Exploration of Digital Health Technologies

Open Exploration

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Reimagining vaccine advocacy: a digital health and policy perspective to overcome HPV hesitancy

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Academic Editor: Sil Aarts, Maastricht University, Netherlands

Received: July 10, 2025 **Accepted:** November 12, 2025 **Published:** January 3, 2026

Cite this article: Adeniyi PI. Reimagining vaccine advocacy: a digital health and policy perspective to overcome HPV hesitancy. Explor Digit Health Technol. 2026;4:101177. https://doi.org/10.37349/edht.2026.101177

Abstract

Vaccines have eliminated once-deadly diseases, yet rising vaccine hesitancy threatens these gains. Human papillomavirus (HPV) illustrates this crisis: Although it is one of the few vaccines that directly prevents cancer, uptake remains low in the United States and globally, particularly in regions with high cervical cancer incidence. This persistent gap undermines both individual and public health. This paper examines how digital health technologies, aligned with policy frameworks and community engagement, can address HPV vaccine hesitancy. We propose the Digital Vaccine Advocacy Toolkit, a structured, HPV-focused framework that integrates electronic health record (EHR)-based clinical decision support, personalized reminders, population dashboards, AI-driven misinformation surveillance, and culturally tailored education. As a conceptual model, it draws on secondary evidence and policy recommendations rather than original empirical data, emphasizing interoperability, privacy safeguards, equity-driven design, and stakeholder engagement to support feasibility across diverse health systems. The Toolkit is organized into illustrative workflows that demonstrate how technical features could be combined with policy mechanisms and financing models to strengthen HPV vaccination. By situating HPV within the World Health Organization's 90-70-90 elimination targets and the recent adoption of single-dose schedules, the framework highlights both translational relevance and global applicability, though its recommendations require pilot testing and empirical validation. Overall, the Digital Vaccine Advocacy Toolkit offers a practical roadmap for improving HPV vaccine uptake through the integration of technology, policy, and ethics, and provides a transferable model for advancing digital health strategies to increase vaccine confidence and equity in immunization programs worldwide.

Keywords

digital health, vaccine hesitancy, human papillomavirus, electronic health records, clinical decision support, artificial intelligence, public health policy

Introduction

Human papillomavirus (HPV) vaccine hesitancy illustrates how misinformation, stigma, and systemic inaction converge to undermine even cancer-preventing interventions. Although safe and effective against cervical cancer and other HPV-related diseases, uptake remains low [1]. Substantial declines in cervical precancers among young women since vaccine introduction emphasize its impact [2, 3]. Gendered misinformation has framed HPV as solely a women's issue, leaving many men unprotected against HPV-related cancers [4]. HPV strains also cause anal and oropharyngeal cancers in both sexes, genital warts, and recurrent respiratory papillomatosis (RRP), a rare condition that impairs breathing [5]. These outcomes show HPV's broad risks and the urgency of equitable vaccination strategies.

Despite this urgency, health systems underuse digital tools that could improve uptake. A meta-analysis found electronic medical record (EMR)-based interventions increased HPV vaccine initiation and completion by 4–7% [6], while a U.S. border clinic showed EMR prompts nearly doubled immunization odds and boosted completion by over 10 points [7]. These results demonstrate feasibility but also fragmentation: Effective tools exist but remain scattered. This paper addresses that gap by proposing a Digital Vaccine Advocacy Toolkit to unify such approaches for HPV.

Framing HPV hesitancy within wider vaccine refusal shows why integration matters. Vaccine hesitancy, delaying or refusing vaccines despite availability, poses an escalating threat to public health. Smallpox eradication illustrates vaccination's power when coverage is broad. Persistent gaps in vaccine uptake, the share of individuals who accept vaccination when offered, continue to hinder disease prevention, including cervical cancer [8]. These gaps stem less from scientific limitations than from misinformation, politicization, and eroding public trust [9]. Sociodemographic factors such as education, employment, geography, and political identity further drive inequities [9–11]. The COVID-19 pandemic intensified these dynamics, politicizing health information and accelerating coverage declines [12, 13].

While this research highlights the complexity of vaccine hesitancy, it also exposes a critical gap: Limited attention has been paid to how digital health infrastructure can directly address HPV-related barriers. The central question posed in this paper is whether digital health technologies, such as electronic health records (EHRs), telehealth, and artificial intelligence (AI)-powered surveillance, when integrated with policy frameworks and community engagement, can form a structured HPV-focused Digital Vaccine Advocacy Toolkit. Positioning HPV within this lens highlights broader system-level shortcomings in vaccine implementation, including policy inertia, fragmented health communication, and underuse of digital innovation. Addressing HPV vaccine hesitancy requires an integrated, data-driven approach that leverages health information technology (Health IT) tools alongside policy and community engagement. This perspective outlines a scalable, Health IT-enabled framework, centered on digital tools, public policy, and community engagement, to counter vaccine misinformation, improve HPV vaccine uptake, and inform broader public health strategy.

