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The impact of the COVID-19 pandemic on vaccination uptake in the United States and strategies to recover and improve vaccination rates: A review

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ABSTRACT

The COVID-19 pandemic disrupted routine healthcare delivery, causing declines in CDC-recommended vaccination rates across the life-course in the United States (US). Ensuring protection against disease outbreaks and associated morbidity and mortality depends on improving vaccine coverage rates (VCRs) and uptake. The authors conducted a targeted literature review to assess the pandemic's effects on routine vaccination rates across different populations, evaluating VCR recovery and improvement efforts. The review highlights articles published with data measuring or evaluating VCR decline across the US during the COVID-19 pandemic from January 2020 to April 2022, associated health impacts, and policy and programmatic strategies to recover routine VCRs. While vaccination rates stagnated or declined across some populations pre-pandemic, the review indicated there were further VCR declines in 2020 and 2021 compared to 2019 across numerous CDC-recommended vaccines, ages, and geographies, with some vaccines and sub-populations disproportionally impacted. The review additionally identified declines in patient healthcare visit frequency and increases in morbidity and mortality associated with vaccine-preventable disease (VPD) complications. Reviewed publications highlighted multifaceted strategies that could aid in recovering VCRs. Overall, findings demonstrate a significant reduction in VCRs across all age groups and highlight promising solutions to inform vaccine uptake efforts and ensure broader protection against VPDs.

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Introduction

To reduce COVID-19 disease transmission in the United States (US), a combination of interventions were implemented, including social distancing measures and telehealth visits. Coupled with this, concerns of COVID-19 exposure risk resulted in missed preventive health services, including vaccinations.[1–3] Leading health authorities, such as the Centers for Disease Control and Prevention (CDC), American Academy of Pediatrics (AAP), American Academy of Family Physicians (AAFP), and state health departments have raised concerns about the potential short- and long-term implications resulting from a decline in routine vaccination rates.[4–7] The recent reemergence of measles[8] and polio[9] in the US has shown that if declines in routine vaccination rates are left unchecked, communities could continue facing upticks in vaccine-preventable diseases (VPD).

Understanding vaccination rate declines across populations during the pandemic provides insights into the potential risk of VPD and HPV-associated cancers. It also highlights deficits in preparedness and health system infrastructure within the US public health landscape. Synthesis of these challenges can inform future evidence-based strategies to recover vaccination coverage rates (VCRs). To assess these areas of interest, a targeted literature review was conducted to evaluate the pandemic's impact on VCRs for CDC-recommended vaccines across demographics and programs deployed to recover and improve VCRs. This analysis 1) reviews trends in vaccination rates during the COVID-19 pandemic, 2) highlights how suboptimal VCRs impact future morbidity, mortality, and healthcare usage, and 3) presents programs and policies aimed at improving the uptake of CDC-recommended vaccinations in the US.

Materials and methods

Search strategy, article screening, and selection

The authors completed a targeted search using PubMed and Google Scholar databases from January 1, 2020 to April 19, 2022. Additional articles were sourced from the references of relevant publications identified through the primary search. Key search terms for the original search included vaccine, immunization/vaccination, routine vaccination, catch-up, recovery, uptake, and missed doses. The full search strategy can be found in Supplemental Table 1. Additional targeted searches were conducted after the initial review to seek out further information and identify

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Table 1. Literature inclusion/exclusion criteria.

	Inclusion Criteria	Exclusion Criteria
Population	Human population, all ages	None
Intervention	Routine vaccines	Travel vaccines COVID-19 vaccines
Comparator	N/A	N/A
Outcomes	US-specific vaccine coverage declines	Non-US-specific data and findings
	Other US-specific impacts of vaccine Vaccination coverage decline US-specific vaccination recovery (Note: recovery and interventions articles outside of the US were included if US-specific, stratified results were available)	
Study Design	Any design, peer-reviewed studies and non-peer-reviewed gray literature (including but not limited to government websites or web-based publications, and previously unpublished data by the authors)	Opinion pieces
Other	Written in English; published between January 1, 2020, to April 19, 2022	N/A

Table 2. Summary of literature findings.

