



Understanding the factors that shape vaccination ecosystem resilience: a qualitative assessment of international expert experiences and perspectives

Suepattra May ¹, Meaghan Roach,¹ Melissa Maravic,¹ Rachel Mitrovich,² Rozanne Wilson,³ Nadya Prood,¹ Amanda L Eiden ²

To cite: May S, Roach M, Maravic M, *et al*. Understanding the factors that shape vaccination ecosystem resilience: a qualitative assessment of international expert experiences and perspectives. *BMJ Public Health* 2024;**2**:e000381. doi:10.1136/bmjph-2023-000381

► Additional supplemental material is published online only. To view, please visit the journal online (<https://doi.org/10.1136/bmjph-2023-000381>).

Received 6 July 2023
Accepted 26 February 2024



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¹PRECISIONheor, New York, New York, USA

²Merck & Co., Inc, Rahway, New Jersey, USA

³PRECISIONheor, Vancouver, British Columbia, Canada

Correspondence to
Dr Amanda L Eiden;
amanda.eiden@merck.com

ABSTRACT

Introduction ‘Shocks’ or external stressors to vaccination programmes can lead to decreased vaccination coverage rates. The capacity of vaccination ecosystems to effectively respond and adapt to shocks demonstrates programme resilience. This study sought to describe components that contribute to resilience in national immunisation programmes.

Methods Mixed-methods study comprising in-depth interviews and surveys with n=30 vaccination programme experts in eight countries (Brazil, Costa Rica, Greece, Japan, Nigeria, Philippines, Spain and the USA). We elicited data on country-specific shocks, associated effects and factors that facilitated or impeded programme resilience. Interviews and open-ended survey responses were analysed qualitatively, with closed-ended survey questions analysed using descriptive statistics.

Results Experts described immediate effects of shocks including decreased vaccine uptake and negative perceptions of vaccination from the public and media. Late emerging impacts included increased vaccine hesitancy and vaccine-preventable disease (VPD) rates. Stakeholder education, immunisation information systems (IIS) and programme financing were key factors to strengthening programme resilience. Appropriately trained frontline healthcare personnel can counter vaccine misinformation that otherwise erodes trust and contributes to hesitancy. The COVID-19 pandemic also exposed structural weaknesses in programme resilience, with experts highlighting the need for robust IIS and workforce support to mitigate burnout and strengthen resilience when a shock occurs.

Conclusions Our findings provide preliminary insights into factors that experts believe to be associated with vaccination programme resilience. Anticipating, adapting and responding to shocks is central to strengthening systems, ensuring ecosystem resilience and protecting against current and future VPD threats.

INTRODUCTION

Globally, immunisation prevents an estimated 4–5 million deaths across the age spectrum annually and is a valuable and cost-effective

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ While the benefits of vaccination are generally well understood vaccination coverage rates continue to vary globally demonstrating a need to broaden immunisation systems and reconsider programme effectiveness from the perspective of resilience, particularly in light of the burgeoning literature on the impact of shocks to the vaccination ecosystem, including the COVID-19 pandemic.

WHAT THIS STUDY ADDS

⇒ Across multiple country settings, policy experts described immediate and late emerging effects of shocks that have increased vaccine hesitancy and vaccine-preventable disease (VPD) rates. A vaccination ecosystem resilience is dependent on a number of factors including pervasiveness of misinformation, lack of investment in system critical resources and workforce development. The recent pandemic revealed several systemic strengths and weaknesses to vaccine uptake as observed by experts on the ground.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Anticipating, identifying, adapting and responding to shocks is central to strengthening vaccination programmes, ensuring ecosystem resilience and protecting against current and future VPD threats. Recent crises, including the COVID-19 pandemic, highlight the critical need for continued research into policy and programmatic changes to develop vaccination ecosystem resilience.

public health intervention.¹ The Global Alliance for Vaccines and Immunization (GAVI) quantified that vaccines administered in Gavi-eligible countries between 2000 and 2020 generated >\$230 billion (2022 US\$) in economic benefits by preventing illness, premature death and disability.^{2 3} Despite the well-recognised benefits of vaccination, vaccination coverage rates (VCRs), or the

proportion of an eligible population that is vaccinated, vary globally, demonstrating a continued need to ensure that vaccination programmes reach their full potential.

At the health system level, various functions work together to effectively deliver quality services (eg, infrastructure, workforce, surveillance data, medical products and technology, finance, governance).⁴ When exposed to a disruption to the system, such as a vaccine-preventable disease (VPD) outbreak, supply chain interruption or a financial crisis, health system functions may be vulnerable to interruptions that can result in health system strain or collapse.⁴ System disruptions have also been referred to as 'shocks', defined as a '*sudden and extreme change which impacts a health system, and is thus different from the predictable and enduring health systems stresses, such as aging populations*'.⁵ How a health system responds and adapts to a shock is known as 'resilience'. The concept of resilience was first applied in Holling and Walker's seminal work on ecological systems, which has since been studied and applied to health systems.⁶ Specifically, in examining the Ebola epidemic, Kruk and colleagues defined resilience as the '*capacity of health actors, institutions, and populations to prepare for and effectively respond to crises; maintain core functions when a crisis hits; and, informed by lessons learned during the crisis, reorganize if conditions require it*'.⁷ During an infectious disease outbreak, resilient health systems can minimise social and economic disruption through '*engaging people as partners in containment efforts, reducing fear, and hastening resumption of normal activity*'.⁷ Dubé and MacDonald further defined resilient immunisation programmes as those that (1) are able to withstand major shocks and disruptions, (2) quickly adapt to changing circumstances and (3) maintain high vaccine uptake and acceptance over time.⁸