The significance of HPV vaccine hesitancy becomes clearer when considered alongside other vulnerable populations. Patients with immune-mediated conditions such as systemic lupus erythematosus (SLE) and systemic sclerosis (SSc) face heightened infection risk, like influenza and pneumococcus. Despite proven vaccine benefits, hesitancy persists due to concerns about immune response and disease flares [14]. This pattern illustrates how even effective vaccines face uptake barriers in high-risk groups, emphasizing the need for tailored advocacy strategies for HPV. To operationalize this vision, the following sections explore how Health IT interventions, including EHR-based clinical decision support (CDS), mobile applications, telehealth, and AI surveillance, can enhance HPV vaccine uptake.

Health IT interventions to improve HPV vaccine uptake

Electronic health records and clinical decision support

EHRs, digital systems that store and share patients' health information, are essential for improving vaccine uptake. During COVID-19, EHRs, mobile apps, and analytics expanded coverage and enabled real-time monitoring [15]. These systems store up-to-date patient data and, when paired with CDS, which provides patient-specific recommendations, prompt providers to recommend the HPV vaccine at the right time. EHRs also track vaccination history, flag missed doses, and send automated reminders via portals, text, or email [16]. Randomized controlled trials confirm that EHR-based interventions improve HPV vaccination initiation, completion, and follow-up [6].

Emerging ambient AI tools that "listen" to provider-patient encounters could extend CDS by generating real-time prompts and adapting messaging to patient demographics. Early studies show promise, but validation and large-scale deployment remain limited [17]. Scaling these tools requires interoperability standards such as Health Level Seven International (HL7) and Fast Healthcare Interoperability Resources (FHIR). These enable data exchange across platforms and support population-level tracking.

Lenert et al. [18] showed how extending Bulk FHIR improved access to state immunization registries for coordinated outreach, yet integration remains uneven in under-resourced systems, particularly in low- and middle-income countries (LMICs) and rural areas where infrastructure and workforce capacity are limited. Ensuring compliance with established privacy regulations like the Health Insurance Portability and Accountability Act (HIPAA) in the United States and the General Data Protection Regulation (GDPR) in Europe remains essential, as these frameworks protect patient confidentiality while allowing data exchange for public health purposes [19–21].

EHR-based CDS reminders are highly scalable, as they integrate across health systems and adapt to local HPV vaccination guidelines. A New York City trial showed EHR reminders improved immunization opportunities, demonstrating feasibility for wider implementation [16]. When enhanced with analytics, these systems can also monitor HPV vaccine efficacy by linking records with later diagnoses of HPV-related disease. This strengthens confidence in its cancer-preventing benefits and helps identify gaps in coverage and patient behavior. Together, EHR/CDS interventions, augmented by ambient AI and supported by interoperability, function as infrastructure-level enablers of equitable HPV vaccine delivery.

Mobile health applications and telehealth access

Mobile health (mHealth) applications are accessible tools for delivering accurate vaccine information. They offer schedules, education, and links to trusted providers, helping patients navigate HPV vaccination decisions [22]. Evidence consistently links these tools with improved HPV awareness and vaccine adoption [23].

When paired with telehealth services, mHealth extends reach through real-time provider-patient engagement. Telehealth, the remote delivery of care through digital platforms, is especially valuable in underserved regions where healthcare access is limited [24]. Virtual consultations allow providers to address misinformation, discuss HPV vaccine safety, and deliver tailored recommendations that sustain engagement and reduce stigma [25].

The COVID-19 pandemic demonstrated scalability: Both mHealth and telehealth sustained immunization campaigns when in-person visits collapsed, proving feasibility for HPV vaccination in constrained settings [15]. HPV-specific digital tools, such as a culturally U.S.-Mexico border program, improved provider communication and uptake in Hispanic communities, where uptake is historically lower [26]. While promising, outcomes vary by population due to differences in digital literacy and access [27].

Together, these tools function as more than communication channels; they operate as equity-focused infrastructure, reducing barriers, expanding reach, and building continuity of care, while laying the groundwork for advanced AI and natural language processing (NLP) systems to further optimize delivery and misinformation surveillance.

Artificial intelligence and misinformation surveillance

AI, which enables computers to perform tasks requiring human intelligence, and NLP, which allows computers to understand and analyze human language, can be applied to monitor vaccine-related discourse online. For HPV, AI-driven tools are especially valuable for identifying persistent myths, such as the misconception that the vaccine is only relevant for women, and detecting emerging narratives that discourage uptake. These systems can flag misinformation and trigger timely responses from public health authorities [28, 29].

Practical applications are already visible: Platforms such as X (formerly Twitter) have introduced community-driven fact-checking [30]. Beyond detection, AI can perform sentiment analysis, helping public health organizations understand vaccine-related perceptions and tailor outreach to HPV-specific concerns. HPV studies using NLP on X (2008–2017) tracked sentiment shifts and false versus verified claims, showing misinformation spreads faster and engages more users; Instagram analyses found similar patterns, highlighting surveillance challenges [31, 32].