Literature Themes	Key Findings
Observed Declines in VCRs or Vaccine Administration	• Adult and pediatric vaccine administration and VCRs decreased across CDC-recommended routine vaccines; some vaccines had higher rates of decline, including HPV.[10–14] • Vaccine coverage disparities were more pronounced among Black and Hispanic children compared to White and Asian children.[4,5] • Larger disparities were observed among Medicaid-enrolled children, who were less likely to receive recommended vaccines than those privately insured.[4] • Among states with diverse population distributions, rural regions generally reported lower vaccine administration compared to urban regions.[2]
Impacts Due to COVID-19	• Deficits in VCRs are predicted to increase disease burden, including excess and preventable HPV, herpes zoster, and oropharyngeal cancer (OPC)-related morbidity and mortality.[13,15,16] • Well-child visits decreased, leading to fewer, in-person routine vaccine administration opportunities.[3,17–20] • Decrease in pro-vaccine attitudes and intention to receive routine vaccinations.[21]
Potential Recovery Strategies	• Multisectoral interventions provide opportunities to facilitate routine vaccination recovery.[22–24] • Interventions include increased outreach to individuals lagging on their vaccinations,[1,14,18,22–24] expanding pharmacist authority as vaccinators,[22,25] allowing patients to access their vaccination status records through patient portals,[22,26–29] and use of widespread vaccine education and awareness campaigns[14,23,30]

gray literature which may not have been captured from the primary search. All identified and obtained publications were selected through a two-phased process, where articles were initially screened by three reviewers for eligible titles and abstracts, using defined inclusion and exclusion criteria. This was followed by a full-text review of the selected articles to finalize inclusion or exclusion based on the predefined criteria.

Data extraction

The authors extracted the following items from each selected study: title, authors, geographic focus (US region, state, or city), study design, and where relevant study setting, number of subjects, and analysis type. When available, the vaccine type(s) studied and outcomes reported, including quantitative data on VCRs, were captured. Significance values related to quantitative outcomes of interest were appropriately included; however, not all studies include relevant statistical analyses.

Synthesis and categorization of literature

Through the use of thematic analysis, interventions were grouped to align with review objectives and selected articles were categorized based on their reported findings into three themes: 1) decline in VCRs due to the COVID-19 pandemic, 2) impacts from declining vaccination rates, and 3) recovery strategies on the local, state, and federal levels. A summary of the findings, organized by theme, is included in Table 2. For a full summary of the selected articles, see Supplemental Tables S2–4.

Results

The title and abstract review yielded 50 publications, 20 of which were selected for inclusion within the full-text review based upon relevance to the inclusion and exclusion criteria. Data elements of interest were extracted and summarized using thematic analysis. Articles focused on 14 different vaccine types, as detailed in Figure 1, with some studies evaluating multiple vaccines. HPV vaccines were most frequently included in study evaluations ($n = 10$), followed by tetanus-containing vaccines ($n = 9$). Study designs included case studies, reviews of literature/strategies, surveys, data analyses, interviews, cohort analyses, and model-based analyses. Study populations varied and were categorized based upon data that included infants (<24 months), children, adolescents and teenagers (2–18 years), and adults ≥18 years.

Decline in VCRs due to the COVID-19 pandemic

Eight articles quantified the pandemic's impact on routine VCRs or vaccine administration rates, including five that were immunization information system (IIS) or health department data analyses,[2,5,10–13] one predictive modeling analysis,[1] and one Medicare fee-for-service (FFS) claims analysis.[14] Seven of the articles focused on children, adolescents, and teenagers,[1,2,5,10-13] and one included adult vaccination rates.[14] Within the eight studies, three were nationally comprehensive[1,13,14] and among the other five, vaccination data from 12 states were represented.[2,5,9,10] All eight studies

