in a cyclical manner as the number of individuals without immunity builds up to a critical mass[47, 48, 49, 54].

6. Malnutrition and Weak Immune Systems:
Malnutrition, especially vitamin A deficiency, can weaken the immune system and increase the susceptibility of individuals to measles and the severity of the disease. Populations with high rates of malnutrition may experience more rapid and widespread outbreaks[1, 45].

7. Lack of Access and Weak Healthcare System:
Limited access to healthcare services can delay the diagnosis and treatment of measles, allowing infected individuals to spread the virus to others before being isolated. Inadequate healthcare infrastructure and limited access to healthcare services, especially in rural or conflict-affected areas, hinder continuous vaccination efforts[23]. This sporadic access to vaccination contributes to the cyclical pattern of outbreaks as unvaccinated or under-vaccinated populations accumulate over time. Furthermore, without prompt and effective treatment, complications from measles can become more severe, increasing mortality and morbidity.Nigeria's health system faces several challenges, including insufficient funding, inadequate healthcare workforce, and poor health infrastructure. These weaknesses hinder effective vaccination delivery and disease surveillance[50].

8. High Birth Rates:
Nigeria has one of the highest birth rates globally, which leads to a large number of children being born every year who need vaccination. If the healthcare system fails to keep up with the increasing demand for vaccinations, a significant proportion of the child population remains at risk, contributing to the cyclical nature of outbreaks. As new cohorts of children are born, they need to be vaccinated to maintain herd immunity. If a significant number of these children are not vaccinated promptly, it can create a pool of susceptible individuals large enough to sustain an outbreak[45, 49].

9. Public Gatherings:
Large public gatherings, such as markets, religious gatherings, and school events, can be hotspots for the transmission of measles among unvaccinated populations. These events can facilitate the spread of the virus among a large number of people in a short period[46].

10. Insufficient Disease Surveillance and Response:
Inadequate disease surveillance systems and a lack of rapid response to contain outbreaks can allow measles to spread unchecked. Quick identification, isolation of cases, and vaccination campaigns are crucial to controlling outbreaks and preventing their spread[4, 7, 10, 13, 30, 41, 43].

Barriers to measles vaccination coverage
Efforts to increase measles vaccination coverage face numerous barriers including (Figure 6):

i. Inadequate healthcare infrastructure:
Inadequate healthcare infrastructure and shortages of healthcare professionals, especially in rural areas, limit vaccination coverage[20].

ii. Supply Chain Issues:
Poor road networks and transportation difficulties, particularly in remote and rural areas, complicate vaccine distribution and access to healthcare services. Logistical challenges in vaccine supply chains can lead to vaccine shortages, affecting timely immunization campaigns[20].

iii. Resource Constraints:

Limited financial and human resources constrain the capacity of the health system to conduct widespread and effective vaccination campaigns. Funding gaps affect vaccine procurement, cold chain maintenance, and outreach activities[51].

iv. Socio-Economic Factors:
Poverty, lack of education, and gender disparities also contribute to lower vaccination rates, as families prioritize short-term economic survival over preventive healthcare[47].