To ensure reliability, AI and NLP models are evaluated with metrics such as accuracy, precision, recall, F1-score, and area under the receiver operating characteristic curve (AUC). Transformer models like BERT and RoBERTa have been applied to HPV misinformation detection, with RoBERTa embeddings and logistic regression achieving AUC 0.958 and F1 0.88. Large-scale analyses of 650,000 HPV-related tweets achieved 71.4% recall and 31.2% precision when classifying concerns [33]. These benchmarks are vital for reducing misinformation and misclassification of marginalized voices, showing that HPV surveillance has moved from concept proposals to measurable, real-world applications.

Ultimately, AI's impact lies not in detection alone but in integration: Misinformation insights can feed into public health dashboards, guide provider scripts, and inform school-based campaigns, transforming raw surveillance into coordinated HPV-focused responses.

Policy and social considerations

Reducing structural barriers and promoting equity

Addressing HPV vaccine hesitancy also requires strong policy action. Financial constraints remain a significant barrier. Sustained vaccination requires coordination across governments, providers, schools, and civil groups to ensure scalable, culturally relevant interventions [34]. A rural U.S. study found that public health and education leaders identified school-based promotion programs and cross-sector collaboration as key opportunities to increase HPV vaccination uptake and overcome systemic barriers [35]. Free or subsidized vaccinations in schools and clinics, supported by national programs and Gavi, are critical for access and sustainability [36, 37].

Gavi's co-financing model promotes gradual country ownership while maintaining support until programs are self-sustaining, a feature especially vital for LMICs with weak insurance systems and limited resources [37]. Gavi-supported countries have demonstrated notable increases in HPV coverage through program introduction into national schedules [38].

Legislative measures like school-entry HPV vaccination and insurance mandates for preventive vaccines can further reduce inequities and institutionalize access [39]. However, mandates often face political resistance, and financing mechanisms are shaped by broader political economies, which can affect implementation. Linguistic and cultural barriers require attention; multimedia materials and interpreter services can improve outreach to immigrant and minority communities [40]. School-based delivery with sustainable financing and community partnerships is often the most practical starting point, especially in resource-limited settings.

Structural reforms lay the foundation for equity, but policy must also address the digital influences on vaccine perceptions.

Holding social media platforms accountable

Social media is a powerful vehicle for misinformation [29]. Regulatory bodies such as the Federal Trade Commission (FTC) have issued enforcement orders requiring transparency in how platforms filter health-related ads and deceptive content [41]. The FDA has proposed draft guidance allowing "tailored responsive communications" to address third-party misinformation on medical products [42]. These steps show that voluntary measures are inadequate; binding standards like content labeling, algorithm transparency, and user education tools are needed to counter false narratives. Yet, policy reforms alone are insufficient if communities carry deep-seated mistrust shaped by historical and cultural experiences.

Historical and cultural sensitivities

Mistrust in the medical system, particularly among communities of color, cannot be ignored. Historical injustices like the Tuskegee experiment have left lasting scars [43]. Digital health interventions must therefore be coupled with culturally tailored communication and meaningful community engagement to rebuild trust. This also means ensuring that emerging surveillance tools are deployed ethically, with safeguards that protect privacy and equity.

Ethical considerations in digital surveillance

While monitoring misinformation online is an essential component of modern vaccine policy, the privacy of users must be carefully protected [44]. Clear data-use guidelines are needed to limit intrusion and prevent misuse, and algorithmic bias, such as marginalized communities being unfairly flagged, must be addressed because these disparities can reinforce existing inequities in vaccine access and trust [45]. Real-world cases, such as healthcare prediction tools underestimating Black patients' needs, show how bias can perpetuate inequities unless systems are designed with equity and auditability from the start [46]. If similar biases emerge in digital surveillance tools, they risk undermining trust in HPV vaccination efforts, particularly among marginalized communities. Implementing safeguards such as transparency in AI decision-making, independent audits of surveillance tools, and mechanisms for community oversight are key strategies for addressing these challenges [47]. Balancing surveillance with human rights ensures that digital interventions remain trustworthy and equitable. Governance mechanisms such as algorithmic audits and community advisory boards can help ensure transparency, equity, and accountability in digital surveillance tools.

Global policy context

Global commitments are already underway to improve HPV vaccine uptake and eliminate cervical cancer through the World Health Organization's (WHO) 90-70-90 strategy: By 2030, 90% of girls under 15 years old should be fully vaccinated, 70% of women screened by ages 35 and 45 using high-performance tests, and 90% of women diagnosed with cervical disease should receive appropriate treatment [48]. Achieving these targets will require leveraging digital health implementation frameworks, as the WHO has emphasized that robust health information systems are essential for tracking coverage, sending reminders, and enabling population-level data analytics to ensure accountability and equitable progress [49].

WHO has also endorsed a single-dose HPV vaccine schedule, which substantially reduces logistical and financial barriers to vaccination [50]. This shift is especially critical in LMICs where resource constraints and weak follow-up systems make multi-dose schedules difficult. LMICs, which bear nearly 90% of the global cervical cancer burden, stand to benefit most from simplified regimens, digital tracking tools, and community-based delivery approaches that improve completion rates and reduce inequities [49, 51]. However, implementation remains uneven, particularly in LMICs and rural areas where digital infrastructure and provider capacity are limited. Together, these efforts show how technology, paired with global policy, can drive sustainable and equitable HPV elimination [51].

