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Resilience learning from the COVID-19 pandemic and its relevance for routine immunization programs

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ABSTRACT

Introduction: The COVID-19 pandemic represents a threat that has posed a challenge to public health response and threatens immunization programs globally. Despite recommendations to continue routine immunization services, disruptions have been observed to these and mass vaccination campaigns. This may result in setbacks to immunization initiative successes and a rise in cases of vaccine-preventable diseases.

Areas Covered: We conducted a systematic literature review to identify studies globally that described how indicators of health system resilience, defined using the Resilient Health System Framework, enabled routine immunizations to continue during the COVID-19 pandemic. A systematic search was conducted in Embase, Web of Science, PsychInfo, medRxiv, bioRxiv, and the gray literature between 1 January 2020, and 12 November 2021. Information was extracted from the studies identified describing how the specific elements of resiliency (being aware, diverse, self-regulating, integrated, and adaptive) were applied to their routine immunization programs.

Expert opinion: Our study demonstrates the use of tools that contributed to immunization program resilience during the COVID-19 pandemic in all geographic regions and for countries with different income levels. These tools may help inform preparations for other immunization programs to catch up from the COVID-19 pandemic or mitigate the impact of future threats.

ARTICLE HISTORY

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KEYWORDS

Resilience; immunization program; routine immunization; COVID-19; pandemic

1. Introduction

New infectious disease outbreaks such as COVID-19 represent an unknown threat and therefore pose a challenge to public health response efforts [1]. The COVID-19 pandemic quickly transformed into a geopolitical, economic, and out-of-the-ordinary health crisis [2]. The COVID-19 response has shown the need for governments to utilize a joint approach involving both public health systems (those focusing on prevention of infectious diseases and chronic illness over time at a population level) and health systems (organizations responsible for daily prevention and treatment of illness in individuals) to improve their outbreak preparedness and response [3]. Several recommendations for guiding government action have been put forth, such as the World Health Organization's (WHO's) health system framework and the COVID-19 Assessment Scorecard, which is a list of 19 criteria that allows countries or individuals to assess their governments' response to the pandemic and its preparedness for public health emergencies, including the provision of routine immunization services [3].

A resilient healthcare system may be measured by the extent to which an effective response to an epidemic or pandemic is implemented while at the same time maintaining

stability and sustainability of core functions in healthcare systems. Kruk and colleagues [4] defined resilient health systems 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.' The Resilient Health System Framework proposed by Kruk and colleagues [4] included the following elements: aware, diverse, self-regulating, integrated, and adaptive (Figure 1) [4]. The activities needed to address each of these elements for a resilient health-care system are as follows: (1) aware – identify system weaknesses, strengths, and emergent risks and thus map out strategies to reduce weaknesses and draw from strengths; (2) diverse – infer the possession of resources, assets, and a broad range of skills to meet the system's needs; (3) self-regulating – quickly isolate and minimize threats to essential services; (4) integrated – ensure coordination and recognition between key system players or sectors; and (5) adaptive – position system to mitigate threats or better position itself to continue providing essential services [4].

The COVID-19 pandemic is the biggest global health crisis in recent times and can upend and reverse progress achieved to date with routine immunization uptake. In the United States

Article highlights

- The COVID-19 pandemic has posed a challenge to routine immunization programs globally and despite recommendations to continue with routine immunizations, disruptions have still been observed. This may cause a setback to the success of immunization initiatives and a rise in VPDs
- This paper describes a systematic review to identify studies that illustrated elements of health system resilience
- The Resilient Health System Framework proposed by Kruk et al (2017) was used to measure the extent to which an effective response was implemented
- Results showed that there were immunization programs in all regions that demonstrated resilience, using tools to mitigate the negative impact of the pandemic
- Resilience was demonstrated through communication strategies, diversifying available resources, collaboration with global, public, and private groups to develop guidelines and adapting immunization programs to allow safe vaccination procedures and by using alternative vaccination points
- These tools may help to inform preparations for other immunization programs that need to mitigate the impact of future threats or 'shocks' to their routine immunization services

(US), as in many countries, the COVID-19 pandemic response resulted in disruptions in the healthcare system's ability to provide non-COVID-19 curative and preventive care, including routine immunizations for many vaccine-preventable diseases [5]. According to the joint statement from the WHO/United Nations Children's Fund (UNICEF) and Gavi, the Vaccine Alliance as of May 2020, these disruptions have been on a global scale, where more than half of 129 countries surveyed describing the complete suspension of routine immunization services and others reported moderate-to-severe disruptions [6]. Childhood immunization campaigns for polio were suspended in 38 countries, and measles immunization was put on hold in 27 countries. Reductions in routine immunizations put more than 80 million children under 1 year of age at risk for

vaccine-preventable diseases [6]. Routine immunization programs were suspended or delayed in several countries based on national guidance, in contrast to the WHO's recommendations that all routine vaccinations be given as scheduled [7]. Other reasons for disruptions in routine immunization were lockdowns/transportation barriers, demand-side concerns about COVID-19 transmission, and uncertainty about clinic opening hours [8]. Healthcare providers reported shortages of personal protective equipment (PPE), infection control and prevention measures, staffing (because of ill health or diversion of staff to support pandemic response), vaccine stock and supplies, and transportation issues [9,10].

The WHO/UNICEF and Gavi joint statement in May 2020 noted that in many countries, resources were diverted to respond to the crisis, with the resultant suspension of routine immunization programs and a lack of planning as to how they would be recovered. Thus, the question arises as to whether the health systems are able to adapt to a shock in ways that protect overall health [6,11]. The comprehensive review by Shet and colleagues [5] on the pandemic's impact on routine immunization services globally concluded that a key approach to recovery and rebuilding immunization programs could be to 'shift thinking from equity of coverage to equity of resilience.' This paper describes studies illustrating elements of health system resilience that improved the ability of specific immunization programs to deliver routine immunization services during the pandemic.

2. Methods

A systematic literature review (SLR) was conducted using reproducible and rigorous methods in line with those recommended by the Preferred Reporting Items for Systematic Reviews and Meta-analyses statement (PRISMA) [12]. This study was not registered in PROSPERO.