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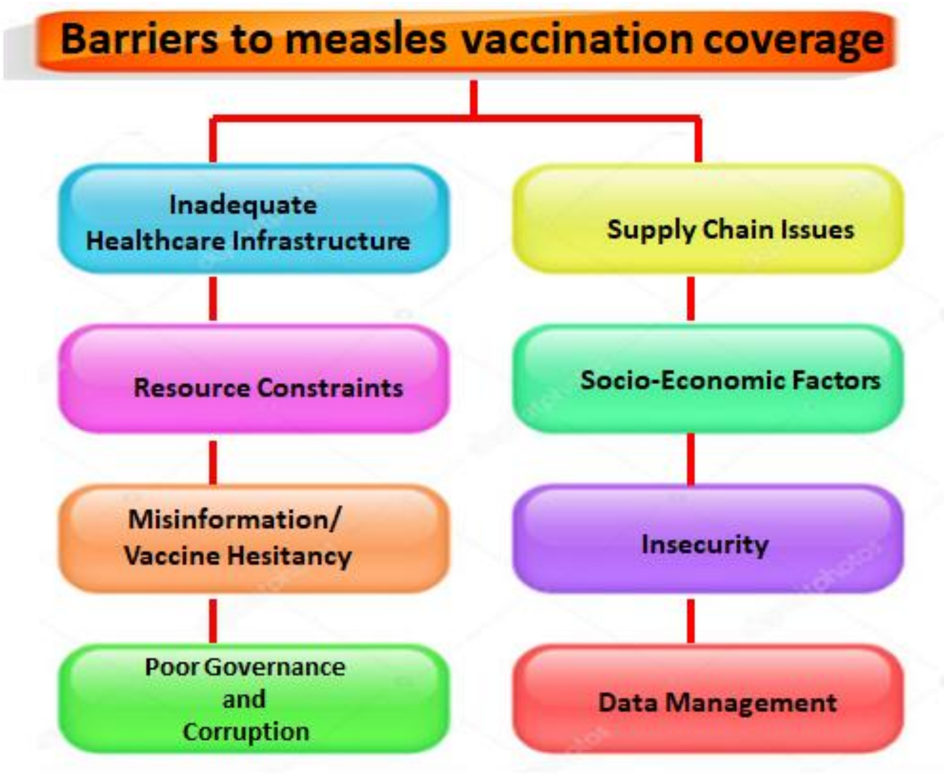

Figure 6: A flow chart showing key barriers to measles vaccination coverage in Nigeria.

v. Misinformation and Vaccine Hesitancy:

Misinformation about vaccines and cultural beliefs contribute to vaccine hesitancy. Myths and misconceptions about the safety and efficacy of vaccines deter parents from immunizing their children[3, 23, 25, 26, 50].

vi. Insecurity:

In conflict zones, insecurity hampers the delivery of health services, including vaccination campaigns. Health workers may face threats, and infrastructure may be damaged, limiting access to care[15, 19, 48, 49].

vii. Poor Governance and Corruption:

Poor governance can undermine public health efforts, including vaccination campaigns. Corruption and mismanagement of resources can lead to inefficiencies in the health system, reducing the availability and quality of vaccination services. Additionally, political instability can disrupt healthcare programs, diverting attention and resources away from preventive measures like vaccination to more immediate political or security concerns. This can result in interrupted vaccine supplies and lower prioritization of immunization programs[15, 19, 46].

viii. Data Management: Ineffective data collection and management impede the ability to monitor vaccination coverage accurately and respond to outbreaks swiftly[10, 13, 41].

Public Health Interventions for combating measles in Nigeria

To combat measles effectively, Nigeria has implemented several public health interventions (Figure 7). Key strategies include:

Figure 7: Public health interventions for combating measles in Nigeria

1. Enhanced Vaccination Campaigns:
Vaccination is the most effective way to prevent measles. High vaccination coverage is essential to achieve herd immunity, which can protect vulnerable populations, including those who cannot be vaccinated due to medical reasons. Implementing widespread vaccination campaigns, targeting both children and adults, is crucial for controlling the spread of measles outbreaks. Supplementary Immunization Activities (SIAs) have been pivotal in increasing measles vaccination coverage. These campaigns target children under five years old, focusing on areas with low routine immunization rates. SIAs helps to reach children missed by routine services. These campaigns should target high-risk areas and populations, including internally displaced persons (IDPs)[9, 24].

2. Strengthening Routine Immunization:
Ensuring high routine immunization coverage is essential to prevent measles outbreaks. Governments and healthcare systems should prioritize the administration of the measles vaccine as part of routine childhood immunization schedules. Timely and complete vaccination of infants and young children is key to reducing the susceptibility of the population to measles. Efforts to improve routine immunization services include training healthcare workers, enhancing cold chain systems, and improving vaccine supply chains. Initiatives like the National Primary Health Care Development Agency (NPHCDA) aim to bolster the health infrastructure and workforce[9, 47].