Within a health system's infrastructure, vaccination systems form a complex interconnected network or ecosystem. The vaccine ecosystems comprised (1) local, national and international healthcare actors or organisations (eg, healthcare professionals), community and policy/government leaders and (2) sectors that promote user uptake (ie, research and development, manufacturing, procurement and finance, distribution, logistics, and supply chain management, and healthcare, including systems designed to support surveillance and monitoring/tracking).⁹ Each is responsible for provision of services during periods of stability as well as response and recovery in crisis periods.^{9 10} Ecosystems face political, economic, environmental (ie, natural disasters/climate change) and sociocultural pressures that are shaped by multiple stakeholders, microsystems and policies, as well as supranational entities and geographical regions. Additionally, the degree to which vaccination is deemed acceptable and impacts subsequent uptake is variable and influenced by multiple factors.^{11 12} For example, perceptions of vaccine safety or efficacy can impact coverage rates, and lack of vaccine confidence, as well as personal and religious beliefs about vaccination can lead to hesitancy or refusal.

Health system shocks that disrupt the vaccine ecosystem may include conflict and political unrest through destruction and/or displacement of healthcare facilities, healthcare workers, infrastructure, resources and equipment.¹³ Moreover, ecosystem disruptions can result in VPD outbreaks and losses in programme development investments.¹⁴ Since early 2020, the global COVID-19 pandemic has caused substantial disruption to routine vaccination across the life course.^{15 16} Throughout the pandemic, the core elements of health and vaccination ecosystems have been pressure tested, bringing renewed attention to strategies for developing and maintaining resilience.

Despite the articulation of theoretical frameworks and toolkits around the concept of health systems resilience, there remains limited research examining the resilience of vaccination ecosystems in response to an infectious disease outbreak.¹⁷ The primary aim of this study was to identify and describe the key components and attributes of ecosystems that facilitate or impede ecosystem resilience during a crisis or shock.

METHODS

Study design

To obtain an understanding of vaccination ecosystem resilience, a convergent parallel, mixed-methods cross-national study, involving a 1-hour qualitative interview or an online survey, was conducted with vaccination experts. The survey option was provided because the study was conducted during the COVID-19 pandemic; therefore, many participants reported time constraints and were unavailable for a 1-hour interview. Survey and interview data were collected during the same period, analysed separately, and results were interpreted together.¹⁸

Case study country selection

To inform case study country selection and local vaccination ecosystem context, a targeted literature review was conducted. Specifically, we were interested in understanding the (1) key factors that may support or impact a system resilience and (2) interaction of identified factors, over time, in specific shocks or crises and (3) how these factors strengthened, sustained and/or eroded system resilience. The targeted literature review included peer-reviewed and grey literature published between 2006 and 2018. Additionally, data were extracted on infectious disease burden, immunisation programme policies and VCRs. The review was updated in 2022 to provide the most recent literature context in interpreting study results. We identified 27 potential case study countries whose vaccination ecosystems had experienced a shock within the past decade. Several factors were considered in selection: geopolitical and social/cultural diversity; size, scope and duration of the crisis; and spillover effects to neighbouring countries/regions. Eight countries were selected representing variation across: WHO member state region, population size, healthcare provision

landscape, country income, VPD incidence/prevalence and morbidity, and characteristics of the delivery system, which are detailed in online supplemental figure 1. A summary of select characteristics at the time of case study country selection is included in online supplemental table 1.

Sampling and recruitment

We employed a purposive convenience sampling strategy to recruit individuals based on their professional experiences and role within each of the selected case study countries of interest. International and in-country partnerships and literature review findings were used to identify potential key informants from each case study country. The recruitment strategy was supplemented by snowball sampling supported by interview participants who offered to identify and refer other individuals with similarly relevant professional expertise. Potential participants held a broad cross section of positions within vaccination ecosystem programme policy development, implementation and surveillance and included policy experts, current and former leaders of governmental and non-governmental healthcare agencies, clinicians, academic researchers and health agency personnel. Eligibility criteria included at least 1 year of direct experience in implementation, policy or decision-making capacity in the fields of advocacy, health education, policy or care delivery, public health programme implementation, a graduate or medical degree and/or an established peer-reviewed publication record. We were particularly interested in identifying individuals involved in decision-making related to or implementation of a response following a VPD-related crisis. All potential participants were initially assessed for eligibility by the study team based on publicly available information pertaining to their professional backgrounds, prior to being invited to participate.

This approach provided the study with participants possessing a mix of individual characteristics and expertise across the vaccine ecosystem. A letter of invitation to participate in the study was emailed to prospective participants. The letter described the project goals and purpose. Interested respondents were scheduled for an interview or provided a personalised link to the online survey. All participants provided their informed consent for their participation in the study. Although the research study was sponsored by a life sciences company, there was no link to any products. The ideas and opinions reported here belong solely to the authors. The life sciences sponsor had no editorial discretion over any of the reported research findings.