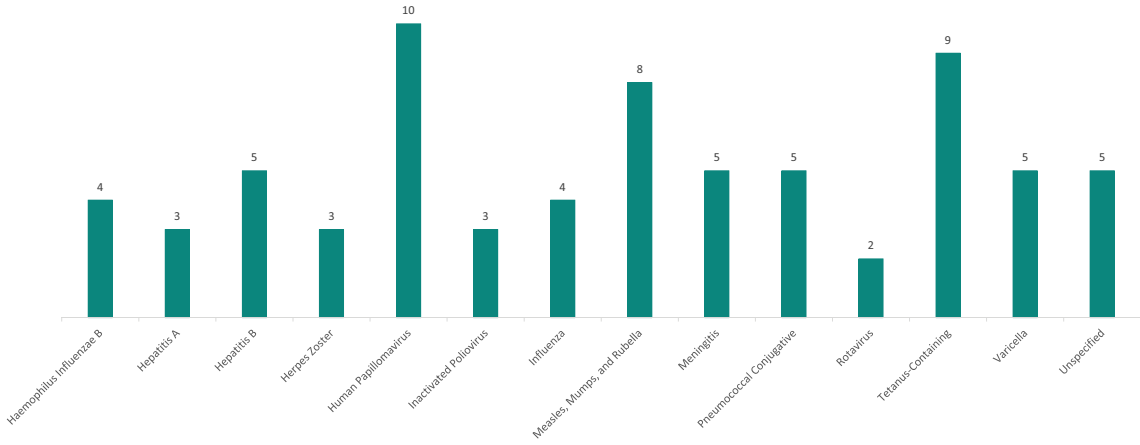

Figure 1. Number of studies by vaccine type ($n = 20$)*. *Some studies focused on multiple routine vaccine; therefore, the total number of studies exceeded the sample size, $n = 20$.

documented actual or modeled decreases in routine vaccination at the onset of the COVID-19 pandemic compared to similar time periods in 2019, with two of the studies also comparing rates to those observed in 2018.[11,12]

Research suggests that the proportion of children up-to-date with age-appropriate vaccinations was lower than targeted VCRs set by the Department of Health and Human Services (DHHS)[15] before the COVID-19 pandemic. In January 2020, a review of nationally tracked objectives from the Healthy People 2020 initiative indicates coverage targets were not met for several age-appropriate recommended immunizations (Vaccination Rate: 72.8% vs Target Rate: 80%).[16] Additional data from eight US Health Systems indicate infants reaching 7 months of age in May 2020 had 72% coverage of all age-appropriate recommended vaccines [95%CI: 71%–73%] compared to 82% from February 2019–2020, and infants reaching 18 months in May 2020 had 56% coverage [95%CI: 55%–57%] compared to 61% from February 2019–2020.[5] However, the COVID-19 pandemic further exacerbated low vaccination rates across age groups and geographies. Across the reviewed studies, the observed decreases in vaccine administration ranged from 32% for adults,[14] 62% (33,261 doses in 2019 to 12,746 doses in 2020) among infants <24 months, and 96% (23,631 doses in 2019 to 1,054 doses in 2020) among children, adolescents, and teenagers between 2 and 18 years across multiple ACIP-recommended routine vaccines.[10]

Nationally, adult vaccine administration claims were analyzed across commercial, Medicaid, Medicare Advantage, and Medicare FFS from December 2020 to July 2021 and compared to analogous months in 2019.[14] Among adults with commercial coverage, vaccine administration claims were reportedly 15% lower in December 2020 compared to December 2019, and 62% lower in April 2021 when compared to April 2019. Medicaid-enrolled adults reportedly had a similar decline in vaccine administration claims, resulting in a 52% decrease in July 2021 when compared to July 2019 rates (previously unpublished data).[14] Within Medicare Advantage, there was a 19%–55% decrease in vaccine administration claims between December 2020 and July 2021, respectively (previously unpublished data).[14] Lastly, Medicaid FFS vaccine claims decreased between 32% in December 2020 to 45% in February 2021 compared to the respective pre-pandemic months (2019) (previously unpublished data).[14] This analysis found a decrease in tetanus-containing (Tdap), HPV, and meningococcal ACWY (MenACWY) vaccine claims for adolescents, dropping on average 36% from January 2020 to July 2021 compared to the same months in 2019.[14] Cumulatively, this is an estimated 37.1 million missed doses of routine vaccinations among adults and adolescents between January 2020 and July 2021 compared to pre-pandemic baseline levels.[14]

Studies among pediatric and infant populations, who have more crowded vaccine schedules, also suggested significant declines with rates varying by vaccine type. As early as April 2020, studies of IIS, such as one in New York City, found administration of vaccine doses dropped 62% in infants <24 months (33,261 vs. 12,746 doses) and 96% in those aged 2–18 years (23,631 vs. 1,054 doses) compared to 2019 rates.[10] These rates also varied by vaccine type. A more nationally representative sample assessing IIS of 10 US jurisdictions similarly found that administration of diphtheria, tetanus, and acellular pertussis (DTaP) vaccine and measles, mumps and rubella (MMR) vaccine in infants <24 months decreased by 15.7% and 22.4%, respectively.[11] Among children and adolescents between ages 9–12 years, the same study observed a decrease of 63.6% and 66.4% of HPV and tetanus-containing (Tdap) vaccination.[11]