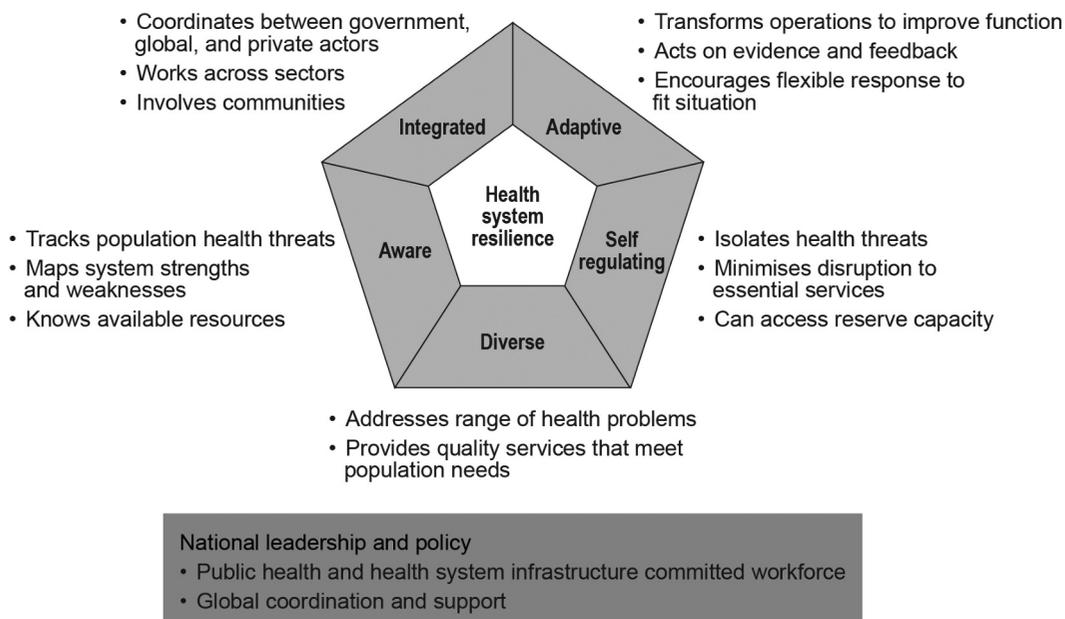


Figure 1. Resilient health system framework [4]. Reproduced from building resilient health systems: a proposal for a resilience index. Kruk ME, Ling EJ, Bitton A, et al. *BMJ*, 2020;357:j2323, copyright notice 2020. With permission from BMJ publishing group Ltd.

The electronic databases Embase, Web of Science, PsychInfo, medRxiv, bioRxiv, and gray literature (including Google Scholar) were searched between 1 January 2020 and 12 November 2021. No geographical limitations were applied to the searches, but the English-language limitation was applied to keep the size of the review viable. In addition, bibliographies of included studies and systematic reviews were hand searched for further relevant studies. The search terms related to the topics of COVID-19, resilience learning, immunization, and vaccine coverage. The search strings utilized were combinations of free-text and Emtree or MeSH terms.

The inclusion criteria were studies that examined the impact of the COVID-19 pandemic on routine immunization services and that described how countries mitigated the impact of the pandemic on their immunization programs through the lens of the healthcare system resilience elements. Only English-language articles were included during screening, and studies had to have been peer-reviewed for inclusion. Excluded studies were those that did not describe the implementation of at least one tool demonstrating a healthcare system resilience element, studies conducted in languages other than English, systematic or narrative literature reviews, commentaries or notes, and studies focusing on nonhumans.

Study inclusion was determined at two levels, with screening at each level completed by two independent reviewers using the pre-defined inclusion and exclusion criteria. At level 1, titles and abstracts of all identified articles were screened. For any article deemed relevant at level 1 screening, the full text was reviewed at level 2 to ensure that all inclusion criteria were met. Any disagreements at either level were resolved by consensus.

The following data elements were extracted from the articles: the country and continent where the study was conducted and the tools and strategies used to mitigate the impact of the pandemic on routine immunization services. For each study, data extraction was conducted from full-text versions, where available, by one reviewer, but all extractions were verified by a second independent reviewer using the original sources. Any disagreements between researchers in the placement of an action or strategy into the elements of the Resilient Health System Framework were resolved by consensus of all authors.

Results of this SLR were summarized qualitatively. The data extraction table shows the similarities and differences in the demonstration of resilience among continents and countries based on their implementation of tools addressing each of the five elements of a resilient healthcare system (Table 1 [13–46]).

3. Results

The search yielded 1,777 studies (database, $n = 1,754$; gray literature, $n = 23$). A total of 952 studies were reviewed after duplicates were removed and were then screened for eligibility based on the inclusion criteria by title and abstract. A total of 802 studies were excluded after title and abstract review, leaving 150 studies. Full-text review led to the removal of 116 studies; they were excluded as they did not describe resilience elements used to reduce the impact of the pandemic on

routine immunization services or were SLRs or narrative reviews. Full-text review led to the selection of 34 studies, which were included in the final review process (Figure 2). Some of these studies provided data from more than one country. Extracted data were organized by continent (Asia, North America, Europe, South America, Oceania) and by country, with province, region, or state noted if provided. Evidence of system resilience was presented for each resilience element: aware, diverse, self-regulating, integrated, and adaptive, as presented in Table 1 [13–46]. Table 1 presents data from 34 studies comprising 11 publications that included data from Asia, 10 that included data from North America, 9 that included data from Europe, 5 that included data from South America, and 4 publications that included data from Oceania.

3.1. Awareness

During the pandemic, 26 (76.5%) of the included studies reported specifically on their program or population awareness. Of these studies, 17 showed that regions studied in India, Pakistan, Nepal, Canada, US, United Kingdom (UK), The Netherlands, Spain, Sweden, Brazil were aware of declining immunization rates and suspension of immunization programs, or they reported vaccine-preventable disease (VPD) outbreaks [14,17–20,22,26,28,29,33,35–39,41,45]. Some studies reported a reduction in available staff and protective equipment and supply of vaccines leading to either a partial or complete suspension of routine immunizations or specific immunizations programs, such as those for polio or human papillomavirus, in regions studied in India, Pakistan, Nepal, Senegal [14,17–19,22]. In the UK, health-care providers reported clinic cancellations [31]. In regions studied in the Philippines, Singapore, Thailand, US, Australia, Senegal, and Ethiopia, population awareness of the importance of maintaining routine immunization was raised through mass and digital media [13,14,16,36,42]. In regions studied in the Philippines, US, and Brazil, scientific or government leaders also stressed the importance of routine immunization despite the pandemic [23,37,44]. In China and Pakistan, the availability of electronic immunization systems allowed for continuous tracking of immunization status in Pakistan within the Sindh Province [22] as well as vaccine stock, appointments, and payments and appointment reminders in China [15]. One study published in 2021 in Brazil [46] reported that regions with higher primary care coverage showed more robust recovery after reopening, while a study in South Korea [24] indicated that immunization coverage for children was sustained during the pandemic.