Building on these insights, the proposed Digital Vaccine Advocacy Toolkit operationalizes these technological, policy, and equity strategies into a coordinated framework to maximize HPV vaccine uptake.

Proposed integrated intervention

To maximize impact, a Digital Vaccine Advocacy Toolkit is proposed. This framework integrates technical infrastructure, policy, equity-focused implementation, and ethical safeguards to strengthen HPV vaccine confidence and uptake.

Technical features

CDS alerts embedded in EHRs prompt timely HPV vaccine recommendations at the point of care. For scale, these alerts must be interoperable across health systems, leveraging exchange standards such as HL7 and FHIR. Personalized reminders delivered through SMS, email, or mobile applications extend this reach by tailoring notifications to patients' vaccine schedules, including both multi-dose and single-dose regimens.

Population dashboards aggregate vaccination data to track coverage and identify gaps, with cloud-based infrastructures enabling population-level analytics while maintaining compliance with privacy regulations. Complementing these tools, AI-powered misinformation surveillance employs NLP to detect emerging narratives online. Reliability requires validation metrics (accuracy, precision, recall, F1-score, and AUC), and fairness safeguards reduce risks of algorithmic bias. Finally, multilingual and culturally tailored education delivered through mHealth platforms ensures inclusivity.

Policy integration

Sustained impact requires policy support. Financing models such as national immunization budgets, Gavi co-financing mechanisms, and public-private partnerships with telecoms provide long-term sustainability. Legislative measures, including school-entry vaccination mandates, insurance coverage for preventive vaccines, and platform accountability for misinformation, reinforce equitable access. Ministries of Health embed interventions into national immunization schedules, while non-governmental organizations (NGOs) and community groups support cultural tailoring and last-mile delivery.

Implementation pathways

Adaptation to context is central. In LMICs, low-bandwidth SMS systems, simplified single-dose tracking, and community health worker dashboards are emphasized. In high-income countries, advanced features such as interoperable EHR/CDS integration and app-based reminders can be prioritized, illustrating adaptability across health systems. Workflow integration creates synergy. Provider prompts trigger reminders that feed into dashboards, misinformation surveillance informs campaigns, and monitoring data guides policy decisions.

Future pilots should incorporate stakeholder feedback and cost modeling, apply implementation science methods to optimize workflow integration.

Evaluation metrics

Effectiveness should be assessed using clearly defined equity-sensitive indicators with baseline comparators and data sources specified, including vaccine initiation and completion rates across demographic groups; provider adoption of CDS alerts; reductions in inequities; and shifts in digital sentiment around HPV vaccination. Using validated tools such as standardized immunization registries and NLP sentiment analysis models can anchor these indicators in measurable outcomes.

Ethical safeguards

Finally, ethical guardrails are essential. Patient data must be managed under HIPAA, GDPR, or equivalent standards. AI tools should undergo independent audits to detect and mitigate algorithmic bias, with transparency in decision-making to ensure accountability. Community oversight mechanisms can further align digital strategies with public expectations, sustaining trust and preventing unintended harms.

Together, these elements form a scalable, ethically grounded framework that positions digital health as a catalyst for sustained HPV vaccine confidence and equity. Figure 1 illustrates the workflow of the Digital Advocacy Toolkit for HPV vaccination, showing how clinical, data, and communication interventions are integrated with ethical safeguards across all components.