3. Catch-up Vaccination:
Identifying and vaccinating individuals who have missed their scheduled vaccinations is crucial for controlling measles outbreaks. Catch-up vaccination campaigns should target individuals who have missed their scheduled vaccinations in order to control measles outbreaks. Specifically, the campaigns should focus on the following groups[4, 9, 49].

a) Unvaccinated Individuals:
Catch-up vaccination campaigns should prioritize individuals who have not received the measles vaccine. This includes children, adolescents, and adults who have not been vaccinated or have missed their scheduled doses[46].

b) High-Risk Populations:
Certain populations may be at a higher risk of contracting and spreading measles. Catch-up vaccination campaigns should target these

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groups to ensure their protection and prevent further transmission[46]. Examples of high-risk populations include:

i. Unvaccinated Individuals: Individuals who have not received the measles vaccine or have not completed their scheduled doses are at a higher risk of contracting and spreading the virus.

ii. Infants and Children: Infants and young children who have not yet received the recommended measles vaccinations are particularly vulnerable to the virus. They have a higher risk of severe complications and are more likely to transmit the disease.

iii. Adolescents and Young Adults: Adolescents and young adults who have not received the measles vaccine or missed their scheduled doses are at an increased risk. This age group may have lower immunity due to incomplete vaccination or waning immunity over time.

iv. Healthcare Workers: Healthcare workers who come into contact with infected individuals are at a higher risk of contracting and spreading measles. They play a crucial role in both preventing the transmission of measles within healthcare settings and providing vaccination guidance to patients.

v. International Travelers: Travelers who visit or return from areas with ongoing measles outbreaks are at a higher risk of contracting the disease. Measles is highly contagious, and international travel can contribute to the spread of the virus across borders.

vi. Crowded Settings: Populations in crowded settings such as schools, colleges, and other institutions are at an increased risk of measles transmission. Close contact and limited personal space can facilitate the spread of the virus among individuals.

Identifying and prioritizing these high-risk populations for vaccination and implementing preventive measures can help control the spread of measles and prevent outbreaks. Vaccination campaigns targeting these groups are crucial in ensuring their protection and reducing the overall transmission of the virus[9, 26, 46].

c) Underserved Communities:

Catch-up vaccination campaigns should also prioritize reaching underserved communities with limited access to healthcare services. This includes low-income communities, remote areas, and marginalized populations who may face barriers to vaccination. It is important to implement targeted catch-up vaccination campaigns to ensure that individuals who have missed their measles vaccinations are identified and provided with the necessary immunization. By reaching these target groups, the spread of measles can be effectively controlled and outbreaks can be prevented[47, 49].

4. Enhanced Disease Surveillance:

Establishing robust disease surveillance systems is crucial for early detection and monitoring of measles cases. Surveillance should involve reporting and investigating suspected cases, laboratory testing, and monitoring of vaccination coverage. Rapid identification of cases allows for prompt response measures to be implemented, including isolation of infected individuals and contact tracing. Strengthening measles surveillance systems is essential for early detection and response to outbreaks. Rapid response teams are deployed to investigate and contain outbreaks, ensuring timely intervention[4, 7, 10].

5. Isolation and Quarantine:

Infected individuals should be promptly isolated to prevent further transmission of the measles virus. Quarantine measures may also be implemented for individuals who have been exposed to the virus but are not yet showing symptoms. Isolation and quarantine can help prevent the spread of measles within communities and healthcare facilities[28].

6. Healthcare Worker Vaccination:

Ensuring that healthcare workers are vaccinated against measles is crucial to protect both the workers themselves and the patients they care for. Healthcare facilities should have policies in place to verify and maintain the vaccination status of their staff members[14, 15, 20].

7. Health Education and Communication:

Effective communication and health education campaigns are essential to inform the public about the importance of measles vaccination, symptoms of the disease, and preventive measures. Clear and accurate information can help dispel myths and misconceptions surrounding vaccines and encourage vaccine uptake. Addressing vaccine hesitancy through community engagement and education is crucial. Collaborating with community leaders, religious groups, and local organizations helps disseminate accurate information about the benefits of vaccination and dispels myths[15].

8. Outbreak Response and Contact Tracing:
Rapid response to measles outbreaks is crucial to contain the spread of the virus. Outbreak response teams should be mobilized to conduct investigations, implement control measures, and coordinate vaccination campaigns. Contact tracing should be carried out to identify and monitor individuals who have been in close contact with confirmed cases[12, 19].

9. International Cooperation:
Measles knows no borders, and international cooperation is important to control the global spread of the disease. Sharing information, best practices, and resources among countries can help strengthen measles control efforts and prevent cross-border transmission[4].