3.2. Diverse

Health systems, by having multiple resources available for their routine immunization programs, were able to ensure the delivery of vaccines during the pandemic in 7 (20.6%) of the included studies [16,20–22,40,43,45]. In Thailand, well-baby and well-adult clinics in hospitals were able to provide immunization services [16]. In Pakistan within the Sindh Province, immunization services included outreach programs

Table 1. Routine Vaccination Immunization Programs Use of Resilience Tools Based on the Resilient Health System Framework.

| STUDY | RESILIENCE INDEX | | | |
|---|---|---|--|--|
| | AWARENESS | DIVERSE | SELF-REGULATING | INTEGRATED |
| | Identifies system weaknesses, strengths, and emergent risks and maps out strategies to reduce weaknesses and draw from strengths. Tracks population health threats. | Possessing resources, assets, and a broad range of skills to meet the system's needs. | Able to quickly isolate and minimize threats to essential service. Minimizes disruption to essential services. | Ensures coordination and recognition between key system players or sectors. |
| Africa | | | | |
| Ethiopia | | | | |
| Shigute et al. [13], 2021 (Tigray, Amhara, Oromia and Southern Nations Nationalities and Peoples' Region) | Awareness campaigns through mass media | N/A | Guidelines developed for safe provision of services using infection-prevention measures and personal protective equipment | COVID-19 management handbook recognized need to maintain "important patient care," including child immunizations, and was supported by political leaders |
| Liberia | | | | |
| Dixit et al. [14], 2021 | N/A | N/A | N/A | Goal of National EPI team is to protect children against vaccine-preventable diseases, which it acknowledges is a basic right of a child. As such, efforts should be made to restore and sustain routine immunization. National EPI team worked with Gavi and other partners |
| Senegal | | | | |
| Dixit et al. [14], 2021 | Reports on declining immunization. Providers of HPV vaccines reported halting vaccine delivery due to school closures. Awareness campaigns through mass media | N/A | Ministry of Health and Social Actions (MHSA) gave instructions to all regions and health centers and tailored guidelines so that they aligned with current local needs and strategies for immunization | House-to-house vaccination against HPV by community health workers was started. Reminder and recall tools by text reminders or telephoning caretakers of children who had missed scheduled immunizations. Continuous vaccination services outside of health posts with greater flexibility from clinics and outreach programs to provide greater flexibility in scheduling visits and locations for catch-up vaccination |
| Asia | | | | |
| China | | | | |
| He et al. [15], 2020 | Vaccination assistance system for child immunizations holds information on vaccine stock, appointments, and payments as well as vaccination reminders | N/A | Government policies alongside private companies | Immunization appointments were made via Teleclinics. Vaccination assistant system introduced as a service provider |
| India | | | | |
| Harris et al. [16], 2021 | N/A | N/A | N/A | Dedicated immunization spaces separate from the unwell were created |
| Shet et al. [17], 2021 | Reports from pediatricians of complete or partial suspension of immunization services | N/A | Guidelines on the safe provision of vaccines through the Indian Academy of Pediatrics | Guidelines on the safe provision of vaccines |

(Continued)

Table 1. (Continued).

| | | RESILIENCE INDEX | | |
|---|---|---|---|--|
| STUDY | AWARENESS | DIVERSE | SELF-REGULATING | INTEGRATED |
| | Identifies system weaknesses, strengths, and emergent risks and maps out strategies to reduce weaknesses and draw from strengths. Tracks population health threats. | Possessing resources, assets, and a broad range of skills to meet the system's needs. | Minimizes disruption to essential services. | Ensures coordination and recognition between key system players or sectors. |
| | Reports routine immunization programs being suspended | N/A | Ministry of Health and Family Welfare India issued guidance to maintain routine immunization | N/A |
| | Reports stopping immunization activities | N/A | Guidance from Ministry of Health and Family Welfare based on WHO guidance regarding the importance of the continuation of immunization services | Ministry of Health and Family Welfare indicated all health services, including the continuation of immunization, are deemed essential and need to be functional |
| | | | | Subsequent vaccination through outreach if necessary, with social distancing, hand washing, and respiratory hygiene in all sessions |
| | | | | Catch-up sessions planned to begin after restrictions lifted |
| | | | | Expanding access via alternate delivery sites, at home immunization, and vaccine by the private sector |
| | | | | Outbreak response immunization centers were designed so that these services were within a 30-minute walk for most people |
| | | | | Expanding access to a range of sites and personnel offering immunizations, including local volunteers |
| | | | | Public sector continued to immunize children, but private sector discontinued immunization services during pandemic |
| Malaysia Harris et al. [16], 2021 | N/A | N/A | N/A | N/A |
| Nepal Dixit et al. [14], 2021 | Reports on declining immunization | | Ministry of Health and Population sought to maintain routine immunization activities wherever possible | Ministry of Health and its agency, Family Welfare Division, worked with local committees to set up outbreak response immunization centers in districts impacted by measles outbreaks |
| Khatiwada et al. [20], 2021 (Katmandu Valley) | Reports a decline in supply of vaccinations and reports decline in those attending vaccination services | Provide education for service providers and users on the value of immunization | N/A | N/A |
| Pakistan Khan et al. [21], 2022 (Islamabad) | N/A | Before pandemic both private and public sector immunized children. | N/A | N/A |

(Continued)

Table 1. (Continued).