Observed decreases continued into September 2020 in three studies, even though evidences suggest a general increase in routine vaccine administration beginning late 2020.[10–12] One study found vaccine administration from June to September 2020 approached or surpassed 2019 levels in some jurisdictions.[9] However, no studies indicated a complete recovery to pre-pandemic levels.[10–12,14] Declines in VCR persisted, as one survey indicated that VCRs of DTaP (93.6%), MMR (93.9%), and varicella (93.6%) among kindergartners nationwide were lower for the 2020–2021 school year compared to previous years. VCRs for all vaccine types remained just below the target of 95% coverage, and compared with the 2019–20 school year, rates decreased by approximately one percentage point for each vaccine.[13]

Research reviewing vaccination opportunities prior to the pandemic's disruption was further highlighted in CDC's

2020 assessment of national VCRs among a cohort of infants <24 months born in 2017 and 2018.[4] The study found VCRs varied not just by age cohort but by race and ethnicity. Of those surveyed, 65% of Black, 66% of Hispanic, and 69% of multi-race infants received a complete series of seven routinely recommended childhood vaccines compared to 75% of White and 75% of Asian infants.[4] In the same study, Medicaid-enrolled infants, representing roughly 35% of infants in the sample, were less likely to receive the complete series of the seven recommended vaccines compared to privately insured infants. Uninsured infants, representing less than 3% of infants in the US, had a 49% completion rate for the series.[4]

Similar pre-pandemic disparities were observed across different geographies. Among states with diverse population densities and distributions, rural counties reported lower vaccine administration compared to urban counties, a discrepancy that was further exacerbated by the pandemic. In 2020, following Texas' implementation of social distancing and stay-at-home guidelines, a state-wide immunization registry analysis found consistently fewer hepatitis B (HepB), rotavirus, DTaP, *Haemophilus influenzae* type B (Hib), pneumococcal conjugate (PCV13), polio, MMR, and varicella vaccination doses administered to infants in rural areas compared to urban areas. This margin grew particularly wide between May 2019 and May 2020.[2] Further, the percentage decline and difference in doses administered in rural versus urban populations was significantly greater among five-month-olds in rural areas (27.2%; 95%CI: 24.3, 30.2%);[2] however, this difference was not observed in cohorts of infants 16 and 24 months of age.

Additionally, five studies revealed a decrease in well-child visits during the COVID-19 pandemic, resulting in fewer in-person opportunities to administer routine vaccinations to children.[3,12,22–24] In a US cross-sectional commercial claims database study comparing rates of well-child visits and vaccine administration from January 2020-March 2021 to rates during 2018–2019, well-child visits and vaccinations reached the lowest point in April 2020, reflecting a 47.3% decrease.[12] The largest reduction in well-child visits occurred among children, adolescents, and teenagers 9–16 years of age, with a reported 71.3% decrease during the study period.[12] Other research indicated that visits rebounded throughout 2020 before decreasing again below baseline levels in early 2021.[20] This trend was also reflected in a national survey using US Census Bureau Household Pulse data, which revealed that 26.4% (95%CI: 25.5%–27.2%) of households reported that at least one child or adolescent in the house had missed or delayed a routine preventive visit in April 2021 or May 2021.[3]

Concurrent to observed declines in vaccine administration and preventive care visits, one nationally focused longitudinal study found that during the first 6 months of the pandemic (March to August 2020), pro-vaccine attitudes and intentions to receive vaccinations significantly decreased ($p < .001$).[20] Survey results from the study period indicated that though COVID-19 cases continued to increase, with more than five million cases in the US, the continued prominence of the pandemic did not improve attitudes toward vaccines. Instead, participants indicated they had less intention to receive routine vaccines, such as the influenza vaccine.