Data collection

Two data collection methods were used for this study: qualitative in-depth interviews and a quantitative online survey. Concepts and gaps identified from the targeted literature review and feedback from public health experts informed development of the semistructured

interview discussion guide and survey instrument, the domains and modules for which are detailed in online supplemental tables 2 and 3. One-on-one interviews and online survey data were collected between May 2021 and January 2022, and May to November 2021, respectively. In-depth interviews help characterise issues most relevant to a vaccine-related crisis because the interviewer can elaborate on individual opinions including the breadth and range of issues considered in vaccination system resilience. The discussion guide was divided into topics on participant experiences with and perspectives on shocks to the immunisation system, and is included in online supplemental table 2. The full discussion guide can be found in online supplemental file 2. All interviews were conducted via web-based conferencing service and were audio recorded. Interviews with participants were conducted in the local language, English or both, with an interpreter present for live translation as needed. The online survey enabled data collection from individuals who were unable to participate in an interview. Similar to the semistructured interview discussion guide, survey questions were organised into topics addressing country-specific vaccination programme infrastructure, impacts on vaccination ecosystems and components of resilience. The survey instrument is included in online supplemental table 3. Survey respondents were provided the option to complete the survey in the local language or English.

Data analysis

Aligned with the convergent parallel, mixed-methods study design, analysis of the interview and survey data was performed separately, followed by integrating results to identify areas of convergence, divergence and expansion during analysis.¹⁹ Interviews were transcribed verbatim and translated into English as necessary. Transcripts were imported into Dedoose (V.9.0.17; 2021) to facilitate coding and analysis. Coding began with the development of an initial framework of a priori codes derived from the interview and survey topics (deductive coding). Members of the study team independently reviewed a subset of transcripts to identify emergent codes and potential themes (inductive coding). Next, the team reviewed the generated codes and prevailing themes and agreed on a revised coding framework to categorise the range of experiences and opinions reported. Codes were further refined into descriptive categories, resulting in a coding dictionary comprising 13 codes based on discussion guide topics and emergent themes. Next, a team of three researchers applied codes to all of the interview data through a systematic review, with quality checks by a senior member of the team to ensure inter-rater consistency among coders.²⁰ Coded segments were analysed using the constant comparative method to identify similarities, differences and patterns in the data around vaccination ecosystem shocks, recommendations for responding to shocks, as well as factors that contributed to resilience or erosion of these systems.^{21 22} Descriptive

statistical analysis was performed on closed-ended survey questions using SAS (V.9.4). Data quality checks were applied to all participant data to ensure completeness, consistency, accuracy and reasonableness (ie, the answer selection made sense) of survey responses. A data saturation grid was employed to determine the prevalence of themes in the interview and survey data across case study country settings.^{23 24} Saturation was considered achieved once no new themes had emerged.^{21 25} Results were then mapped to the updated targeted literature review findings to provide further context.

Patient and public involvement

Although patients or members of the public were not directly involved in the conception and design of the study, seven individuals representing patient advocacy organisations participated in the study, and their perspectives are represented in the findings.

RESULTS

Participant characteristics

Of 128 individuals invited to participate, 55 (42%) responded to the email invitation; 35 (27%) expressed willingness to participate and 30 (23%) participated in the study. Of the participants who completed an interview (n=13), most interview participants were male (69%) between the ages of 50 and 69 years (69%), with more than 10 years of vaccine-related employment experience and worked in an academic (38%) or non-profit/non-governmental agency (38%) setting at the time of the interview. Most participants resided in Japan (31%), Brazil (23%) or the USA (23%). For those participants who completed a survey (n=17), most were female (65%) between 50 and 59 years of age (59%), with more than 10 years of vaccine-related employment experience (88%) and worked in a hospital or clinic (41%), academic institutions (18%) or a national government agency (18%). Most survey participants resided in Costa Rica (29%) or Spain (24%). Participant demographic characteristics are detailed in online supplemental table 4.

Factors that facilitate resilience

Interviewees described various factors that positively support or impact the vaccination ecosystem in their country. Survey participants also were asked to select specific factors that positively impacted the resilience of the ecosystem without further elucidation. Data about positive impacts permitted the identification of factors considered to facilitate vaccination ecosystem resilience (figure 1).

The role of stakeholder education about vaccines and VPDs

Interviewees described the importance of a rapid roll-out of public education campaigns in partnership with professional associations. The aim was to counter antivaccination information, support vaccination and encourage conversations between patients and providers about the importance of vaccination. These campaigns were typically approached in two ways. First, public educational campaigns were developed to drive awareness of and health-seeking behaviours around vaccination. Campaigns aimed at healthcare practitioners who administer vaccines were designed to train providers to communicate clearly and effectively about the importance of vaccination to their patients. This served to augment public health education efforts by ensuring that practitioners themselves were (1) cognisant of the effectiveness of vaccination, (2) confident in vaccine administration and (3) equipped to effectively communicate the value of vaccinations to patients and in doing so, engendering trust among the public. Survey responses validated interview findings with 'educational campaigns for the public' and 'educational campaign for health care practitioners' as the top two factors believed to positively impact vaccination ecosystems.