| | | RESILIENCE INDEX | | | |
|---|--|---|---|---|--|
| STUDY | AWARENESS | DIVERSE | SELF-REGULATING | INTEGRATED | ADAPTIVE |
| | Identifies system weaknesses, strengths, and emergent risks and maps out strategies to reduce weaknesses and draw from strengths. Tracks population health threats. | Possessing resources, assets, and a broad range of skills to meet the system's needs. | Able to quickly isolate and minimize threats to essential service. Minimizes disruption to essential services. | Ensures coordination and recognition between key system players or sectors. | Able to position system to mitigate threats or position itself better to ward off crisis. Encourages flexible response to fit the situation. |
| Bechini et al. [25], 2020 (Tuscany) | N/A | N/A | N/A | N/A | To limit COVID-19 spread, sanitization facilities were provided, such as hand sanitizer in common rooms, limited number of people in pediatricians' offices and waiting rooms, and social distancing |
| Netherlands Middleдорп et al. [26], 2021 | Reports on declined immunization participation | N/A | Guidelines on maintaining immunization | Guidelines on maintaining immunization through the National Institute of Public Health | Catch-up immunization in place Expanding access to Teleclinics |
| Norway Larson et al. [27], 2021 | N/A | N/A | Prioritized vaccinations for older adults who are homebound or in long-term care facilities | N/A | N/A |
| Spain Moraga-Llop et al. [28], 2020 | Reports of decline in vaccine uptake and raised awareness on the importance of routine vaccination | N/A | N/A | The Asociación Española de Vacunología, and the Sociedad Española de Inmunología, the Sociedad Infectológica Pediátrica, and the Asociación Española de Pediatría, published documents warning of the risks from failure to vaccinate or delaying vaccination | N/A |
| Sweden Falkenstein-Hagander et al. [29], 2021 | No disruption to vaccine supply chain but periodic reporting of staff shortages and equipment Reported cancellation of vaccination visits and parent education sessions Reports a delay in boosters | N/A | National, local, and regional guideline prioritized child immunizations Public Health Agency made routine child immunization services a priority during the early days of the pandemic | Regional providers communicated with local centers through multiple means Communication from regional child health offices to child health centers included face-to-face and online education and consultation with psychologists | Immunizations sometimes given in parking lots For the youngest children vaccines received through home visits Nurses used pre-pandemic communication methods to keep families informed during any routine visits to the child health center for immunization |
| Turkey Kara et al. [30], 2021 (Ankara) | N/A | N/A | N/A | Ministry of Information issued vaccine implementation recommendations, but limited information given on completing vaccination | N/A |
| Europe United Kingdom Saso et al. [31], 2020 | Difficulty organizing/attending clinics due to COVID-19 fears and hesitancy Policymakers raised awareness on the importance of routine vaccination/health updates (includes training for HCPs) | N/A | Guidelines for catch-up immunization in place | Royal College of Obstetricians and Gynecologists, Royal College of Pediatrics and Child Health, Royal College of Nurses, and Royal College of General Practitioners urged continuation of immunization | Expanding access via alternate delivery sites Teleclinics, drive-through immunization |

(Continued)

Table 1. (Continued).

| | | RESILIENCE INDEX | | | |
|---|---|--|---|---|--|
| STUDY | AWARENESS Identifies system weaknesses, strengths, and emergent risks and maps out strategies to reduce weaknesses and draw from strengths. Tracks population health threats. | DIVERSE Possessing resources, assets, and a broad range of skills to meet the system's needs. | SELF-REGULATING Able to quickly isolate and minimize threats to essential service. Minimizes disruption to essential services. | INTEGRATED Ensures coordination and recognition between key system players or sectors. | ADAPTIVE Able to position system to mitigate threats or position itself better to ward off crisis. Encourages flexible response to fit the situation. |
| Hungerford et al. [32], 2020 | NA | NA | NA | NHS, Public Health England, and Joint Committee on Vaccination and Immunization call for continuing immunization | NA |
| McDonald et al. [33], 2020 | Reports on declining immunization | N/A | Guidelines on maintaining immunization | N/A | N/A |
| Larson et al. [27], 2021 | N/A | N/A | N/A | N/A | Expanded range of healthcare workers who are able to administer certain vaccinations in addition to pharmacists and physicians School nursing services created drive-thru vaccination clinics to maintain services for some routine immunizations |
| North America | | | | | |
| Canada | | | | | |
| Saso et al. [31], 2020 | N/A | N/A | Guidelines released early in pandemic to prioritize immunizations especially in children aged <6 months | N/A | Expanding access via alternate delivery sites Teleclinics |
| Piche-Renaud et al. [34], 2021 (Ontario) | N/A | N/A | Guidance documents on immunization services during the pandemic prepared and public health organizations released communications for healthcare providers | N/A | Additional clinics for immunization services and reorganization of patient flow, with shortened appointment times and opportunistic vaccinations at other appointments |
| Sell et al. [35], 2021 | Reports decline in immunization appointment attendance | N/A | National Advisory Committee recommends continuation or routine vaccination, especially in children <2 years and in pregnant women | Greater collaboration among public, health services, community agencies, and government | Additional staff and clinics added to catch up on immunizations, with additional contacting of patients Summer catch-up programs for children and opportunistic catch up for adults Infant and preschool immunization programs were adapted so they were shorter, with fewer appointments, and included COVID-19 prevention activities |
| US | | | | | |
| Abuali et al. [36], 2021 (Philadelphia) | Reports limited well child visits Philadelphia Department of Health issued community messaging on the importance of immunization | N/A | N/A | N/A | Practices reached out to families via telephone to explain the value of vaccination Plans for scheduling missed vaccines via telephone |
| Langdon-Embry et al. [37], 2020 (New York City) | Reports on declining immunization, declaring immunization an essential service Policymakers raising awareness on the importance of routine vaccination/health updates (includes training for HCPs) | N/A | Rapid communication with providers, through an effective information system to identify unvaccinated children, and the Vaccines for Children Program | Coordinated efforts between health care providers and public health officials at the local, state, and federal levels | Plans for catch-up immunization Reminder and recall tools for providers to identify and recall children who were overdue for vaccination |
| Santoli et al. [38], 2020 | Reports on declining immunization | N/A | N/A | N/A | Plans for catch-up immunization |

(Continued)

Table 1. (Continued).