10. Integration with Other Health Services:

Integrating measles vaccination with other health services, such as maternal and child health programs, enhances reach and efficiency. Combining efforts helps maximize resource utilization and improves overall health outcomes[4].

11. Strengthening coordination
Strengthening coordination is essential for effective measles control and elimination efforts in Nigeria. The following key activities are critical components of the strategic approach to combating measles in the country[42]:

i. Workshop to Validate National Measles Elimination Strategic Plan 2019 – 2028: The workshop aims to review and finalize the strategic plan designed to eliminate measles by 2028.Bringing together stakeholders from various sectors, including government agencies, international partners, and local organizations, ensures a comprehensive and collaborative approach. The workshop helps align the objectives, strategies, and actions across all involved parties, ensuring clarity and unified efforts towards the elimination goal.

ii. Supportive Supervisory Visit to the Eight Measles, Rubella, and Yellow Fever Laboratories: These visits aim to assess and enhance the operational capabilities of the laboratories responsible for diagnosing and confirming measles cases.Regular supervisory visits ensure that laboratories maintain high standards in testing accuracy and reliability. They also provide opportunities for training and addressing any gaps in resources or knowledge, which is critical for timely and accurate surveillance.

iii. Validation of Measles Outbreak Preparedness and Response (MOBR) Training Materials: This ensure that the training materials used for outbreak preparedness and response are accurate, comprehensive, and effective. Validating training materials guarantees that health workers and other stakeholders are well-prepared and equipped with the necessary knowledge and skills to respond to measles outbreaks efficiently. This is crucial for minimizing the impact of outbreaks and preventing their spread.

iv. Ongoing Measles Outbreak Response (MOBR) Capacity Building Project: This aimed to build and enhance the capacity of health workers and response teams in managing measles outbreaks. Continuous capacity building ensures that response teams are always ready to act promptly and effectively. It also updates them on the latest guidelines and best practices, improving the overall quality of the outbreak response.

v. National Measles Technical Working Group (TWG) Closely Monitoring Measles Surveillance Data and Providing Feedback: This ensures continuous and thorough monitoring of measles surveillance data and offer timely feedback to relevant agencies and partners. Effective surveillance and timely feedback are crucial for early detection and response to measles cases. The TWG plays a vital role in coordinating these efforts and ensuring that data-driven decisions are made to improve measles control activities.

vi. Virtual Biweekly Measles TWG Meetings via Zoom. The purpose is to maintain regular communication and coordination among TWG members. Virtual meetings facilitate consistent and efficient coordination without the need for physical gatherings, allowing for more frequent updates and discussions. This ensures that the response to measles is agile and well-coordinated.

vii. Monthly Surveillance Data Review: Regular thorough reviews of surveillance data on a monthly basis help identify trends, outbreaks, and areas that require more attention or

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intervention. This proactive approach allows for timely adjustments in strategies and resource allocation.

viii. Weekly Surveillance and Laboratory Data Harmonization Ongoing: Harmonizing surveillance and laboratory data weekly ensures that any discrepancies are quickly identified and corrected, providing a clear and accurate picture of measles incidence and spread. This is essential for effective monitoring and response.

The coordinated activities outlined above are integral to Nigeria's strategy for measles elimination. By enhancing coordination among various stakeholders and continuously improving the capacities and capabilities of health systems, Nigeria can make significant strides towards eliminating measles. Regular workshops, supervisory visits, validation of training materials, capacity building, data monitoring, and virtual meetings collectively strengthen the overall response framework, ensuring a robust and effective fight against measles[4, 42, 55].

12. Strengthening laboratory diagnostic capacity

Effective laboratory diagnostic capacity is essential in the fight against measles in Nigeria, ensuring timely and accurate detection of cases, guiding public health responses, and ultimately contributing to the control and elimination of the disease. The key components of this capacity include ongoing sample testing, harmonization of laboratory results, and regular feedback on performance indicators[42].

i. Testing of Samples Ongoing in the Eight Reference Laboratories

The primary objective is to provide accurate and timely diagnosis of measles cases through extensive testing in strategically located reference laboratories. Efficient and widespread sample testing allows for the rapid identification of measles cases, which is crucial for prompt public health intervention. Accurate diagnosis helps in the appropriate allocation of medical resources and the implementation of targeted control measures, such as vaccination campaigns and isolation of infected individuals. Regular testing contributes to a better understanding of the epidemiology of measles in Nigeria, including identifying hotspots and monitoring the spread of the virus.