Interviewees shared that when community organisations and governments collaborated around educational initiatives, such partnerships often resulted in increased community trust about vaccination. Specifically, in Japan, the government's provision of education around vaccines to specialists in internal medicine, paediatrics, and

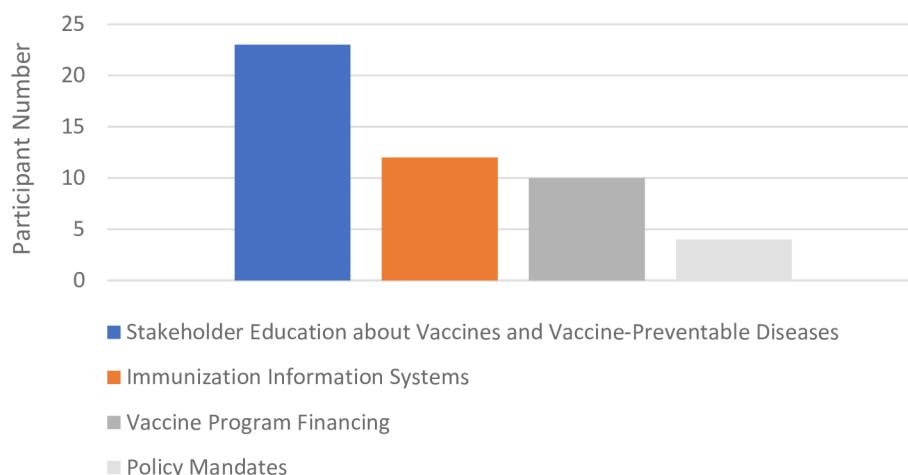


Figure 1 Factors that facilitate resilience.

obstetrics and gynaecology, and midwives led to greater public receptivity. Similarly, in Nigeria, extensive training of healthcare workers such as doctors, nurses and community health workers played a key role in educating the public. One participant described the effectiveness of employing jingles (mass communication on television and radio), photo depictions of communicable diseases and the critical role of patient and immunisation advocacy groups in raising awareness and educating the public about the importance of vaccination.

Investment in vaccination programme financing, infrastructure and delivery

Multiple factors related to financing and investment across the vaccination ecosystem were cited by interviewees as critical drivers to facilitate resilience. Survey participants also ranked 'increased funding for vaccination programs' as a factor that positively impacts the resilience of an immunisation system. Interviewees also reported that priority setting and competition for public health resources impacted immunisation policy development. This, in turn, impacts programme financing and inclusion of specific vaccines in National Immunization Program (NIP) schedules, which is fundamental for overall system performance. Interviewees highlighted the importance of enlisting various influencers in the ecosystem—politicians, media figures, advocacy groups and professional societies—to promote government investment in programme financing and persuade decision-makers to enact policy. In the USA, interviewees cited successful elimination of financial barriers as increasing access to and coverage for paediatric vaccination; although generally viewed as a model of success, participants also noted that similar initiatives had not been attempted in adult populations who have been historically undervaccinated due to health-related disparities.

Interviewees also noted that investment in infrastructure, such as vaccine delivery systems that support access, rapid response systems and immunisation information systems (IIS) were key to facilitating resilience. For example, participants from Brazil described how their NIP invested in its vaccination delivery system by building nearly 50 000 vaccination rooms throughout the country; this facilitated greater access among communities who otherwise may have not received vaccination services. This, in turn, led to observable declines in polio, measles and rubella. The importance of rapid response oversight committees available to evaluate and respond to vaccine safety and efficacy crises augmented IIS data and facilitated action during a shock. An interviewee in Spain described the value of a robust, vigilant system where adverse events are rapidly recognised and addressed. An immediate response, coupled with transparency, was credited with building community trust and increasing VCRs in Spain.

In Brazil, a more cohesive IIS helped to effectively address acute and long-term vaccination supply concerns

which in turn mitigated VPD outbreaks. One Brazilian interviewee shared that IIS had initially been administered under the direction of federal and state levels. This resulted in data collection gaps across and within regions. However, after transitioning to an IIS system whereby responsibility for data collection was coordinated at the municipal level (the level also responsible for health-care delivery), data reporting improved considerably. Similarly, Japan has made IIS system improvements that include real-time communicable disease tracking. Nigeria launched an electronic vaccination monitoring system application for real-time tracking of administration, side effects and hesitancy, connected with the National Primary Health Care Development Agency for streamlined monitoring. Select exemplar narratives highlighting the findings are presented in [table 1](#).

Factors that impede resilience

Participants were asked to share factors perceived to negatively impact a vaccination ecosystem resilience, as well as identifying specific instances they believed contributed to impeding resilience. Participants overwhelmingly noted the influence of antivaccination movements to undermine confidence and contribute to increased hesitancy. In addition, other factors that have impeded resilience include perceptions and reports of vaccine-related adverse events and lack of investment in vaccination programmes ([figure 2](#)).

Vaccine hesitancy and mistrust

Interviewees cited antivaccination movements and vaccine hesitancy as negative impacts on ecosystem resilience, with misinformation about vaccination-related adverse events and subsequent mistrust of vaccine efficacy serving as notable drivers. Nigerian participants described the spread of misinformation about unconfirmed adverse events associated with the oral polio vaccine. Interviewees from multiple countries described how well-respected and revered community leaders—who hold sway among the public—often perpetuated vaccine-related rumours and misinformation. Participants from Japan described how widely publicised media portrayals of alleged adverse events from the human papillomavirus (HPV) vaccine created fear and angst among adolescent girls and their parents, leading to governmental suspension of the programme. This, in turn, impeded resilience and facilitated a precipitous drop in VCRs among the target population. Such depictions demonstrate how the public may focus more on the perceived adverse events and less on the benefit of protection from infectious diseases. Ineffective or inadequate communication strategies to counter misinformation serve to augment the shock, perpetuate mistrust and erode resilience.