Impacts from declining vaccination rates

Nine studies assessed the peripheral impacts of declining routine vaccination rates from COVID-19, including burden of disease and strained healthcare system capacity.[3,12,18–24] Three analyses modeled deficits in vaccine administration, which could lead to excess and preventable HPV and herpes zoster-related morbidity and mortality.[18,19,21] A model-based analysis on the impact of reduced HPV vaccine administration among males and females 9–26 years old (based on Commercial and Medicare data March to August 2020) concluded that up to 213,926 additional cases of genital warts; 48,157 cases of cervical intraepithelial neoplasia (CIN1); 110,192 cases of CIN2/3; and 6,487 cases of cervical cancer could occur compared to status quo over the next 100 years.[21] Another model used oropharyngeal cancer (OPC) natural history and data from nationally representative databases, cancer registries, large clinical trials, and literature to project the impact of decreased and delayed HPV vaccination among children, adolescents, and teenagers 9–17 years.[19] This model simulated a 20%–70% decrease in vaccine uptake rates in 2020 with rebounding rates within one, two, or 3 years. A 20% decline in HPV vaccine uptake coupled with a 1–3-year rebound in OPC was predicted to lead to approximately 600 to 1,700 additional OPC cases. Comparatively, a 70% drop in coverage and a 3-year rebound period could lead to approximately 6,200 additional OPC cases by 2,100 all due to delayed recovery of HPV vaccination during the COVID-19 pandemic.[19]

Recovery strategies

Three articles highlighted policies and programmatic strategies employed by local and state jurisdictions to facilitate recovery of routine vaccination and increase vaccine uptake.[25–27] A collection of state-level recovery strategies found six primary recovery intervention themes: 1) increased communication from providers and states to the general public to convey the importance of routine vaccination, 2) authorization of more vaccinators (e.g., through expanded scope of practice), 3) utilization of digital tools, 4) expanded school vaccination requirements and enforcement, 5) vaccine education and awareness campaigns, and 6) comprehensive funding for catch-up efforts for all adults and children.[25]

Two additional commentaries recommended supplemental strategies and perspectives, citing success with some regional examples. These included 1) the use of personalized communication from providers with individuals not up-to-date on routine vaccinations, 2) liaising with trusted community-based messengers to build vaccine confidence through direct outreach and education, and 3) changes to the Vaccines for Children (VFC) program. Among the VFC-related recommendations, strategies included federal policy efforts, such as expanding VFC sites beyond Federally Qualified Health Centers (FQHCs) and Rural Health Centers (RHCs), allowing for exchange of vaccine doses between VFC and private stock, and comprehensive Medicaid reimbursement for multicomponent vaccines.[26,27]

Increased outreach

Articles identified reminder/recall systems as one tool that providers and health departments are leveraging to notify individuals lagging on their vaccinations.[22] City health departments, for example, have worked to improve vaccination uptake by sending health alerts to providers, encouraging them to use reminder/recall tools in their practices.[1,27] Innovative state-level influenza vaccination campaigns, such as walk-through or drive-through clinics, have provided convenient, accessible routes for vaccine administration.[25] School-based vaccination programs and initiatives are cited as another opportunity to increase routine vaccine administration. For example, despite Pennsylvania extending the window for proof of vaccination for the 2020–2021 school year, Philadelphia school nurses conducted extensive outreach to offer vaccines in schools in October and November 2020 through partnerships with local providers.[26] While intervention outcomes were not reported, this example highlights an on-the-ground approach to increasing vaccine access and uptake.

Articles cited other efforts aiming to strengthen vaccination of children, adolescents, and teenagers with the adoption of vaccine-based admission or entry requirements. Articles referenced the importance of school vaccination requirements in helping to ensure children are up-to-date on recommended vaccines and protected against VPDs.[13,25] States that allow only medical exemptions for required school vaccinations historically have higher levels of VCR than states that allow non-medical exemptions.[28] While the national percentage of kindergartners with an exemption for at least one required vaccine was similar between the 2020–2021 school year (2.2%) and the 2019–2020 school year (2.5%), medical exemptions (0.2%) are far less common than non-medical exemptions (1.9%).[13]

Alternative vaccinators

Articles also highlighted expanding pharmacist authority to order and administer childhood vaccines beyond the public health emergency to expand vaccine access. Under the Public Readiness and Emergency Preparedness Act (PREP Act), pharmacists who had previously been prohibited from vaccinating children under state law can provide vaccination services to children, adolescents, and teenagers 3–18 years until October 1, 2024, or end of the Declaration of Emergency, whichever occurs first.[29] While pharmacists have historically participated in administering seasonal vaccines to adolescents and adults, the expanded authority under the PREP Act facilitates additional opportunities for children to be vaccinated. Additionally, some states – separate from the PREP Act – have utilized emergency authorizations or passed local legislation to authorize pharmacists to administer vaccines.[25,29]