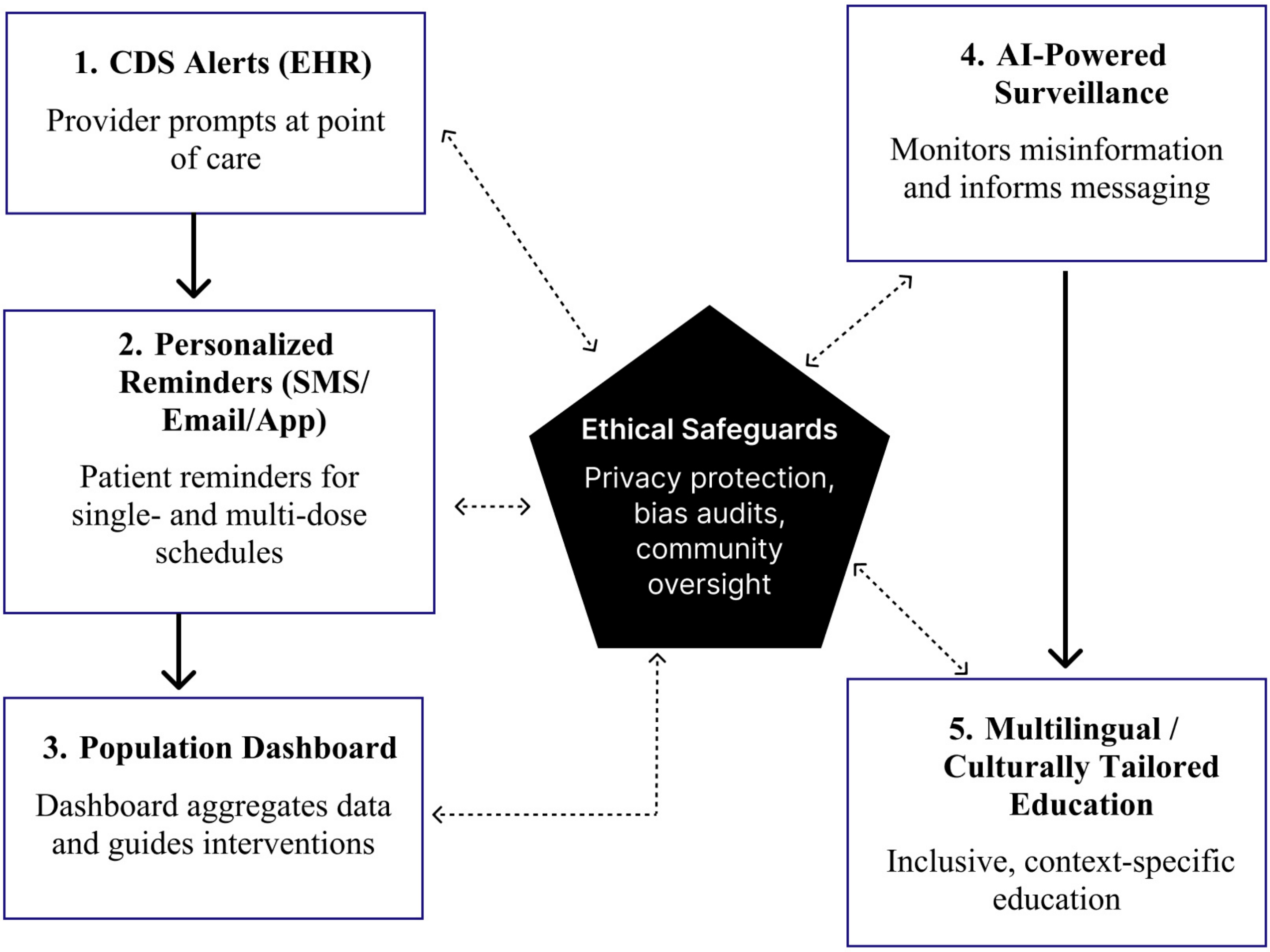

Figure 1. Workflow of the Digital Vaccine Advocacy Toolkit for HPV vaccination. The framework integrates provider prompts, patient reminders, and dashboards (clinical/data flow) with AI surveillance and inclusive education (communication/education flow). Ethical safeguards, including privacy protection, bias audits, and community oversight, apply across all components to ensure equity and trust. CDS: clinical decision support; EHR: electronic health record; AI: artificial intelligence; HPV: human papillomavirus.

Conclusions

This paper introduces the Digital Vaccine Advocacy Toolkit as a novel, structured framework that integrates technical, policy, and ethical dimensions to address HPV vaccine hesitancy. Unlike broader proposals, the Toolkit is HPV-focused, technically detailed, and operationalized with clear pathways. By uniting EHR prompts, telehealth, AI misinformation monitoring, and financing models into a coherent structure, it provides a practical roadmap for high- and low-resource settings.

Its contribution lies not in listing interventions, but in weaving them into a system-level translation strategy that balances scalability with ethical safeguards and equity-driven design. The inclusion of WHO's 90-70-90 elimination targets and the single-dose HPV vaccine schedule further situates the framework within global elimination efforts.

Future steps include piloting the Toolkit in diverse health system contexts, empirically testing its impact on HPV vaccine uptake, and evaluating policy pathways that enable scale-up. If implemented effectively, the Toolkit offers a blueprint not only for improving HPV vaccination but also as a transferable model for digital health strategies in other immunization programs worldwide.

Limitations

This perspective has several limitations. First, it is a conceptual paper that relies primarily on secondary sources rather than original empirical data. While the framework is grounded in existing literature and global policy recommendations, it has not yet been validated through pilot studies. Second, the proposed Digital Vaccine Advocacy Toolkit is intended as a flexible model, and its effectiveness will depend on local health system capacity, resources, and sociocultural context. Certain components, such as AI-powered misinformation surveillance, are still technically evolving and may raise concerns about equity, privacy, and feasibility in low-resource settings. The proposed evaluation metrics lack baseline comparators or statistical validation; future studies must demonstrate measurable impact. Comparative evaluations between HPV-specific interventions and other immunization programs could further clarify the Toolkit's broader applicability. Although this paper focuses on HPV vaccine hesitancy, broader applications of the framework to other immunization programs remain to be fully explored. Future research should prioritize pilot implementations with rigorous study designs to empirically validate the framework across diverse contexts. Caution is warranted in generalizing from HPV to other vaccines, which may face distinct behavioral, logistical, and policy challenges. Despite these limitations, the Toolkit provides a foundation for future research, testing, and adaptation in diverse settings.