Lack of resource investment and lack of workforce development

While investment was identified as a key driver to facilitating resilience, several interviewees also reported that insufficient investment in ecosystem critical resources

Table 1 Exemplar narratives of factors that facilitate resilience

Factor	Exemplar narratives
Stakeholder education about vaccines and vaccine-preventable diseases	<p><i>'I think in terms of education, what's important and what we've seen... is that it comes from trusted community members or providers... People trust their doctors. They trust their nurses. They trust their pharmacists... The idea that you're getting these recommendations, and they're coming from that trusted source, is essential. It's not just necessarily about a campaign going out, but... that it's personalized to the community so that you're actually talking in the right language and the right manner, using the right content to reach that audience.'</i> (US participant)</p> <p><i>'...so public awareness has been the main key in driving immunization in Nigeria...without that, I mean, it's literally a nonstarter. We also have NGOs, non-governmental organizations...to educate people on immunization...there is a group...they have unleashed an advocacy program towards educating people on the need of the HPV vaccine...in the last couple of months, has taken over literally everywhere. People are coming to ask questions. Where is this vaccine? How do we access the vaccine? What are the problems? Education, fundamentally, is the number one issue. If there is no advocacy, there is no awareness.'</i> (Nigerian participant)</p>
Immunisation programmes and information systems	<p><i>'I think the strongest aspect is our unified healthcare system...the SUS, and the PNI, the immunization program...they can reach the whole of the population...a crucial factor for the success of the vaccination is... Brazilians, they believe in vaccines. And this is largely due to the previous success of the immunization program... Brazilians do believe, and we also believe that now, with COVID, Brazil is going to be one of the countries with the largest, uh, vaccination covers. As long as we have, uh, vaccines, the population accepts to be vaccinated.'</i> (Brazilian participant)</p> <p><i>'...There is always a technical working group that actually meet before there is any rollout of vaccination. They have a system, electronic medical system, before the rollout. Then that electronic system kind of—it's a vaccination system monitoring app, really, that is in almost all the centres around the country, where it is monitored, where you can actually real-time monitor when vaccines are administered, if there are any side effects, or if there is any hesitancy, and so on and so forth. It is all keyed into the electronic medical vaccination system. That also is one of the new innovations that has been developed locally here in Nigeria, to be able to really, really monitor the vaccination system across the country. It is all over, at the state level, at the local government level, where immunizations are administered, so they have that system. It's connected to a central system at the National Primary Health Care Development Agency, so that if there's any concerns at any particular time, the Agency is able to monitor it real time and quickly provide solutions. I think that's one of the key thing that have really, really helped in systematically putting the immunization program on check, literally.'</i> (Nigerian participant)</p>
Vaccine programme financing	<p><i>'We do have some infrastructure that's worked really well. The Vaccines for Children program has been hugely successful in taking away financial barriers and providing access for children. What we saw in the measles outbreaks in the... the 80s and 90s, is very different now because they instituted the Vaccines for Children program... We can still work on that in the adult space, but children have access across the board to a really important preventive service, and so taking away financial barriers has been a huge success....'</i> (US participant)</p>
Policy mandates	<p><i>'...in Greece it has been mandated implementing a health book for every child that is born...every health act that takes place...in the child's life is recorded, including all vaccinations, which are required, throughout the child's life in order to be enrolled and be in elementary schools and high schools... and the fact that this was implemented and the vaccinations were mandated, this has resulted in-- and recorded, this has resulted in a very high percentage of children vaccinations at about 93%.'</i> (Greek participant)</p>

confers myriad negative impacts. Interviewees shared first-hand their observations of how governing bodies and political actors shaped vaccination priorities and policies, and impeded investment in ecosystem infrastructure. One participant from Brazil described how cost-cutting measures directly led to vaccine shortages, which impacted VCRs in the short term and accelerated VPD outbreaks over the long term. Another Brazilian participant noted the importance of investing in workforce development as high personnel turnover led to disruptions in the delivery system. Participants across settings emphasised how lack of investment in any one critical area of the system impeded overall system resilience.

Select exemplar narratives highlighting the findings are presented in [table 2](#).

Shock of COVID-19 pandemic to vaccination ecosystems

Because the study was conducted during the COVID-19 pandemic, interviewees were asked about the impact of COVID-19 on the vaccination ecosystem, strategies and programme operations.

Revealed system weaknesses

Interviewees described how the pandemic exposed structural weaknesses in vaccination ecosystem resilience, with participants highlighting the need for robust data

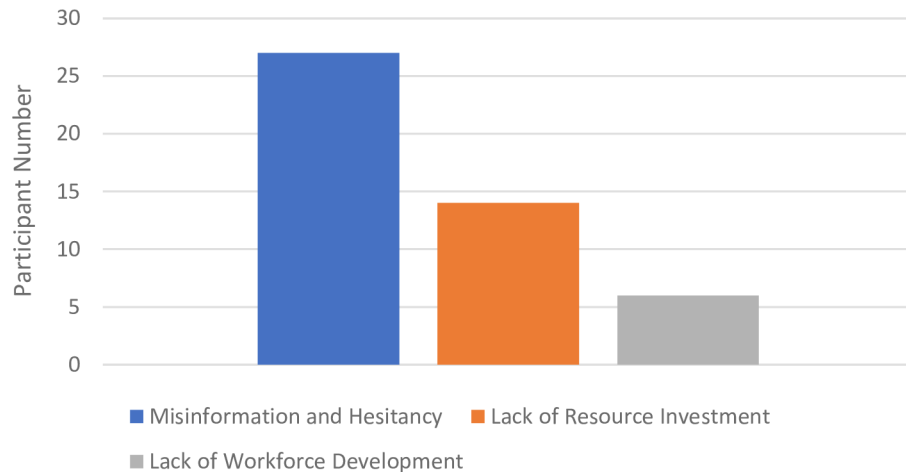


Figure 2 Factors that impede resilience.