Digital tools

The COVID-19 pandemic propelled some jurisdictions, such as Maryland, Illinois, and Wisconsin, to expand patient access to vaccination records through patient portals.[25,30–32] This strategy is supported by findings from the Public Health Immunization Data and Consumer Access Pilot Projects, a survey conducted in partnership between the Office of the National Coordinator for Health Information Technology (ONC), the CDC, and the National Vaccine Program Office (NVPO). The pilot program found that 35% of surveyed adults who accessed their records reported they were overdue for a recommended vaccine. Of these individuals, 36% subsequently reached out to their healthcare provider via an in-person visit or a phone call.[33]

Vaccine education and awareness campaigns

In addition to notifying individuals that they are behind on routine vaccination, articles emphasized that education on the importance of routine vaccine uptake remains critical. Widespread and culturally competent messaging that focuses on the efficacy and safety of vaccines, coupled with encouraging dialog between patients and providers, can help combat vaccine hesitancy and build confidence.[26] Local, city, and state initiatives also play a role in educating the public and equipping providers to better-reach communities. In Colorado, the state health department provided local public health agencies with lists of elementary schools reporting low MMR coverage among kindergartners. With support from the state health department, community-specific strategies were implemented to encourage vaccination, including digital media campaigns targeting parents and reminder/recall systems.[26] Additionally, in April 2021, Connecticut's governor signed legislation that removed all non-medical vaccine exemptions.[26,34]

Discussion

Decline in vaccination due to the COVID-19 pandemic

Lower vaccination rates due to the change in practices during the COVID-19 pandemic have been documented across ages, races and ethnicities, insurance status, and geographic location.[2,4] While routine vaccination rates declined across populations, greater disparities are reported among historically marginalized and underserved populations, suggesting that the pandemic exacerbated existing disparities.[4] Several factors contributed to declines in VCR, such as vaccine hesitancy[20,24] and change in/loss of insurance coverage.[3] Other cited factors that thwarted individuals' willingness or demand to receive routinely recommended vaccines include fear of exposure to COVID-19 while visiting a healthcare provider's office,[24] stay-at-home orders,[1] and virtual schooling.[13]

While the reviewed literature captures the overall decline in vaccination during the COVID-19 pandemic, data from ongoing studies will continue to illustrate the evolving trajectory of vaccination to better inform efforts to improve vaccine uptake. Additionally, while several studies began to examine factors leading to declines in vaccination, more research is needed to better understand how those factors continue to inhibit vaccine uptake. For example, while loss of insurance coverage was documented as a factor that resulted in missed vaccinations, it is important to understand the extent to which uninsured individuals continue to lack access to recommended vaccines. Furthermore, while observed declines in vaccine uptake span several CDC-recommended vaccines, HPV and tetanus-containing vaccinations were the most studied in the literature. Future studies may continue to build out a more robust understanding of declines in

vaccination across vaccine types and ages. Such information could be useful in informing policy solutions to recover routine vaccination rates.

Impacts from the declining vaccination rates

While outcomes due to missed doses varied by vaccine type, several studies documented modeled future impacts of declining VCR, including increased incidence of VPD and loss of quality-adjusted life years (QALYs).[18,19,21] While it may be too early to comprehensively understand the long-term consequences of declining vaccination rates, continued research is critical to fully understand the impact of reduced vaccine uptake on progress toward eliminating VPD and HPV-associated cancers. During the COVID-19 pandemic, social distancing requirements and exposure concerns contributed to missed medical encounters. These missed or delayed well-child visits preclude individuals from receiving developmental, physical, and mental health evaluations, as well as age-appropriate vaccinations. Such disruptions have the potential to negate significant progress made toward eliminating VPDs.[3]

Recovery strategies

Findings suggest that public health stakeholders are responding to the declines in vaccination rates by deploying strategies aimed at increasing the uptake of routine vaccination, ranging from policy-focused initiatives to programmatic approaches. Many of the strategies referenced in the articles reflect frequently cited opportunities to increase awareness and uptake of routine vaccinations, while other initiatives focus on expanding patient access across provider types and care settings.