Abbreviations

AI: artificial intelligence

AUC: area under the receiver operating characteristic curve

CDS: clinical decision support

EHRs: electronic health records

EMR: electronic medical record

FHIR: Fast Healthcare Interoperability Resources

GDPR: General Data Protection Regulation

Health IT: health information technology

HIPAA: Health Insurance Portability and Accountability Act

HL7: Health Level Seven International

HPV: human papillomavirus

LMICs: low- and middle-income countries

mHealth: Mobile health

NLP: natural language processing

WHO: World Health Organization

Declarations

Acknowledgments

The author thanks Dr. Charles Bieberich, who taught genetics and emphasized HPV vaccination as a cancer prevention tool. Deep gratitude is extended to Professor Paul Mulhern, Health IT and Policy instructor at the University of Maryland, Baltimore County, whose guidance inspired the exploration of policy's role in public health through informatics, and who reviewed the final manuscript draft. The author also thanks Dr. Erin Van Dyke, department head, for feedback on the early draft, and Professor Amanda Williams, whose Process and Quality Improvement course shaped the implementation pathways discussed. Finally, appreciation goes to Hero-Godsway Zilevu for assistance with figure design.

Author contributions

PIA: Conceptualization, Investigation, Methodology, Writing—original draft, Writing—review & editing, Project administration. The author read and approved the submitted version.

Conflicts of interest

The author declares that there are no conflicts of interest.

Ethical approval

Not applicable.

Consent to participate

Not applicable.

Consent to publication

Not applicable.

Availability of data and materials

Not applicable.

Funding

Not applicable.

Publisher's note

References

1. Smith DL, Perkins RB. Low rates of HPV vaccination and cervical cancer screening: Challenges and opportunities in the context of the COVID-19 pandemic. Prev Med. 2022;159:107070. [DOI] [PubMed] [PMC]
2. Preventing HPV-Associated Cancers [Internet]. U.S. Centers for Disease Control and Prevention; [cited 2025 Sep 9]. Available from: https://www.cdc.gov/cancer/hpv/preventing-hpv-associated-cancers.html
3. HPV Vaccine Safety and Effectiveness Data [Internet]. U.S. Centers for Disease Control and Prevention; [cited 2025 Sep 9]. Available from: https://www.cdc.gov/hpv/hcp/vaccination-considerations/safety-and-effectiveness-data.html
4. Grandahl M, Nevéus T. Barriers towards HPV Vaccinations for Boys and Young Men: A Narrative Review. Viruses. 2021;13:1644. [DOI] [PubMed] [PMC]
5. Diakite I, Martins B, Owusu-Edusei K, Palmer C, Patterson-Lomba O, Gomez-Lievano A, et al. Structured Literature Review to Identify Human Papillomavirus's Natural History Parameters for Dynamic Population Models of Vaccine Impacts. Infect Dis Ther. 2024;13:965–90. [DOI] [PubMed] [PMC]
6. Chandeying N, Thongseiratch T. EMR-Based Interventions on HPV Vaccination Initiation, Completion, and Receiving the Next Dose: A Meta-Analytic Review. Vaccines (Basel). 2024;12:739. [DOI] [PubMed] [PMC]
7. Molokwu J, Mendez M, Bracamontes C. The Effect of Clinical Decision Prompts in Improving Human Papillomavirus Vaccination Rates in a Multispecialty Practice in a Predominantly Hispanic Population: Quasi-Experimental Study. JMIR Cancer. 2023;9:e42890. [DOI] [PubMed] [PMC]