systems and personnel training to reduce burnout and increase resiliency when a stressor arises. For example, in Nigeria, distribution of the COVID-19 vaccine illuminated shortcomings in the vaccine delivery system, particularly around basic infrastructure such as availability of temperature-controlled storage facilities. Second, pandemic-related disruptions to routine vaccination schedules eroded resilience by substantially reversing gains in coverage levels, effectively wiping out

years of progress made in increasing VCRs. Specifically, decreased VCRs for measles due to the pandemic threatened gains previously made towards elimination. Several interviewees noted that the pandemic further highlighted racial, ethnic and financial disparities, both within countries and around the world. Participants perceived racial and ethnic minorities as having been disproportionately affected by COVID-19, in that the stakeholders had not developed partnerships within these communities to

Table 2 Exemplar narratives of factors that impede resilience

Factor	Exemplar narratives
Vaccine hesitancy and mistrust	<p><i>'What happened was that there was a lot of denial, really, not just even hesitancy, but total denial of the vaccine because of the fact that people believed that for political reasons, for religious reasons...that there were some things that were put inside the vaccine...studies had been conducted around the world...that the polio vaccine was quite safe...'</i> (Nigerian participant)</p> <p><i>'...some journalists in Japan believe that...attacking the government, academia, and big pharmaceutical companies are good things... most mass media tries to be on the victims' side...always the vaccine victims are quite visible...and they appear on the screen [with] symptoms and signs after the vaccination. However, the people that get benefit from vaccination...are invisible...we can't see it...see them because many people are healthy because of vaccination...but who knows that they are healthy because of vaccination?'</i> (Japanese participant)</p>
Lack of resource investment	<p><i>'...in more recent years, we've seen...a shortage of different types of vaccines.... when we made sure that we had enough BCG doses...there would be an issue with supply of some other vaccine. And when that other vaccine was restored or the supply was restored, there was an issue with some other vaccines.... the problem is that when a family goes to a clinic, and doesn't find the vaccine that they need, they're not coming back.'</i> (Brazilian participant)</p> <p><i>'...having a strong public health infrastructure is probably the best way wherever you are, and so the shocks might be different. Your storage and handling capacity going to remote outposts is gonna be important, but if you have a strong public health infrastructure that supports that, it mitigates the shock. If you have these huge hesitations coming through from populations and protests and things like that, having a strong public health infrastructure that is actively educating, that is actively doing quality improvement, that's actively promoting messages and campaigns that work to change behaviour and support the attitudes that you want to see, a well-funded, well-led program can mitigate a lot of the challenge.'</i> (US participant)</p>
Lack of workforce development	<p><i>'...for the system to be resilient and to have resilience, we need some form of stability... For example people need to think about career plans, and institutions need to think about career plans for their healthcare professionals....in Brazil, there is a great focus on tertiary health but no decent career plans for physicians or for people who want to continue working in collective health....the institutions don't exist without people, and we need to provide better conditions and decent careers for people to make up these institutions.'</i> (Brazilian participant)</p>

Table 3 Exemplar narratives on resilience during the COVID-19 pandemic

Factor	Exemplar narratives
Revealed weaknesses	<p><i>'The vaccines must be global, must reach out every part of the world so that we can sustain humanity... this is one of the key things that COVID has really shown us...the inequalities are real, and we must find a way of really... really bridging the gap between the poor and the not so poor countries around the world.'</i> (Nigerian participant)</p> <p><i>'I think it's also exposed the racial and ethnic disparities, and maybe just in a different way than what we traditionally hear about it... when I see that we are wanting to work with people of colour, black, brown, whatever the situation may be, what that underscores for me is that we have not as an immunization community consistently invested in appropriate healthcare services in communities of colour so we don't have those relationships where trust has been built where you can easily plug and play vaccination efforts. Instead, we're starting from scratch and saying... you should come take this vaccine... COVID has shown that we need those community partnerships, and we need to invest in them consistently not just for vaccination, but healthcare services overall... into communities that maybe disproportionately affected.'</i> (US participant)</p> <p><i>'I cannot recall any other incident that has impacted or threatened the health of the Greek population... The obstacles are coming from three different categories of the population that are refusing to be vaccinated: The one category of people against vaccinations, and they are the anti-vaccination population. The second category is the people that are afraid that the vaccine for COVID, the COVID vaccine, was produced a little bit too fast and thus has not have enough trial time in order to know exactly what the consequences-- what the outcome would be from that. And the third category is mostly younger individuals that just don't consider and don't think that it is a serious threat to their life and thus don't believe that it is necessary to be vaccinated.'</i> (Greek participant)</p>
Revealed strengths	<p><i>'I would use the word 'transparency' in general terms, which is what's going to make the population very trustful, but when I say transparency that is very important because you have to have a robust system of vigilance also, and that system of vigilance has to be transparent. Also, we have a system where adverse effects are addressed very quickly. That creates trust also, but it's very important that we have this quick response for adverse effects. And then, that the general health system and also the regional governments also are very open and clear with the media when they inform, and it's transparency which also build in the trust.'</i> (Spanish participant)</p> <p><i>'I'd like to think that there's a lot of opportunity moving forward. I think some of that's already started. I think there's a new recognition of the value of vaccines, which I think can't be understated. That is huge, right?... People understand what they do, why they're important, and how amazing it is that they were able to create this vaccine for COVID so quickly. Of course, the technology is 10 years in the making, but it's still the fact that they're able to do this. I think there's a really bright future and a bright opportunity ahead of us. I think some areas infrastructure, of course, funding, as we've talked about, the IIS's we've talked about, where we're working hard to try to bring parity to access, right?'</i> (US participant)</p>