| | | RESILIENCE INDEX | | | |
|--|---|---|--|---|---|
| STUDY | AWARENESS | DIVERSE | SELF-REGULATING | INTEGRATED | ADAPTIVE |
| | Identifies system weaknesses, strengths, and emergent risks and maps out strategies to reduce weaknesses and draw from strengths. Tracks population health threats. | Possessing resources, assets, and a broad range of skills to meet the system's needs. | Able to quickly isolate and minimize threats to essential service. Minimizes disruption to essential services. | Ensures coordination and recognition between key system players or sectors. | Able to position system to mitigate threats or position itself better to ward off crisis. Encourages flexible response to fit the situation. |
| Bramer et al. [39], 2020 (Michigan) | Reports on declining immunization | N/A | N/A | Coordinated efforts between the public and private sectors to increase routine immunization | Plans for catch-up immunization |
| Larson et al. [27], 2021 | N/A | N/A | N/A | N/A | Established policies that allowed pharmacists to administer some routine vaccinations during the pandemic |
| Brooks et al. [40], 2021 | Pharmacists do not keep a large stock of pediatric vaccines | Pharmacists able to give vaccines | N/A | Pharmacists given broad permission to administer any ACIP-recommended vaccination to individuals aged 3–18 years | Pharmacists given broad permission to administer any ACIP-recommended vaccination to individuals aged 3–18 years |
| Murthy et al. [41], 2020 (Idaho, Iowa, Louisiana, Michigan, Minnesota, New York City, North Dakota, Oregon, Washington, and Wisconsin) | Reports on declining immunization | N/A | CDC guidelines for maintaining immunization | N/A | CDC call to action to encourage healthcare systems, healthcare providers, schools, parents, and state and local governments to work together to ensure students are caught up on all routinely recommended vaccinations |
| Oceania | | | | | |
| Australia | | | | | |
| Larson et al. [27], 2021 | N/A | N/A | N/A | N/A | Created an opportunistic vaccination program that aimed to address access barriers due to COVID-19 restrictions by providing some in-home vaccinations for individuals 18 years of age or younger |
| Hull et al. [42], 2021 (Victoria) | Public health services providing effective messaging on the importance of routine vaccination | N/A | N/A | N/A | Provision of COVID 19 safe vaccination centers |
| South America | | | | | |
| Brazil | | | | | |
| Gois-Santos et al. [43], 2020 | N/A | A contingency plan to increase support for primary healthcare facilities | Guidelines to reinstate the administration of vaccines at healthcare facilities and schools and ensuring safe practices for administration | N/A | Expanding access via alternative delivery sites (open spaces and drive-through) |
| Medina et al. [44], 2020 | Raised awareness on the importance of routine vaccination | N/A | Guidelines/calls on maintaining immunization | Multisector approach (scientific leaders and civil societies) to raising awareness on the importance of routine vaccination | N/A |

(Continued)

Table 1. (Continued).

| | | RESILIENCE INDEX | | |
|--------------------------------|---|---|--|--|
| STUDY | AWARENESS | DIVERSE | SELF-REGULATING | INTEGRATED |
| | Identifies system weaknesses, strengths, and emergent risks and maps out strategies to reduce weaknesses and draw from strengths. Tracks population health threats. | Possessing resources, assets, and a broad range of skills to meet the system's needs. | Able to quickly isolate and minimize threats to essential service. Minimizes disruption to essential services. | Ensures coordination and recognition between key system players or sectors. |
| Matos et al. [45], 2020 | Reports of an increase in measles cases | Free universal immunization services were maintained through the pandemic | N/A | N/A |
| Larson et al. [27], 2021 | N/A | N/A | Prioritized vaccinations for those under 15 years of age | N/A |
| Santos et al. [46], 2021 | Reports that regions with higher primary care coverage showed more robust recovery after re-opening | N/A | N/A | Brazilian Society of Pediatrics issued a call to maintain immunization during the pandemic No national policy to promote vaccine recovery post shutdown |
| Chile | | | | |
| Larson et al. [27], 2021 | N/A | N/A | N/A | N/A |
| El Salvador and Bolivia | | | | |
| Larson et al. [27], 2021 | N/A | N/A | N/A | N/A |
| | | | | ADAPTIVE |
| | | | | Able to position system to mitigate threats or position itself better to ward off crisis. Encourages flexible response to fit the situation. |
| | | | | Dedicated immunization spaces separate from the unwell were created |
| | | | | Drive-through vaccination services developed |
| | | | | Vaccination sites include community health agents who survey the needs of the community and who promote awareness about the importance of updating vaccines in childhood |
| | | | | Drive-through vaccination services |
| | | | | Vaccination in banks and nursing homes for older adults |

ACIP = Advisory Committee on Immunization Practices; CDC = Centers for Disease Control and Prevention; EIR = electronic immunization registry; EPI = Expanded Programme on Immunization; HCP = healthcare provider; HPV = Human papillomavirus; N/A = not applicable; NIP = National Immunization Program; WHO = World Health Organization.