8. Beavis AL, Meek K, Moran MB, Fleszar L, Adler S, Rositch AF. Exploring HPV vaccine hesitant parents' perspectives on decision-making and motivators for vaccination. Vaccine X. 2022;12:100231. [DOI] [PubMed] [PMC]
9. Chido-Amajuoyi OG, Onyeaka H, Amonoo H, Shete S. The influence of political ideology on awareness of HPV and HPV vaccine among adults in the United States. Hum Vaccin Immunother. 2023;19: 2232706. [DOI] [PubMed] [PMC]
10. Spencer JC, Calo WA, Brewer NT. Disparities and reverse disparities in HPV vaccination: A systematic review and meta-analysis. Prev Med. 2019;123:197–203. [DOI] [PubMed] [PMC]
11. Vasudevan L, Wang Y, Ostermann J, Yelverton V, Yang J, Fish LJ, et al. Rural-urban disparities in human papillomavirus vaccination: Findings from a cross-sectional survey of 13 southern US states, December 2019-January 2020. J Rural Health. 2025;41:e12913. [DOI] [PubMed] [PMC]
12. Chen E, Chang H, Rao A, Lerman K, Cowan G, Ferrara E. COVID-19 misinformation and the 2020 U.S. presidential election. Harv Kennedy Sch Misinformation Rev. [DOI]
13. Cunniff L, Alyanak E, Fix A, Novak M, Peterson M, Mevis K, et al. The impact of the COVID-19 pandemic on vaccination uptake in the United States and strategies to recover and improve vaccination rates: A review. Hum Vaccin Immunother. 2023;19:2246502. [DOI] [PubMed] [PMC]
14. Murdaca G, Orsi A, Spanò F, Puppo F, Durando P, Icardi G, et al. Influenza and pneumococcal vaccinations of patients with systemic lupus erythematosus: current views upon safety and immunogenicity. Autoimmun Rev. 2014;13:75–84. [DOI] [PubMed]
15. Pavia G, Branda F, Ciccozzi A, Romano C, Locci C, Azzena I, et al. Integrating Digital Health Solutions with Immunization Strategies: Improving Immunization Coverage and Monitoring in the Post-COVID-19 Era. Vaccines (Basel). 2024;12:847. [DOI] [PubMed] [PMC]
16. Stephens AB, Wynn CS, Hofstetter AM, Kolff C, Pena O, Kahn E, et al. Effect of Electronic Health Record Reminders for Routine Immunizations and Immunizations Needed for Chronic Medical Conditions. Appl Clin Inform. 2021;12:1101–9. [DOI] [PubMed] [PMC]
17. Duggan MJ, Gervase J, Schoenbaum A, Hanson W, Howell JT 3rd, Sheinberg M, et al. Clinician Experiences With Ambient Scribe Technology to Assist With Documentation Burden and Efficiency. JAMA Netw Open. 2025;8:e2460637. [DOI] [PubMed] [PMC]
18. Lenert L, Jacobs J, Agnew J, Ding W, Kirchoff K, Weatherston D, et al. VACtrac: enhancing access immunization registry data for population outreach using the Bulk Fast Healthcare Interoperable Resource (FHIR) protocol. J Am Med Inform Assoc. 2022;30:551–8. [DOI] [PubMed] [PMC]
19. FHIR Release R5: Overview [Internet]. Health Level Seven International; [cited 2025 Oct 15]. Available from: https://hl7.org/fhir/overview.html
20. HIPAA and Access to Patient Records During IQIP and VFC Visits Frequently Asked Questions [Internet]. U.S. Centers for Disease Control and Prevention; [cited 2025 Aug 20]. Available from: https://www.cdc.gov/vaccines/php/requirements-laws/hipaa-patient-records-iqip-vfc.html
21. HIPAA Overview and Vaccine Administration [Internet]. U.S. Centers for Disease Control and Prevention; [cited 2025 Aug 20]. Available from: https://www.cdc.gov/vaccines/php/requirements-laws/hipaa-overview.html
22. Shaw G Jr, Nadkarni D, Phann E, Sielaty R, Ledenyi M, Abnowf R, et al. Separating Features From Functionality in Vaccination Apps: Computational Analysis. JMIR Form Res. 2022;6:e36818. [DOI] [PubMed] [PMC]
23. Onyeaka HK, Muoghalu C, Deary EC, Ajayi KV, Kyeremeh E, Dosunmu TG, et al. The Role of Health Information Technology in Improving Awareness of Human Papillomavirus and Human Papillomavirus Vaccine Among U.S. Adults. Telemed J E Health. 2023;29:886–95. [DOI] [PubMed] [PMC]
24. Bouabida K, Lebouché B, Pomey MP. Telehealth and COVID-19 Pandemic: An Overview of the Telehealth Use, Advantages, Challenges, and Opportunities during COVID-19 Pandemic. Healthcare (Basel). 2022;10:2293. [DOI] [PubMed] [PMC]