efficiently deliver vaccines and instil vaccine confidence. Inequities were observed at the country level as well, with wealthier countries receiving preferential treatment over lower income countries.

Revealed system strengths

Interviewees shared that despite challenges, the COVID-19 pandemic provided an opportunity to evaluate current structures and processes to better strengthen vaccination ecosystems. Specifically, while the pandemic exposed current vaccination programme weaknesses, the rapid roll-out of the COVID-19 vaccine highlighted a range of innovative interventions that could be leveraged and incorporated into routine vaccination programmes. For example, US participants described how provider payment for vaccination had been revised to increase compensation for administering the COVID-19 vaccine. One participant noted that this revision should be applied across all vaccines, with COVID-19 serving as the precedent. Select exemplar narratives highlighting the findings are presented in [table 3](#).

DISCUSSION

This study sought to identify, elucidate and describe how shocks have impacted vaccination ecosystems and examine divergence between theoretical frameworks of resilience and how resilience manifests in practice. In so doing, we highlight the degree to which key components associated with resilience are inter-related and multifactorial. Through an analysis of the data and theories on health systems resilience, our study reveals the on-the-ground impacts and outcomes that can be mapped back to elements of resilience explicated in the published literature.

In describing the emerging concept of resilience, Fridell *et al*⁴ identified several terms (eg, major shock, adapt, maintain, absorb, respond, change, learn, transform, withstand) and characteristics (eg, financing, health workforce, information, leadership and governance, access to projects/technology, service delivery) to describe resilience and the degree to which a health system is equipped to deal with acute shocks and chronic

stressors.⁴ Nuzzo *et al*²⁶ described capacities needed to achieve and maintain health systems resilience in the wake of an infectious disease shock. Many of the elements described in these works were highlighted by our study participants, for example, the importance of maintaining critical infrastructure, adequately trained workers, timely access to finances, collaboration and communication with partners both inside and outside of the healthcare delivery system, including the integral role the public plays with in the ecosystem with respect to vaccine awareness, access and acceptance.^{26 27} A notable stressor and impediment to resilient systems described by study participants is the pervasive mistrust in vaccination more generally, be that concerns around vaccine efficacy and safety, or mistrust in the personnel who administer them. The long and complex history around perceptions of vaccine-related side effects has been well established across multiple vaccines and disease areas in the peer-reviewed literature, with vaccine acceptance dependent on public confidence and trust.^{28–31} It is believed that reversing the trend away from mistrust and towards trust is best operationalised within the specific context at local and regional levels. In examining the resilience of Kenya's health system, Kagwanja *et al*³² focused on chronic stressors (rather than acute shocks) and the responses and organisational capacities underpinning the responses.³² In this study, health manager participants reported a wide range of health system stressors related to resource scarcity, lack of clarity in roles, political interference, reduced autonomy in resource allocation and decision-making, and poor human resource management. Everyday resilience emerged from strategies enacted by managers drawing on a combination of organisational capacities depending on the stressor and context.

The COVID-19 pandemic served as a major shock to vaccination ecosystems across the world, resulting in acute and extended stress to all aspects of the global ecosystem. Social distancing measures disrupted essential primary healthcare services and vaccine administration globally.^{15 16 33–36} UNICEF reported that as a result of the pandemic, 23 million children missed basic vaccinations in 2020 and approximately 17 million of them did not even receive a single vaccine ('zero dose children').^{37 38} The impact was particularly concerning in under-resourced countries where infants and children are at higher risk of VPDs such as polio and diphtheria.^{35 36} With these disruptions, some governments and health systems have implemented approaches to address low vaccination rates, including engaging non-physician healthcare professionals as vaccinators, leveraging alternative sites for vaccination services and increasing the use of IIS.^{33 39} Study participants reported substantial disruptions but also opportunities to re-evaluate and strengthen current systems, with addressing vaccine hesitancy and misinformation as a key component. Although vaccine hesitancy has been a historical public health threat, COVID-19 vaccine hesitancy may have spillover effects with other

vaccines, especially in the context of declining trust in health experts, political polarisation and the spread of misinformation.^{40 41}