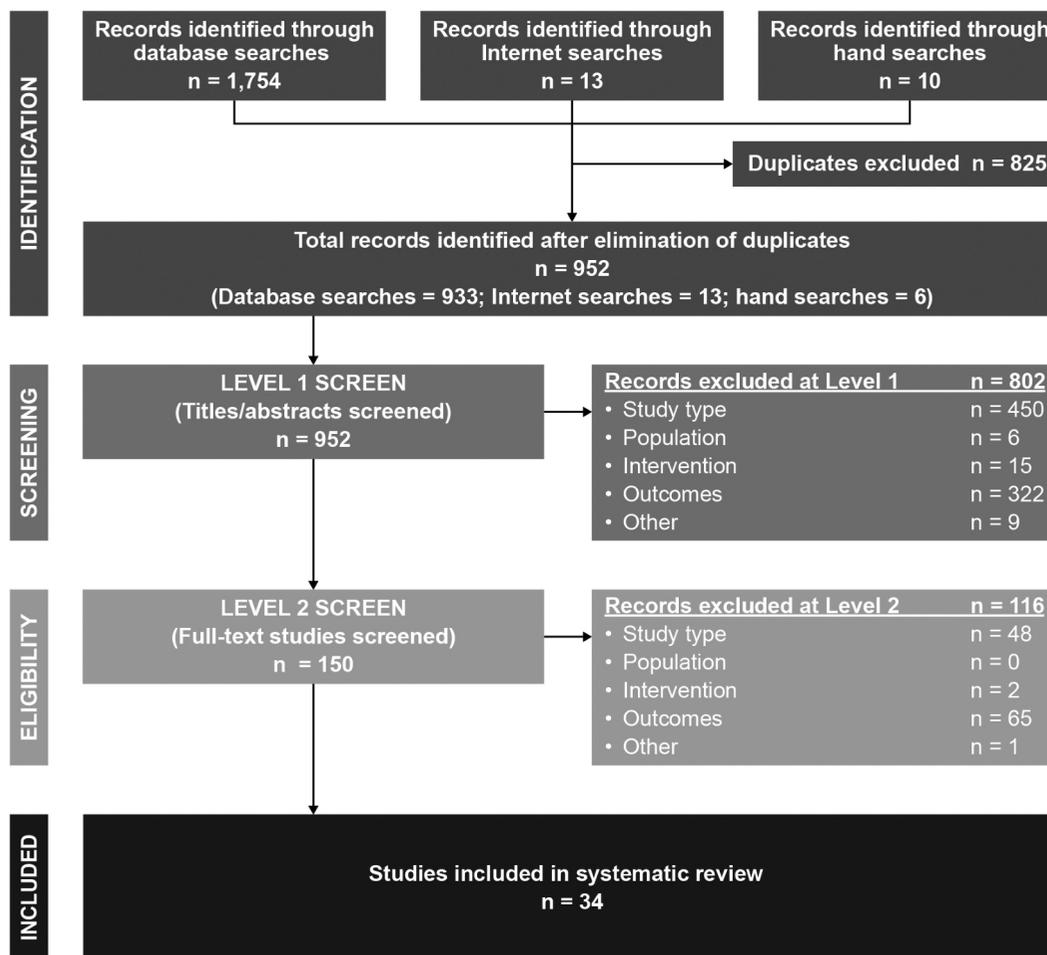


Figure 2. Study Selection for Review PLOS Medicine (OPEN ACCESS). Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. PLOS Medicine. 2021;18(3):e1003583. doi: 10.1371/journal.pmed.1003583.

for vaccine delivery [22], and in the Katmandu Valley in Nepal, local volunteers were available for vaccine administration [20]. In Brazil, contingency plans were put in place to increase support for primary health facilities that usually provide immunization services [43], and free universal immunization services were maintained through the pandemic [45]. In Islamabad, Pakistan, both the public and private sectors administered vaccines to children [21]. In Alabama, US, pharmacists may administer some childhood vaccines (Brooks) [40].

3.3. Self-regulating

Eighteen (52.9%) of the included studies described countries' or regions' ability to self-regulate, primarily through the provision of guidelines for maintaining immunization programs during the pandemic [13,14,16,18,19,23,24,26,27,29,31,33–35,37,41,43,44]. These guidelines provided information on the importance of continuous routine immunization, prioritizing certain populations for immunization, methods for ensuring safe vaccination procedures, designing efficient appointment systems, using existing information systems to identify patients missing routine vaccines, and designing catch-up systems. The Philippines, India, Nepal, Canada, US, UK, the Netherlands, Sweden, and Brazil created guidelines to ensure the maintenance of routine immunization provision in

the regions studied [13,14,18,19,23,26,29,31,35,41,44]. Canada also proposed prioritization of immunization in children aged less than 6 months [31] or less than 2 years and in pregnant women [35], and Brazil gave precedence to those aged less than 15 years [27]. Norway prioritized immunizations for the elderly and homebound [27], and Sweden prioritized routine child immunization [29]. Brazil also put in place guidelines to reinstate the administration of vaccines at schools and facilities [43]. South Korea, Canada, Brazil, and Ethiopia created guidelines for safe vaccination procedures in the regions studied [13,24,34,43]. In Thailand, self-regulation was demonstrated through the institution of guidelines for initiating an appointment system for vaccines [16]. In New York City within the US, there was the availability of an immunization infrastructure to rapidly communicate with providers that offered an effective method to identify unvaccinated children [37].

3.4. Integrated

Integration among different groups in different countries was demonstrated in 19 (55.9%) of the included studies [13–17,19,23,24,26,28–32,35,37,39,44,46]. In China, the government issued policies on e-medicine to strengthen vaccine delivery, alongside other agencies (vaccine assistant system) [15]. South Korea has an integrated immunization management system

that enabled sustained coverage during the pandemic [24]. In the Philippines and Thailand, there were coordinated efforts between the public and private sectors to increase routine immunization [16,23]. India provided guidelines on the safe provision of vaccines through the Indian Academy of Pediatrics [17], and both the Ministry of Health and Family Welfare deemed routine immunization essential [19]. In Nepal, there was a collaboration between the Family Welfare division of the Ministry of Health and Population and local communities to develop a response to measles outbreaks [14]. In the US, the Centers for Disease Control and Prevention (CDC) called for coordinated efforts between health-care providers and public health officials at the local, state, and federal levels, including the CDC and the American Academy of Pediatrics [37,39]. In Canada, public health services, community agencies, and the government engaged in collaborative efforts to maintain immunization practices [35]. The UK demonstrated integration through coordination among the Royal College of Obstetricians and Gynecologists, Royal College of Pediatrics and Child Health, Royal College of Nurses, Royal College of General Practitioners, WHO, the National Health Service (NHS), Public Health England, and Joint Committee on Vaccination and Immunization, which all urged continuation of routine immunization through the pandemic [31,32]. In Spain, associations for vaccines and immunology, such as the Asociación Española de Vacunología, collaborated with pediatric societies to warn of the risks from failure to vaccinate or to delay it [28]. In Ankara, Turkey, the Ministry of Information issued vaccine implementation recommendations [30]. In the Netherlands, guidelines on maintaining immunization were provided through the National Institute of Public Health [26]. In Sweden, there was communication and education from regional child health offices to child health centers [29]. In Brazil, the multisector approach to raising awareness on the importance of routine immunization lay in the strength of utilization of the Family Health Strategy (FHS), which involves the mobilization of community healthcare workers to ensure that primary care services such as immunization continued during the pandemic [44]. But another Brazilian study pointed out that there was no national policy to promote catch-up immunization after the shutdown [46]. In four regions of Ethiopia (Tigray, Amhara, Oromia and Southern Nations, Nationalities and Peoples' Region [SNNP]), the COVID-19 handbook that recognized the need to maintain child immunization was supported by political leaders [13]. In Liberia, the National Expanded Program on Immunization (EPI) team worked with Gavi to restore and sustain immunization [14].