At the state level, several governors issued proclamations to recognize August as National Immunization Awareness Month and encouraged parents to make sure that their children are up-to-date with routine vaccinations. Other states implemented state-wide immunization campaigns by standing up mobile or drive-through vaccination clinics.[25] State legislation has previously worked to curb declines by decreasing the types of exemptions individuals may seek to avoid vaccination, as states that permit only medical exemptions, rather than philosophical exemptions, historically have higher VCRs.[25] From one CDC assessment of VCR among children, data suggest that the elimination of non-medical vaccination exemptions was associated with six states having significantly increased MMR VCR, following reports of measles outbreaks in the same states the prior school year[13]

Additionally, immunization infrastructure improvements may increase access and user-friendliness of IIS. An IIS allows states and jurisdictions to monitor vaccination rates in communities, target interventions to support vaccination uptake, and address vaccination disparities. Providing patients with access to their vaccination records stored in an IIS can also reduce the burden associated with obtaining vaccination records from healthcare providers and contribute to informed decision-making.[25]

While many of the articles focused on state-level initiatives, the review also found examples of innovative federal activity. For example, policymakers leveraged novel interventions to aid in vaccine delivery, such as expanding vaccination sites and authorizing pharmacists as vaccinators beyond the public health emergency.[25,26] Further, the Medicaid and Children's Health Insurance Program (CHIP) Payment and Access Commission (MACPAC) recently released recommendations targeted at improving vaccine access for individuals enrolled in Medicaid. MACPAC plans to examine strategies focused on pediatric vaccination rates, citing the decline in vaccine uptake.[35]

Overall, the targeted literature review did not identify one clear policy-based or programmatic intervention that successfully returned VCRs to pre-pandemic levels, but rather suggests that cross-sector collaboration and a multi-prong approach tailored to community needs is the most effective path forward. While some studies showed evidence that vaccine uptake was rebounding as the pandemic progressed, each of these studies suggested that rates eventually plateaued or returned to declining during influxes of COVID-19 activity. For example, while adult vaccination levels increased moderately in the second half of 2020, as COVID-19 activity temporarily declined and influenza vaccinations became available, these gains leveled off or steadily declined through the end of 2020 and into 2021 as COVID-19 resurged. COVID-19 vaccines also became available during this time, and in May 2021, the CDC updated guidance to allow coadministration of COVID-19 vaccines with other routine vaccines.[17]

Limitations and gaps

Of note, a limitation of the review is the inability to significantly speak to adult vaccination declines to the same extent as infant and childhood vaccination. Most of the articles identified focused on infant, children, and adolescent populations rather than adults 19–64-years and older adults (≥ 65 years), limiting ability to appropriately characterize impacts or outcomes of fragmented care in these age groups. Continued research and innovation have led to the addition of more vaccines to the adult immunization schedule. The dearth of data coupled with the expansion of the vaccination schedule in this age group highlights the need for timelier evidence across the lifespan to better address life-course vaccination deficits. Additionally, many studies included in the review centered on HPV, MMR, and tetanus-containing vaccines and fewer examined hepatitis A, herpes zoster, polio, and rotavirus vaccines. As the pandemic has continued, and recovery efforts did not begin in earnest until the loosening of restrictions in 2021, longer-term data on results from recovery strategies are not yet available.

Conclusions

The COVID-19 pandemic has had a significant and sustained impact on routine vaccination programs and public health. Deficits in vaccine uptake were estimated to lead to excess and preventable morbidity and mortality through modeled future impacts. Policymakers and stakeholders from the local to federal levels should continue to pursue strategies aimed at increasing vaccine uptake across the life-course. Literature

suggests that multi-pronged, multi-level recovery efforts are promising strategies to address gaps in vaccine administration. Improved immunization infrastructure, innovative interventions that expand access, and education that emphasizes the importance of routine vaccination are identified as opportunities to achieve and exceed pre-pandemic VCRs. Advancing comprehensive and effective strategies to achieve vaccine recovery will help ensure individuals of all ages are protected against vaccine-preventable diseases.

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Authors' contributions

Conceptualization, K.M., A.B., and L.C.; Methodology, E.A., A.F., M.N., M.P., K.M., A.B., A.E., and L.C.; Validation, L.C., A.B., A.E.; Formal Analysis, M.N. and M.P.; Data Curation, E.A.; Writing – Original Draft Preparation, E.A., M.N., M.P., A.B., A.E., and L.C.; Writing – Review and Editing, E.A., A.F., A.B., K.M., A.E., and L.C.; Supervision, A.B. and A.E.; Project Administration, E.A. and L.C. All authors have read and agreed to the published version of the manuscript.

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