Separately (with the exception of one interview participant from Greece), vaccine mandates and demand side interventions, such as incentives to vaccinate, were not discussed by study participants as a component related to resilience, however were identified as an area to explore more in future work considering it as an important aspect related to vaccine ecosystem resilience. For example, in the USA, vaccines are federally regulated, while vaccine mandate (or exemption) authority rests with individual states where policies may vary; state-level and school-entry mandates have been associated with historical declines in diseases such as measles, mumps, pertussis and polio.^{42 43} In response to VPD outbreaks and anti-vaccination movements, some countries have adopted or reformed vaccine mandate policies, with varying degrees of success. Attwell *et al* compared the construction, introduction/amendment and operation of six vaccine mandates in Australia, France, Germany, Italy, California and Washington; finding that mandates differed in their effects on behaviour, as well as with regard to their structure, exemptions, target populations, consequences and enforcement, with diverse outcomes as far as the degree to which mandates restrict or incentivise behaviours around vaccination.⁴⁴ Another review of vaccination mandate effectiveness in improving uptake of COVID-19 vaccines in the USA reported that while mandates play a role in promoting uptake of vaccination, it cannot be the only approach as 'imposing mandates does not remove the need for effective messaging to overcome vaccine hesitancy'.⁴⁵

Several study participants noted that shocks can serve as an opportunity for vaccine ecosystem stakeholders to assess resilience, develop capacity-building strategies and implement lessons to inform future preparedness and resilience, particularly at the country level. Ozair and Singh⁴⁶ detailed an approach in their examination of the Indian healthcare system, which was under chronic stress before the COVID-19 pandemic, and how the acute shock of the pandemic created an opportunity to explore innovative short-term and long-term strategies for equitable health services.⁴⁶ Participants in our study, as well as previously published research, highlight the continued need for developing methodologically sound and relevant research, not just concepts or theories, on how health systems—across stakeholders, sectors and layers—can maintain resilience in the face of a VPD crisis.^{47 48} We acknowledge that challenges remain in addressing impediments to resilience; however, this study provides formative insights based on vaccination ecosystem stakeholder experiences and areas in which to pursue future rigorous, meaningful and sustained research on resilience in both concept and practice.

Strengths and limitations

Conducting in-depth interviews and online surveys with study participants allowed for a preliminary investigation of factors and insights into the considerations that participants perceived as integral to impacting resilience of the vaccination ecosystem. A key strength of this study was the participation of a broad range of stakeholders responsible for or contributing to decisions about vaccination policy, programme development, implementation and outbreak response. However, our study also has limitations. The findings represent the views of a small convenience sample of vaccination experts who were asked to participate in the study while an ongoing global pandemic was impacting healthcare delivery and immunisation systems. Due to the small sample size, we were unable to explore how findings diverged by country setting or study participant characteristics. Data were collected using qualitative interviews and an online survey. While both methods have advantages, results are not always directly comparable. Qualitative research is inherently formative research, and the small sample size of both survey and interview respondents limits generalisability. In addition, the survey format did not allow for in-depth discussion or elicitation of insights that participants may have had but did not record in their responses. Lastly, further validation of views expressed by study participants is warranted via an in-depth ethnographic study or larger scale surveys within a specific country setting, and including participants across all levels of the public and private sectors to understand how resilience is conceptualised and enacted (if at all) to various stakeholders across the vaccine ecosystem.

CONCLUSION

To achieve and maintain resilient vaccination ecosystems, participants in this study emphasised the need for investment in comprehensive programme development and implementation, infrastructure and vaccine access. Additionally, educational campaigns to raise awareness, build trust in the effectiveness of health systems and in the providers who administer vaccines, as well as ensure confidence in the efficacy of vaccines were deemed critical to ensuring programmes reach their full potential. Anticipating, identifying, adapting and responding to shocks is central to strengthening vaccination programmes, ensuring ecosystem resilience and protecting against current and future VPD threats. Recent crises, including the COVID-19 pandemic, highlight that resilient vaccine ecosystems require the capacity to swiftly adapt and respond to VPD-related shocks by implementing policy and programmatic changes to help minimise declines in VCRs.

X Suepattra May @Suepattra

Acknowledgements This manuscript was sponsored by Merck Sharp & Dohme (MSD), a subsidiary of Merck & Co. The interviews and survey which inspired the development of this article were also funded by MSD.

Contributors Conception or design, or the acquisition, analysis or interpretation of data for the work: SM, MR, MM, RM, RW, NP, ALE. Drafting the work or reviewing it critically for important intellectual content: SM, MR, MM, RM, RW, NP, ALE. Final approval of the version to be published: SM, MR, MM, RM, RW, NP, ALE. Agreement to be accountable for all aspects of the work: SM, MR, MM, RM, RW, NP, ALE. ALE is the guarantor, responsible for the overall content.

Funding This work was supported by Merck Sharp & Dohme through a contract awarded to PRECISIONheor to conduct the research.

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Competing interests ALE and RM are currently employed at Merck Sharp & Dohme LLC, a subsidiary of Merck & Co., Inc., Rahway, NJ, USA, who may own stock and/or stock options in Merck & Co., Inc., Rahway, NJ, USA. SM, MM, MR, RW and NP are employees of PRECISIONheor, a consulting firm awarded funding by Merck Sharp & Dohme to conduct this study. SM, MM and MR own equity interest in Precision Medicine Group, the parent company of PRECISIONheor.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Ethics approval The Advarra Institutional Review Board reviewed study procedure documents and exempted this study from full review due to the non-interventional nature of the project (approval: Pro00041189). Participants gave informed consent to participate in the study before taking part.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement All data relevant to the study are included in the article or uploaded as supplementary information.

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ORCID iDs

Suepattra May <http://orcid.org/0000-0002-7228-8440>

Amanda L Eiden <http://orcid.org/0000-0001-9422-1215>

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