3.5. Adaptive

Twenty-eight (82.4%) of the included studies demonstrated that countries in all five continents for which studies were identified showed adaptability to maintain immunization rates during the COVID-19 pandemic [13–20,22–27,29,31,34–43,45,46]. China introduced the use of telemedicine through online medical platforms by developing apps specific for immunization called 'Little bean' to enable individuals to make appointments for immunization [15]. They also provided

services such as scientific knowledge, payment services, inoculation reminders, and electronic immunization certificates as well as providing an increase in allocation for healthcare/immunization programs [15]. The Philippines, South Korea, Thailand, Malaysia, India, Nepal, Singapore, UK, Sweden, US, Canada, Brazil, El Salvador, Chile, Australia, Senegal, and Ethiopia planned for the expansion of vaccine access via alternate delivery sites, such as private clinics and pharmacies, drive-through system immunization, dedicated immunization spaces or clinic hours, community-based immunization including walking distance to sites, house-to-house or in-home immunization, and fixed-point immunization such as squares and sport courts, to meet the needs of the local community in the regions studied [13,14,16,20,23,24,27,29,31,43,45]. Studies in Nepal, China, the US and the UK indicated that additional types of providers were allowed to administer routine immunizations, including volunteers in Nepal in the Katmandu Valley, immunization assistants in China, pharmacists in the US, and nurses, midwives, paramedics, and physiotherapists in the UK in the regions studied [15,20,27,40]. In the study carried out in New York City (NYC) by Langdon-Embry et al. [37], as a response to the decline in immunization, the Department of Health provided webinars on strategies for increasing immunization and sent alerts to health care providers several times reminding them to continue routine immunization.

Changes to make immunization appointments safer for those receiving the vaccine and their caregivers were noted in studies in South Korea, Thailand, Singapore, India, Pakistan, Canada, Italy, Brazil, Australia, and Liberia in the regions studied [14,16,17,19,22,24,25,34,35,42,45]. These changes included shorter appointments, separation of hours or spaces for treatment and immunization visits and use of PPE.

Outreach plans were implemented through awareness campaigns through mass and digital media or telephone or in-person reminders to those eligible for immunization in the Philippines, South Korea, Thailand, Singapore, India, US, Sweden, Brazil, and Senegal in the regions studied [14,16,19,22,24,29,36,37,46]. For example, in the US, healthcare providers in Philadelphia reached out to families by telephone to explain the value of immunization [36]. India, Pakistan, Canada, US, the Netherlands, Senegal, and Liberia introduced plans for catch-up immunization programs for children who missed their scheduled vaccines because of the pandemic in the regions studied [14,19,22,26,35–39,41]4

4. Discussion

This study highlights the resilience tools for each element included in the Resilient Health System Framework [4] that were used for maintaining routine immunization programs during the COVID-19 pandemic in studies identified in the SLR. The reporting of different tools used for each element of resilience in the resilience framework was not consistent across studies, but all studies reported using tools in one or more of the resilience elements: being aware, diverse, self-regulating, integrated and adaptive. These studies were performed in all geographic regions and indicated that resilience tools were implemented by immunization programs as they attempted to mitigate negative effects of the pandemic

despite differences in income level and susceptibility to outbreaks of VPDs. The three case studies presented by Kruk et al. [4] indicated that while a new shock to the system might initially stress a country's health system, building resilience using the tools suggested in the Resilient Health System Framework enabled them to recover from shocks such as unanticipated influx of refugees (Lebanon), Ebola epidemic (Liberia), and natural disasters (Indonesia) as well as to respond proactively to similar shocks in the future. These three examples as well as the studies identified in our SLR might be used by other immunization programs to speed recovery from the COVID-19 pandemic as well as build greater program resilience for similar shocks in the future.

The importance of having a resilient routine immunization program is highlighted by recent studies investigating the impact of the COVID-19 pandemic on routine immunization. A recent study reported that during May 2020, 57% of mass vaccination campaigns were either postponed or canceled in 57 countries because of COVID-19, and during 16 December 2021% of mass vaccination campaigns were postponed or canceled in 54 countries [47]. When investigating the impact of the pandemic on selected infant and toddler vaccine uptake in 170 countries and territories, Shet et al. [5] found the lowest number of vaccine doses administered was in April 2020, with recovery beginning in June 2020 and continuing throughout the year. A study by Saxena and colleagues [48] focusing on adolescent vaccine uptake in the US also showed a significant drop in vaccine uptake, possibly related to the availability of COVID-19 vaccination in this age group and school closures as well as the other factors influencing uptake of vaccines in infants and toddlers. Saxena and colleagues [48] estimated that in a pessimistic scenario where COVID-19 had a further negative impact on adolescent routine immunization, the cumulative deficit of missed doses could take until 2031 to be cleared.

COVID-19-related disruptions in routine vaccination also highlight the need for formal catch-up strategies as part of a robust immunization program. The WHO has emphasized that vaccination catch-up strategies are an integral part of a well-functioning immunization program but notes that it is only during interruptions to routine immunization services that we see their importance [49]. SAGE recommendations from June 2022 state that the COVID-19 pandemic has raised opportunities to make immunization programs stronger and highlighted the need for custom made catch-up vaccination approaches to build more resilient health systems [50]. Shet et al [5] conclude that there is an urgent need for 'ongoing assessment of recovery, catch-up vaccination strategy implementation for vulnerable populations and ensuring vaccine coverage equity and health system resilience.' Our study used the Resilient Health System Framework designed by Kruk and colleagues [4] to describe the tools that contributed to health system resilience in maintaining routine immunization programs during the COVID-19 pandemic in different geographic regions. The Kruk and colleagues' framework was designed before the COVID-19 pandemic to apply to all aspects of a health system for the prevention of disruptions due to pandemics or other shocks to the system. Response to the shock caused by the COVID-19 pandemic has required

prevention and management of COVID-19 as well as the maintenance of other essential health-care services. A study by Haldane et al. [51] that reviewed health systems resilience in 28 countries during the COVID-19 pandemic focused on the prevention and management of COVID-19 [51]. This study used a different conceptual framework grounded in the WHO health systems framework. In this framework, four resilience elements of health systems with highly effective responses to the COVID-19 pandemic were identified in countries with varying levels of deaths from COVID-19. Specific examples of the tools used to contribute to each of these elements of resilience were provided. The four elements considered most important for a resilient health system in Haldane et al. [51] activate comprehensive responses, adapt health system capacity, preserve health system functions and resources, and reduce vulnerability. Both the Haldane and Kruk resilience frameworks include many of the same tools within the different elements.