ii. Weekly Harmonization of Laboratory Results

The primary objective is to ensure consistency and accuracy in the reporting of measles data by harmonizing laboratory results from the eight reference laboratories on a weekly basis. Harmonizing results ensures that there is uniformity in the data reported from different laboratories in the country, minimizing discrepancies and errors. Consistent data across laboratories is essential for accurate epidemiological surveillance and effective outbreak management. Regular harmonization fosters better coordination and communication among the laboratories, promoting a unified approach to measles diagnostics and reporting.

iii. Weekly Feedback of Key Performance Indicators to Measles Laboratories

The primary objective is to provide weekly feedback to measles laboratories on their key performance indicators (KPIs) to ensure they meet set standards and improve their diagnostic performance. Feedback on KPIs helps laboratories maintain high standards of diagnostic accuracy and reliability. Regular feedback allows laboratories to identify areas needing improvement and implement corrective measures promptly. Monitoring KPIs such as turnaround time, test accuracy, and reporting rates ensures that laboratories operate efficiently and effectively contribute to the overall measles control efforts[9, 42].

Overall, the laboratory diagnostic capacity is a cornerstone in Nigeria's strategy to combat measles. The coordinated efforts of sample testing, harmonization of laboratory results, and feedback on performance indicators are pivotal. These activities ensure that the diagnostic process is robust, accurate, and timely, enabling health authorities to respond swiftly and effectively to measles cases. By maintaining high standards and continuous improvement in laboratory diagnostics, Nigeria can significantly enhance its measles surveillance, control, and elimination efforts. By implementing these measures, the government and people of Nigeria can effectively control the spread of measles outbreaks and protect the health of vulnerable populations[42, 55].

CONCLUSION

Combating measles in Nigeria demands a concerted effort that addresses the underlying drivers of transmission and barriers to

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vaccination while scaling up effective public health interventions. By leveraging data-driven strategies, engaging communities, and ensuring equitable access to health services, it is possible to reduce the burden of measles and move closer to achieving health for all. The road ahead is challenging but navigating it successfully will require persistent effort, innovation, and collaboration from all stakeholders involved in public health. By enhancing immunization coverage, engaging communities, and strengthening the health system, Nigeria can make significant strides towards eliminating measles. Sustained commitment, adequate funding, and international collaboration are essential to achieving this goal and ensuring the health and well-being of Nigerian children.

HIGHLIGHTS:

1. Nigeria faces fluctuating measles incidence and periodic outbreaks despite vaccine availability, driven by low immunization coverage, population displacement, and rapid urbanization.
2. Measles control efforts are hampered by factors such as misinformation, vaccine hesitancy, cultural beliefs, mistrust in the healthcare system, insecurity in conflict areas, and logistical challenges.
3. Strengthening surveillance systems, integrating measles vaccination with other health services, and enhancing immunization campaigns are critical to improving measles control and outbreak response in Nigeria.

List of Abbreviations

CD150 - Cluster of Differentiation 150 (also known as SLAM)
CD4+ - Cluster of Differentiation 4 positive
CD8+ - Cluster of Differentiation 8 positive
F - Fusion protein
FCT - Federal Capital Territory
H - Hemagglutinin protein
IDPs - Internally displaced persons
IFN - Interferon
IL – Interleukin
L - Large protein
LGAs - Local Government Areas
M - Matrix protein
M&RI - Measles and Rubella Initiative
MCV1 - Measles-containing vaccine first dose
MCV2 - Measles-containing vaccine second dose
MeV - Measles virus
MHC - Major Histocompatibility Complex
N - Nucleocapsid protein
NK - Natural Killer
P - Phosphoprotein
PRRs - Pattern Recognition Receptors
R0 - Basic reproduction number
RIG-I - Retinoic acid-inducible gene I
RNA - Ribonucleic acid
SIAs - Supplementary Immunization Activities
SLAM - Signaling Lymphocytic Activation Molecule
TLRs - Toll-like receptors
TNF - Tumor Necrosis Factor
WHO - World Health Organization

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Not applicable.

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