25. Fabra ME, Jung J, Katz R. The contribution of ICTs and telemedicine to COVID-19 vaccination: Evidence from the United States. Health Policy Technol. 2025;14:100980. [DOI]
26. Martinez J, Cordero JI, Whitney M, LaRoche KL, Frietze G, Moya EM, et al. Web-Based Human Papillomavirus Education and Professional Skills Intervention for Health Care Providers: Protocol for a Randomized Controlled Trial. JMIR Res Protoc. 2025;14:e60790. [DOI] [PubMed] [PMC]
27. Sood RA, Carpo BG, Leheste JR. Bridging the Gap: Enhancing HPV (Human Papillomavirus) Education to Combat Rising Cancer Rates. Cureus. 2024;16:e74023. [DOI] [PubMed] [PMC]
28. Uppu SP. Leveraging AI/NLP to combat health misinformation and promote trust in science. Eur J Comput Sci Inf Technol. 2025;13:63–85. [DOI]
29. Larson HJ, Lin L. Generative artificial intelligence can have a role in combating vaccine hesitancy. BMJ. 2024;384:q69. [DOI] [PubMed] [PMC]
30. Allen MR, Desai N, Namazi A, Leas E, Dredze M, Smith DM, et al. Characteristics of X (Formerly Twitter) Community Notes Addressing COVID-19 Vaccine Misinformation. JAMA. 2024;331:1670–2. [DOI] [PubMed] [PMC]
31. Luo X, Zimet G, Shah S. A natural language processing framework to analyse the opinions on HPV vaccination reflected in twitter over 10 years (2008 - 2017). Hum Vaccin Immunother. 2019;15:1496–504. [DOI] [PubMed] [PMC]
32. Kearney MD, Selvan P, Hauer MK, Leader AE, Massey PM. Characterizing HPV Vaccine Sentiments and Content on Instagram. Health Educ Behav. 2019;46:37–48. [DOI] [PubMed]
33. Rai S, Kornides M, Morgan J, Kumar A, Cappella J, Guntuku SC. Detecting and monitoring concerns against HPV vaccination on social media using large language models. Sci Rep. 2024;14:14362. [DOI] [PubMed] [PMC]
34. Xie YJ, Liao X, Lin M, Yang L, Cheung K, Zhang Q, et al. Community Engagement in Vaccination Promotion: Systematic Review and Meta-Analysis. JMIR Public Health Surveill. 2024;10:e49695. [DOI] [PubMed] [PMC]
35. Fish LJ, Harrison SE, McDonald JA, Yelverton V, Williams C, Walter EB, et al. Key stakeholder perspectives on challenges and opportunities for rural HPV vaccination in North and South Carolina. Hum Vaccin Immunother. 2022;18:2058264. [DOI] [PubMed] [PMC]
36. Goel K, Vasudevan L. Disparities in healthcare access and utilization and human papillomavirus (HPV) vaccine initiation in the United States. Hum Vaccin Immunother. 2021;17:5390–6. [DOI] [PubMed] [PMC]
37. How Gavi's pioneering co-financing model ensures sustainable vaccine programmes [Internet]. VaccinesWork; [cited 2025 Aug 21]. Available from: https://www.gavi.org/vaccineswork/how-gavis-pioneering-co-financing-model-ensures-sustainable-vaccine-programmes
38. Gavi, the Vaccine Alliance [Internet]. IFPMA; c2025 [cited 2025 Aug 21]. Available from: https://globalhealthprogress.org/collaboration/gavi-the-vaccine-alliance
39. Hoss A, Meyerson BE, Zimet GD. State statutes and regulations related to human papillomavirus vaccination. Hum Vaccin Immunother. 2019;15:1519–26. [DOI] [PubMed] [PMC]
40. Roux K, Roux F, Burns S, Guy R. Effective strategies in human papillomavirus (HPV) vaccination interventions to increase uptake in rural, low socioeconomic, indigenous and migrant populations: A scoping review. Vaccine. 2025;61:127359. [DOI] [PubMed]
41. FTC Issues Orders to Social Media and Video Streaming Platforms Regarding Efforts to Address Surge in Advertising for Fraudulent Products and Scams [Internet]. Federal Trade Commission; [cited 2025 Aug 21]. Available from: https://www.ftc.gov/news-events/news/press-releases/2023/03/ftc-issues-orders-social-media-video-streaming-platforms-regarding-efforts-address-surge-advertising
42. FDA shares draft guidance on tackling misinformation online, offering flexibility to industry [Internet]. Questex LLC; c2025 [cited 2025 Aug 21]. Available from: https://www.fiercepharma.com/marketing/fda-shares-draft-guidance-tackling-misinformation-online-offering-flexibility-industry

43. Scharff DP, Mathews KJ, Jackson P, Hoffsuemmer J, Martin E, Edwards D. More than Tuskegee: understanding mistrust about research participation. J Health Care Poor Underserved. 2010;21: 879–97. [DOI] [PubMed] [PMC]
44. Karafillakis E, Martin S, Simas C, Olsson K, Takacs J, Dada S, et al. Methods for Social Media Monitoring Related to Vaccination: Systematic Scoping Review. JMIR Public Health Surveill. 2021;7:e17149. [DOI] [PubMed] [PMC]
45. Hasanzadeh F, Josephson CB, Waters G, Adedinsewo D, Azizi Z, White JA. Bias recognition and mitigation strategies in artificial intelligence healthcare applications. NPJ Digit Med. 2025;8:154. [DOI] [PubMed] [PMC]
46. Joseph J. Algorithmic bias in public health AI: a silent threat to equity in low-resource settings. Front Public Health. 2025;13:1643180. [DOI] [PubMed] [PMC]
47. Amann J, Blasimme A, Vayena E, Frey D, Madai VI; Precise4Q consortium. Explainability for artificial intelligence in healthcare: a multidisciplinary perspective. BMC Med Inform Decis Mak. 2020;20:310. [DOI] [PubMed] [PMC]
48. Global strategy to accelerate the elimination of cervical cancer as a public health problem [Internet]. World Health Organization; c2025 [cited 2025 Aug 23]. Available from: https://www.who.int/publications/i/item/9789240014107
49. Rossman AH, Reid HW, Pieters MM, Mizelle C, von Isenburg M, Ramanujam N, et al. Digital Health Strategies for Cervical Cancer Control in Low- and Middle-Income Countries: Systematic Review of Current Implementations and Gaps in Research. J Med Internet Res. 2021;23:e23350. [DOI] [PubMed] [PMC]
50. WHO adds an HPV vaccine for single-dose use [Internet]. World Health Organization; c2025 [cited 2025 Aug 23]. Available from: https://www.who.int/news/item/04-10-2024-who-adds-an-hpv-vaccine-for-single-dose-use
51. Gomes M, Provaggi E, Pembe AB, Olaitan A, Gentry-Maharaj A. Advancing Cervical Cancer Prevention Equity: Innovations in Self-Sampling and Digital Health Technologies Across Healthcare Settings. Diagnostics (Basel). 2025;15:1176. [DOI] [PubMed] [PMC]