A strength of this study is that we have demonstrated the use of tools that contributed to five elements of resilience in immunization programs during the pandemic in all geographic regions and in countries with different income levels using a systematic approach. These five elements have previously been shown to be associated with resilience of health-care systems to shocks such as epidemics or pandemics, influx of refugees, or natural disasters [4,51]. A limitation of this study is the fact that the pandemic is still ongoing, and the use of tools that contribute to all elements of resilience in immunization programs might not have been fully captured, particularly tools required for the implementation of catch-up programs. Furthermore, only limited data on the success of resilient behaviors were captured because the included studies were written during the pandemic and sufficient time had not passed for the success of these behaviors to be determined. Other limitations include incomplete and inconsistent reporting in the identified studies regarding the tools used to implement the elements of resilience defined in the Resilient Health System Framework and the possible overlap among elements. In addition, findings in one country or region may not be generalizable to others, for instance studies identified in the US were limited to specific states rather than the entire country. Furthermore, some level of subjectivity was used by reviewers to assign the different actions of countries to the different elements of resilience. However, by reaching consensus among study authors on the placement into the framework elements, the impact of subjectivity on the review findings should be minimal. Finally, the limit to only English-language studies may have introduced a language bias into the systematic review. Despite these limitations, we believe our study significantly contributes to the current scientific evidence that demonstrates the tools that can be used to increase the resilience of routine immunization programs during shocks to the health-care system.

5. Conclusions

Studies presenting tools that contributed to the elements of resilience as defined in the Resilient Health System Framework described by Kruk and colleagues [4] were identified in all

geographic regions using a systematic approach. The studies indicated that there were immunization programs in all regions that demonstrated program resilience by using tools to mitigate the impact of the COVID-19 pandemic on routine immunizations. Resilience was demonstrated through awareness and communication of the problem to those affected; diversity of available resources; self-regulation through guidelines that were developed by collaborations with global, public, and private groups; and adaptability to allow provision of safe procedures and alternative sites for providing immunization services. These examples of resilience shown by immunization programs in all parts of the world may help inform preparations for other health systems to catch up from the COVID-19 pandemic or mitigate the impact of future threats or 'shocks' to the immunization programs, be it in the form of another infectious disease pandemic, natural disaster, or viral spread of misinformation that undermines trust in immunization.

5.1. Expert opinion

Given that the pandemic is still ongoing, there is an opportunity to identify successful strategies to share with other countries where similar resilience tools could be applied. Ensuring resilient immunization systems to prevent and control infectious disease outbreaks should be carried out with the knowledge of the interconnectedness of ecosystems in which we exist; hence, there is a need for multisectoral strategies when solving problems that pose a threat to public health. Strategies could include restoring and reinvigorating routine immunization services impacted by the pandemic; prioritization of catch-up vaccination campaigns; adopting a life course approach to vaccination; dedicating adequate and sustainable financing for immunization; ensuring system readiness for new vaccines, including for COVID-19; and taking swift action to identify and address hesitancy and building confidence in all aspects of immunization, including education. Specific strategies may look different, depending on the political, cultural, and medical landscape in each country, but the foundational elements included in the Kruk and colleagues' resilience framework should be considered when evaluating the overall resilience of a health system or routine immunization program.

A sustained routine immunization program during the COVID-19 pandemic will ensure the maintenance of the gains made in preventing vaccine-preventable diseases in the past years, especially in communities hardest hit by the pandemic, vulnerable populations and countries with previously low vaccine coverage [10]. When tools that contribute to the elements defined in the Health System Resilience Framework designed by Kruk and colleagues [4] are applied to immunization programs, their ability to catch up from the disruptions caused by the COVID-19 pandemic may increase. Improving the resilience of immunization programs, as key components of the health system, is critical to help communities achieve and sustain high immunization coverage as well as prevent, manage, and recover from both large-scale disease outbreaks like the current pandemic or more isolated or local events such as natural disasters or disease outbreaks. In a study that assessed the

impact of COVID-19 on routine immunization in 170 countries, Shet and colleagues [5] concluded that a shift in thinking from equity of coverage to equity of resilience should be of utmost importance in developing innovative approaches to recover and rebuild from the negative effects of the pandemic. The premise for this inference is that using vaccination coverage rates (VCRs) solely as a metric for defining true health equity across communities might result in spurious conclusions because communities are inherently diverse and therefore will be impacted differently if they experienced similar shocks or disruptions to their vaccine ecosystems. This line of thought when applied to immunization program resilience might prevent immunization programs from being viewed as 'fully resilient' simply because they use tools from each element of the Resilient Health System Framework. Levels of mitigation against similar shocks or disruptions across immunization programs may differ because, regardless of resilience tools possessed, some programs will still remain more vulnerable than others. Although VCRs measured between disruptive periods are a critical indicator of immunization program performance, they do not necessarily correlate with program resilience. Therefore, an important consideration for the development of tools for each element of resilience for a regional immunization program is that the tools align closely with the local immunization program's context, including the differences in vulnerabilities of different subpopulations. This approach will significantly contribute to shifting the paradigm from equity of coverage to equity of resilience.

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Declaration of interests

O. Falope and K. Nyaku were employees at Merck Sharp & Dohme LLC, a subsidiary of Merck & Co., Inc., Rahway, NJ, USA when this study was performed. C O'Rourke, LV Hermany, and B Plavchak, are currently employees at Merck Sharp & Dohme LLC, a subsidiary of Merck & Co., Inc., Rahway, NJ, USA and shareholders in Merck & Co., Inc., Rahway, NJ, USA. J Mauskopf and L Hartley are employees of RTI Health Solutions. RTI Health Solutions received funding from Merck Sharp & Dohme LLC, a subsidiary of Merck & Co., Inc., Rahway, NJ, USA to work on the study. RTI Health Solutions perform consulting services for many pharmaceutical companies. M Kruk is a member of the Harvard T.H. Chan School of Public Health, Boston, MA, USA and received no funding for her participation in this study.

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Author contributions

All authors contributed to formulate concepts, identify important intellectual content, and data interpretation. LH led the systematic search process. OF, JM, and MKN drafted the manuscript. All authors reviewed and edited the drafts of the manuscript and have given final approval of the version to be published.

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- **An alternative resilience framework with similar tools applied to response to prevention and management of COVID-19**